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REMOTE ENVIRONMENTAL MONITORING AND DIAGNOSTICS IN THE PERISHABLES SUPPLY CHAIN PHASE II

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14. ABSTRACT

This report details the Phase II effort conducted by the University of Florida and the University of South Florida under Contract # W911QY-11-C-0011 as part of a multi-year, multi-phase effort entitled "Remote Environmental Monitoring and Diagnostics in the Perishables Supply Chain." This work was conducted during the period March 2011 to September 2013 and involved the evaluation of state-of-the-art technologies including wireless temperature sensors, remote monitoring using radio frequency identification (RFID), algorithms, and diagnostics, to demonstrate that combat ration shelf life can be automatically calculated in real time using predictive models. A prototype system including sensor equipped pallet level RFID tags, handheld readers, and computer shelf life models was developed to determine the remaining shelf life of the First Strike Ration and Meal, Ready-to-Eat based on product time and temperature storage history.

15. SUBJECT TERMS

RADIO FREQUENCY IDENTIFICATION	SENSORY	MILITARY RATIONS	SHELF LIFE
LOGISTICS	ALGORITHMS	DIAGNOSTICS	TAGS
HANDHELD READER	COMPUTER MODELS	PERISHABLE	STORAGE
TEMPERATURE SENSORS	PERFORMANCE TESTING	SUPPLY CHAIN	DISTRIBUTION
BATTERY ASSISTED PASSIVE	WIRELESS	RFID SYSTEM	TEMPERATURE

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Preface

This report details a Phase II effort conducted by the University of Florida and the University of South Florida as part of a multi-year, multi-phase project entitled "Remote Environmental Monitoring and Diagnostics in the Perishables Supply Chain." This work was conducted during the period March 2011 to September 2013 under a Broad Agency Announcement Contract (# W911QY-11-C-0011) awarded by the Natick Soldier Research, Development, and Engineering Center (NSRDEC) to the University of Florida. Efforts conducted during this phase involved the evaluation of new state-of-the-art wireless temperature tags, comprehensive data collection and analysis of physical and compositional quality of ration components stored at various temperatures, completion of development and validation of predictive shelf life model for First Strike Ration® and Meal, Ready-to-Eat™, development of smart decision management tools, and post harvest handling strategies for select fresh fruits and vegetables.

The findings contained in this final project report are not to be construed as an official Department of the Army position unless so designated by other authorized documents. Citation of trade names in this report does not constitute an official endorsement or approval of the use of such items.

This comprehensive research program was made possible through the joint cooperation and collaboration of the following individuals:

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Executive Summary
Scientific and Technical Achievements

The Project Goal

- *The overall goal of this project was to develop a temperature monitoring system that relies on radio frequency identification (RFID) technology for wireless information transfer and for remote monitoring and prediction of remaining shelf life for rations and perishable products. The system is compatible with the U.S. Army Veterinary Services Activity inspection database and can facilitate smarter informed decision making at all points in the Class I supply chain in terms of which rations should be discarded, which rations should be selected for issue first, and where rations can be shipped with confidence that quality requirements will be successfully met upon arrival.*

The Situation:

Shelf-stable (semi-perishable) combat rations are essential for enabling the individual Warfighter to perform assigned missions and survive battlefield threats. The current family of rations [Meal, Ready-to-Eat (MRE) and First Strike Ration (FSR)] has been developed and designed to have sufficient shelf life under normal storage conditions (2 to 3 years at 80°F), however, under high temperature conditions there is significant degradation of the quality and nutrient content of those rations. The challenge is even greater for more perishable foods such as fresh fruits & vegetables (FFV), which can play an important role in promoting Warfighter health and morale. Extreme low or high temperatures can shorten their shelf life so dramatically that the concept of providing perishable food products to the battlefield is almost impossible. Also, incompatibility of individual FFV during handling with respect to temperature, atmosphere and ethylene production/response leads to further quality degradation.

The Solution:

The introduction of highly functional, sensor-equipped radio frequency identification (RFID) tags in the Department of Defense (DoD) supply chain can significantly improve food quality, safety, and security. In addition these new technologies can play an important and significant role in supply chain management. Pilot projects performed jointly by the UF/IFAS Center for Food Distribution & Retailing (CFDR), the University of South Florida, and the U.S. Army Natick Soldier Research, Development & Engineering Center (NSRDEC) were used to exploit that additional functionality in order to improve military logistics, simultaneously providing valuable improvement opportunities for commercial food distribution and retailing.

Project Outcomes:

- *By using wireless temperature sensors, remote monitoring (RFID), algorithms, and diagnostics, it was demonstrated that FSR and MRE shelf life can be automatically*

calculated in real time using web-based computer models. A fully functional prototype RFID system was developed during this project as a result of extensive testing.

- *The quality and shelf life of selected FSR and MRE menu items when exposed to extreme ambient temperatures was determined using measurements of the physical and compositional characteristics of the products and evaluation of the sensory quality. The results of these measurements and evaluations provide valuable information on the rate of FSR/MRE physical and chemical deterioration when exposed to adverse conditions.*

- *Using the data for quality and shelf life changes during storage at different temperatures the shelf life algorithm for FSR developed in Phase I was validated and a new shelf life model for MRE rations was developed. The algorithms iterate each quality factor for each FSR and MRE menu item with specific time increments.*

- *Two RFID front end systems (Caen and Intelleflex) were validated. After successful validation, both RFID systems were updated with two major additions: 1) remote server database access and storage for temperature and shelf life data, and 2) data processing algorithms for enhanced shelf life prediction and smart cold chain logistics. Both systems were programmed with the shelf life models for MRE and FSR rations.*

- *Simulation of mixed marine container loads of FFV within the Pacific region showed that outturn problems with broccoli and Romaine lettuce shipped at 33°F are probably not related to inherently limited shelf life or to exposure to ethylene produced by other products. Rather it is critical to know the time and temperature history of broccoli and Romaine lettuce before accepting those products for such shipments. It was also shown that the quality of vine ripe tomatoes in mixed marine container loads of FFV within the Pacific region can be improved by using a higher shipping temperature of 55°F instead the currently specified 45°F as long as the tomatoes are handled in an appropriate MAP.*

With the food quality monitoring and diagnostics system resulting from this project, logisticians can better plan for a steady flow of rations and other food supplies to support Warfighters in various theaters of operation despite the products potentially encountering extreme environmental conditions during transit and storage at destination. It is our hope that this knowledge can result in reduced losses due to heat stressed rations, as well as reduced inspection time to determine ration serviceability.

- *As a result of these efforts, the NSRDEC Combat Feeding Directorate now has an improved RFID based portable solution to monitor and track the environmental temperature, to accurately estimate the remaining shelf life of FSR and MRE rations, and the tools to efficiently utilize this data, as well as guidelines to improve the quality of FFV within the military supply chain.*

REMOTE ENVIRONMENTAL MONITORING AND DIAGNOSTICS IN THE PERISHABLES SUPPLY CHAIN - PHASE II

1 Evaluation, Selection And Development Of An Integrated Prototype System Of Handheld RFID Readers And Common Protocol Tags For Temperature Tracking And Shelf Life Monitoring of Rations

1.1 Introduction

First Strike Rations (FSR) and Meals Ready-to-Eat (MRE) are individual combat rations that can be classified as "semi-perishable" as they have two to three years of shelf life when stored under normal temperature conditions (27°C or 80°F). However, significant degradations in product quality and nutritional content occur at high temperatures that need to be monitored to quantify the remaining usable shelf life. The main goal of this project is to create a radio frequency identification (RFID) based system to monitor, record and process temperature of military rations during storage and shipment to increase food safety and minimize waste in the Class 1 ration supply chain.

The objective for the first phase of the project (Phase I) which was completed in 2011, involved developing a remote environmental monitoring framework using handheld radio frequency identification (RFID) readers and loggers to record and process stored temperature data for FSR. This second phase of the project (Phase II) expands on the developments and findings of Phase I by introducing database integration of recorded temperature data and shelf life for higher order information processing which enables smart supply chain logistics while extending the full framework to include MRE rations.

In the January 2013 general project meeting at the University of South Florida in Tampa, FL, the full functionality of the RFID temperature and shelf life monitoring system using both Caen and Intelleflex front-end systems as well as the database integration of temperature data storage and shelf life prediction was successfully demonstrated to NSRDEC personnel and representatives from the US Army Veterinary Services Activity.

The main contributions of this portion for Phase II can be summarized as follows:

- ⇨ The shelf life algorithm developed for Phase I (FSR) and the RFID handheld operation were validated through a simulated shipment study carried out with the help of Objective 2 analysis and sensory team.

- ⇨ New state-of-the-art temperature tags (both semi-passive and active technologies) were evaluated using the environmental testing protocol developed in Phase I. Furthermore, additional and in-depth radio frequency protocol tests were carried out for Caen and Intelleflex systems using National Instruments/Nexjen 18000-6C protocol tag testing suite.

- ⇨ A new database was created to retrieve and transmit the logged temperature data and predicted shelf life for both FSR and MRE rations from the RFID handheld to a remote server for further information processing and assisting with first-expired-first-out distribution logistics.

- ⇨ A new shelf life model was developed for the MRE ration components based on quality analysis findings and both FSR and MRE shelf life prediction models were subsequently integrated into handheld software and the backend database system.

- ⇨ The pallet temperature estimation algorithm was extended to container level with the help of adaptive learning systems such as artificial neural networks to study how to use minimum number of wireless sensors to predict product temperature throughout the container accurately.

- ⇨ Develop tools and corresponding rules to enable smart and informed decision making in the supply chain using the acquired data through the use of the RFID system and the predicted shelf life.

1.2 System Validation

In order to carry out the validation of the Phase I prototype system, a common framework was determined between various teams which includes simulation of storage and shipment of FSR products at different temperatures. The food selections as well as analysis via taste panels and chemical decomposition for the validation study are explained in greater detail in later sections of this report.

Between the months of June and September, the first phase validation of the computer shelf life model was completed with successful results. The following products were chosen to be used in validation of the shelf life estimation model developed in Phase I. In alphabetical order:

a. Bacon Cheddar Sandwich (BCS)
b. Filled French Toast (FFT)
c. Honey BBQ Sandwich (HBB)
d. Italian Style Sandwich (ISS)
e. Zapplesauce (ZS)

As was previously discussed and decided over the several conference calls with Natick and the project team on the subject, the quality which determines whether or not the product has expired, or how many more weeks of shelf life the product has, is the overall quality. Even though the model can be trained for other qualities as well, limiting the determinant quality to one, will not only enable the model to work much faster on limited computing power (such as the handheld reader) but also allows for better fine tuning and training.

The shelf life algorithm model was trained on the taste panel experimental data that had been obtained throughout Phase I. Based on the output of the shelf life model with 2 weeks at 85°F and 4 weeks at 95°F, here are the resulting quality factors for the overall quality (again in alphabetical order) vs. the recently performed taste panel validation results.

Table 1. Comparison of shelf life prediction algorithm with taste panel experimental results for the first phase of validation study

After 2 weeks at 85F and 4 weeks at 95F			
Validation study		Shelf life algorithm (Expiration date assumes 100F throughout)	
	Overall		Overall
BCS	6.7	BCS	6.8 (will expire in 138.5 days)
FFT	7.5	FFT	7.5 (will expire in 183.5 days)
HBB	7.1	HBB	6.7 (will expire in 120 days)
ISS	6.5	ISS	7.1 (will expire in 156.5 days)
ZS	6.6	ZS	6.6 (will expire in 150.5 days)

As shown in the above table, the model works extremely well, estimating the quality index accurately almost to the decimal point for multiple products. The reason for discrepancy is simply the fact that the model always assumes that the initial quality index is 8. This assumption, although necessary, can be altered to have a different initial quality index value and in a real life scenario, it is impossible to have a 100% accurate representation of this value. One observation is the fact that the numbers for HBB and ISS seem to be reversed. However, upon further examination, one can see that this is not an error caused by the model. Let's take a quick look at the experimental taste panel data on which the model was trained for these two products.

Table 2. Experimental taste panel data concerning products HBB and ISS

Product:	HBB	**Product:**	ISS
Temperature:	80	**Temperature:**	80
Sampling instant (days)	Overall	Sampling instant (days)	Overall
0	7.9	0	8.0
112	6.7	112	7.2
Product:	HBB	**Product:**	ISS
Temperature:	100	**Temperature:**	100
Sampling instant (days)	Overall	Sampling instant (days)	Overall
0	7.9	0	7.9
42	6.2	42	6.1

The experimental data in the table above is from Phase I. One can see that the quality index drop in HBB and ISS observed during the first phase of the study differs slightly from the validation taste panel data which explains the difference in the output of shelf life model. However, one should remember that a quality index parameter such as overall quality is highly

subjective, especially at higher quality index values and more importantly a change in the initial quality index for these products will have a significant effect on the end results. Hence, overall, the computer model has shown a high level of accuracy averaged over all the 5 products.

As a second step, the model was run on the resulting data assuming that the temperature will now stay at 100°F to find how many more weeks the products can last. Here are the findings from the model as also indicated in the table above:

- ⇨ BCS will expire in 138.5 days.
- ⇨ FFT will expire in 183.5 days.
- ⇨ HBB will expire in 120.0 days.
- ⇨ ISS will expire in 156.5 days.
- ⇨ ZS will expire in 150.5 days.

These findings are consistent with the previous experimental data results and were used in the next phase of validation testing. The second phase validation of the shelf life model was completed during the 3rd quarter of the project. In the third quarter some of the products were subjected to an extreme temperature at 130°F for 2 weeks and some products were left at 100°F for an additional 15 weeks to see if the "expected shelf life" values by the algorithm would correlate with the validation study results. For products which were left at 130°F for 2 weeks, the following table summarizes and compares the validation study results and the shelf life algorithm results:

Table 3. Comparison of shelf life prediction algorithm with taste panel experimental results for the second phase of validation study

After 2 weeks at 85F and 4 weeks at 95F and 2 weeks at 130F			
Validation study		Shelf life algorithm (Expiration date assumes 130F throughout)	
	Overall		Overall
BCS	4.1	BCS	4.5 (will expire in 3.5 days)
FFT	5.7	FFT	5.2 (will expire in 15.5 days)
HBB	4.5	HBB	4.4 (will expire in 4.5 days)
ISS	4.9	ISS	4.8 (will expire in 9 days)
ZS	4.0	ZS	4.2 (will expire in 2 days)

Once again, the shelf life algorithm results correlate extremely well with the validation study results. Note that in the original test plan, we had assumed that the products would have expired after 2 weeks at 130°F but in reality all products still had >4.0 quality index values for overall quality. The "expected shelf life" at 130°F after the date/time of inspection in this case ranged from 2 days (in the case of Zapplesauce) to a little more than 2 weeks (in the case of Filled French Toast (FFT)). A subsequent taste panel, which was performed 2 weeks later, has shown that all the products indeed expired as expected thus validating the model.

Finally, the next study looked at the product overall qualities after 15 weeks at 100°F. The following table summarizes the validation study results and compares them to shelf life algorithm output.

Table 4. Comparison of shelf life prediction algorithm with taste panel experimental results for the third phase of validation study

After 2 weeks at 85F and 4 weeks at 95F and 15 weeks at 100F			
Validation study		Shelf life algorithm (Expiration date assumes 100F throughout)	
	Overall		Ove
BCS	5.3	BCS	4.9 (will expire in 33 days)
FFT	6.1	FFT	5.1 (will expire in 78 days)
HBB	4.5	HBB	4.2 (will expire in 14.5 days)
ISS	5.3	ISS	4.8 (will expire in 51.5 days)
ZS	5.1	ZS	4.7 (will expire in 45 days)

Except in the case of FFT, the shelf life algorithm results once again highly correlated with the validation taste panel studies. The difference between the quality index values of FFT can be explained by two things: 1) the initial quality indexes of the batch used for the original study and the validation study might be different, 2) quality index values are subjective. Another important thing to note is that the "expected shelf life" measured in first phase of the validation study (first table) and the "expected shelf life" deduced from the table above also match well when taking into account the fact that 15 weeks is equal to 15x7 = 105 days.

1.3 New State-Of-The-Art Hardware Testing

1.3.1 RFID-Temperature Tag Testing

In this part of the project, three additional state-of-the-art temperature tags working at three different frequencies (433MHz and 2.4GHz for active tags and 915MHz for passive tags) were evaluated using the environmental testing protocol developed in Phase I. Active technologies in addition to semi-passsive RFID technologies were investigated as part of the overall sensor portfolio in order to see how they might compare and to stay ahead of rapidly evolving technologies on the commercial market. Four test schedules were used for the temperature based accuracy testing along with three test schedules for vibration testing. Additional in-depth radio frequency protocol tests were carried out for Caen and Intelleflex systems using National Instruments/Nexjen 18000-6C protocol tag testing suite.

The protocol for temperature based accuracy testing conducted examined both the population behavior of tags for mean accuracy and overall performance and the individual tags to check for irregularities in temperature recording. The specific temperature tests are described briefly below and in more detail in the Phase I report.

Two-Point Temperature Swing Test
This test measures the accuracy and the performance of tags around two predetermined mean minimum and maximum temperature values for an extended period of time. The parameters for this test are driven by knowledge of the supply chain temperature distribution throughout the transportation cycle of a typical shipment. In order to acquire this knowledge, the user needs to ship out temperature loggers and monitor the supply chain to determine the average maximum and average minimum temperatures. Once these two parameters are determined, the test chamber temperature will swing between these two values with 24-hour intervals to emulate the shipping lane while the reference sensors and RFID tags record the temperature. In order to increase the exposure time, multiple swings are used. The average minimum and maximum temperatures were determined to be 59°F and 118.4°F respectively with a an overall test duration of 96 hours.

Extended Requirement Limit Test
The purpose of this test is to determine whether or not the tags have issues recording temperature accurately after prolonged exposure to extreme temperatures. It is a 24-hour test where the chamber is started at the high requirement limit (140°F) for an extended period of time (8 hours) while the reference sensors and RFID tags are recording the temperature. The temperature is then decreased 10% below the maximum requirement limit (129.2°F) for a shorter period of time (4 hours). A sharp transition in temperature follows to set the chamber temperature at the low requirement limit (-22°F) again for an extended period of time (8 hours). The testing then concludes with the temperature rising 10% over the low requirement limit (-16.6°F) and maintained at this temperature for 4 hours.

80% Requirement Range Span Test
This test is designed to check the overall accuracy of the tag population within the majority of the requirement range. It is a 24-hour test where the highest and lowest temperatures of the test schedule are set at 10% below the requirement limits. The temperature is then changed uniformly from high to low with a consistent rate of change to complete the full cycle within 24 hours. Requirement limits for this effort are 140°F and -22°F, with the 80% range set at 130°F and -16.6°F.

Freezing Temperature Test
This test is used to determine the freezing temperature of the tag and confirm that it is outside the operational requirement range. This is important for continued function as well as accuracy for shelf life calculations. The parameters of this test are driven by the capabilities of the environmental chamber being used for the experiment. In this case, the Conviron chamber used in the project can go as low as -31°F. Hence, the low temperature point is set at this temperature and the chamber temperature is gradually lowered to this temperature from a pre-determined positive temperature of 77°F.

Lastly, environmental accuracy and reliability testing of candidate tags is conducted using vibration in conjunction with temperature to simulate realistic transportation modes and assess

tag functionality. This is conducted through pre-determined random transportation modes such as truck, rail and air as well as sine vibration at different frequencies. Power spectral density (PSD) curves in accordance with American Society for Testing and Materials (ASTM) standards (ASTM D4169 - Truck, Air, Rail for random vibration and ASTM D5112 for sine vibration) are used to simulate different modes of supply chain transportation.

The tags evaluated in this phase of the project are as follows:

- **Phase IV Engineering Inc. RFID SensTAG (UHF):** This temperature tag is semi-passive and operates at 915MHz in the United States (UHF band) which makes it compatible with the original project requirements. The current specification sheet from the manufacturer's website can be found at the end of the report in the appendix.



Figure 1. SensTAG Temperature Tag

- **InfinID vTag (UHF – 2.4GHz Active):** This temperature tag is an active tag operating at 2.4GHz. Although not directly compatible with the original project requirements, the tag –reader setup includes a real-time location system (RTLS) and a humidity sensor alongside the temperature sensor and has a much longer range of 300 ft compared to any semi-passive technology. The current specification sheet from the manufacturer's website can be found at the end of the report in the appendix.



Figure 2. vTag Temperature Tag

- **Evigia EV3-ST Sensor Transponder (UHF – 433MHz DASH7 Active):** This temperature tag is another active tag operating at 433MHz using the DASH7 (ISO 18000-7) industry standard for communication. Although not directly compatible with the original requirement, it uses a common standard based communication protocol which is approved (and in use) by DoD and has a much longer range of 350 ft compared to semi-passive technology. The current specification sheet from the manufacturer's website can be found at the end of the report in the appendix.



Figure 3. Evigia Temperature Tag

In addition to the three tags that were tested during this phase, a newly updated iteration of Intelleflex tag (Model TMT-8500) in their new green casing was also tested. This battery assisted passive tag is based on the ISO Class 3 (ISO / IEC 18000-6) and EPCglobal Gen 2 Class 1 protocols, with extended memory, improved range and reliability. Caen A927Z tags were not included in this round of testing because there were no updates to tag casing during Phase II and the current version was already tested in Phase I.

It is important to note that during the testing none of the tags from Intelleflex or SensTag failed to record temperature, however all the InfinID vTags stopped recording at the 40 hour mark during the first temperature test. Two tags from Evigia failed to work after the initial two temperature tests, and a third Evigia tag failed during the vibration tests. As a result of poor performance by InfinID vTags as compared to other tags, test results are available only for Intelleflex, SensTag and Evigia sensor transponders for tests following the initial two point temperature swing test. The average mean square error (MSE) and standard deviation (SD) are shown for each tag type and test as well as histograms of the average error function.

Two Point Temperature Swing Test

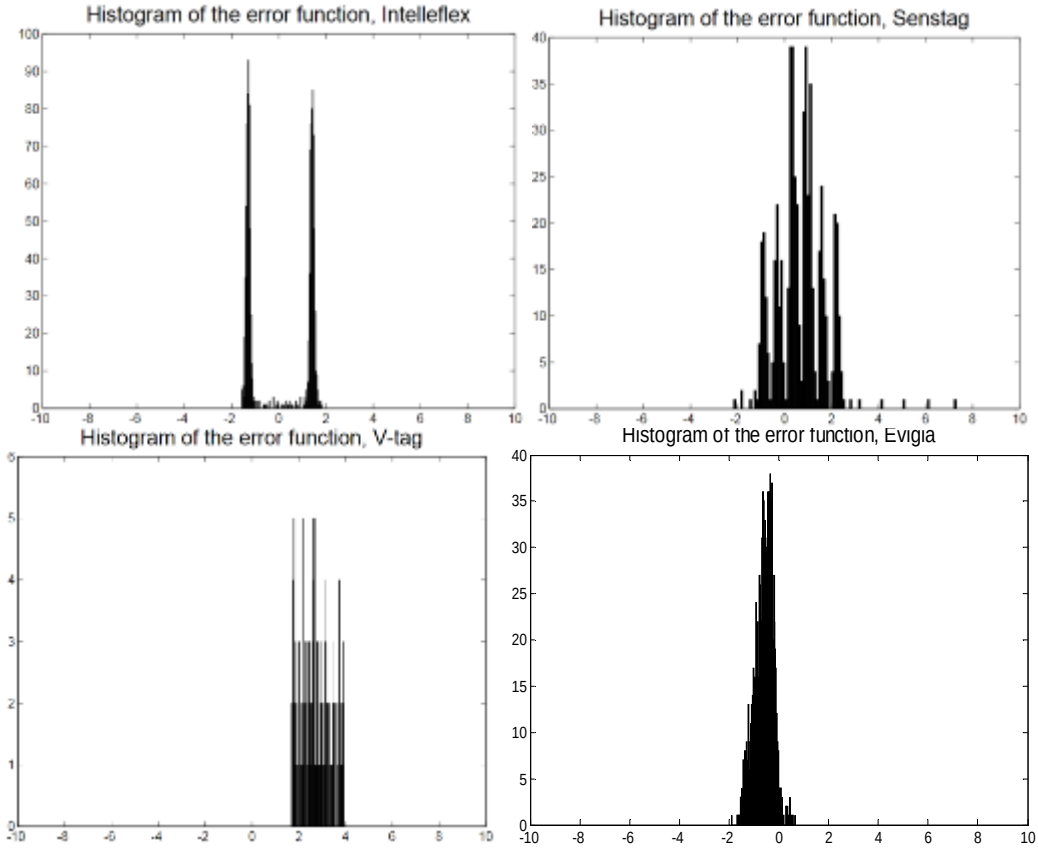


Figure 4. Histogram of the average error function for each tag during the two point swing test

Table 5. Average mean square eror (MSE) and standard deviation (SD) during the temperature two point swing test

Tag	Average MSE	Average SD
Intelleflex	1.8	1.3
SensTag	6.4	2.1
V-tag	8.3	0.7
Evigia	0.6	0.5

Extended Requirement Limit Test

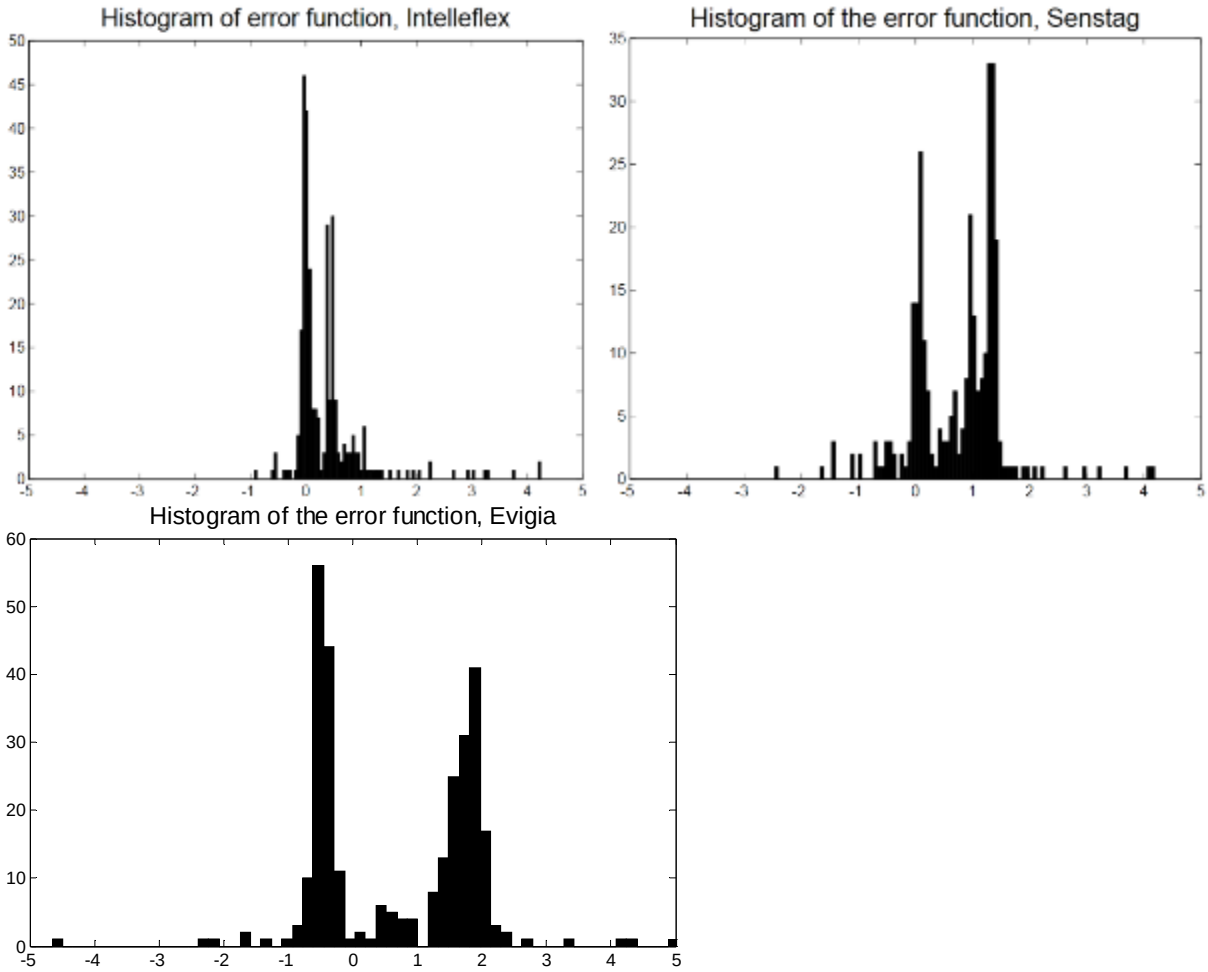


Figure 5. Histogram of the average error function for each tag during the extended limit test

Table 6. Average MSE and SD during the extended limits test

Tag	Average MSE	Average SD
Intelleflex	0.8	0.7
SensTag	3.9	1.6
Evigia	3.1	1.6

80% Requirement Range Testing

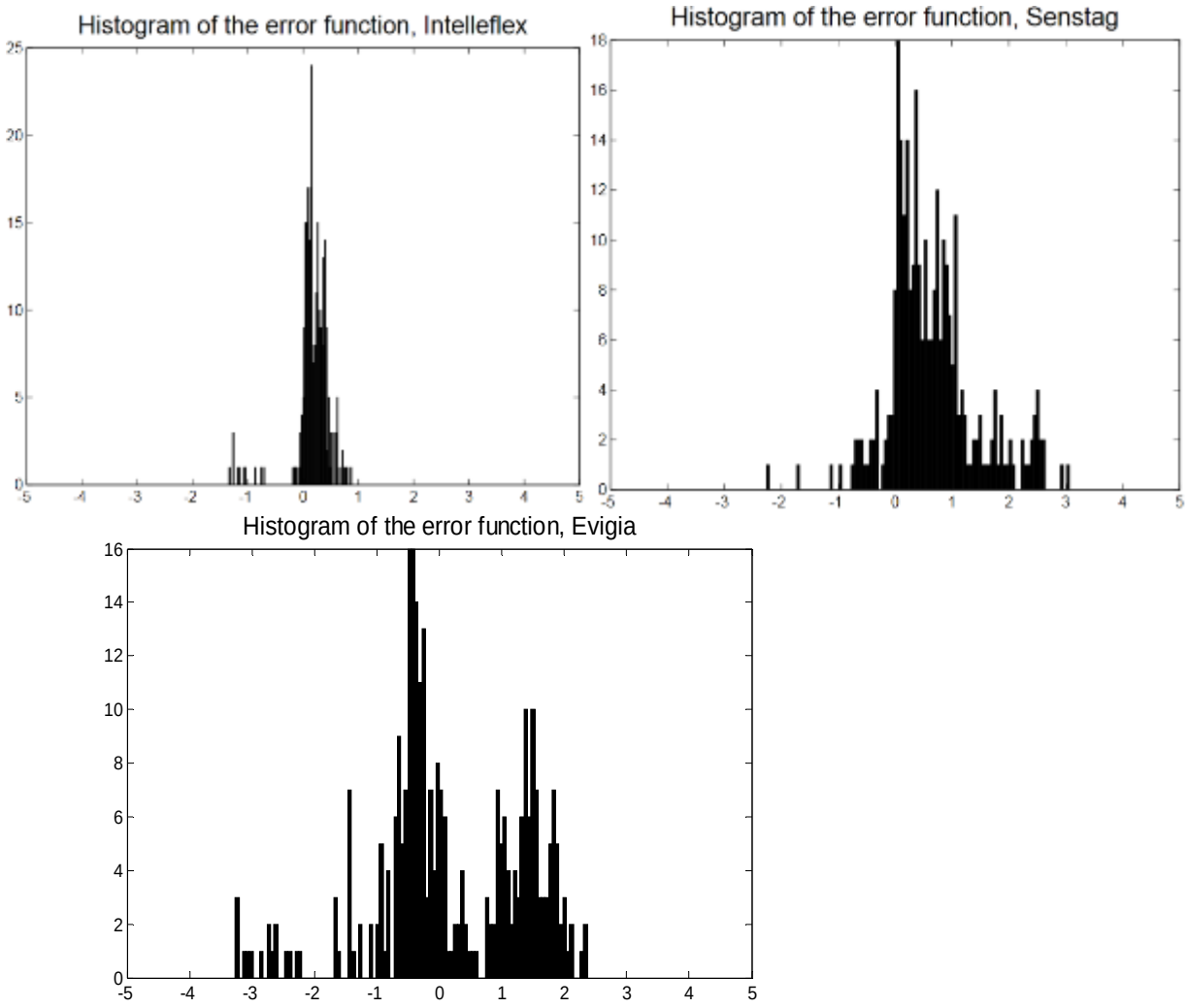


Figure 6. Histogram of the average error function for each tag during the 80% requirement range test

Table 7. Average MSE and SD during the 80% requirement range test

Tag	Average MSE	Average SD
Intelleflex	0.25	0.41
SensTag	2.7	1.2
Evigia	1.6	1.2

Freezing Temperature Test

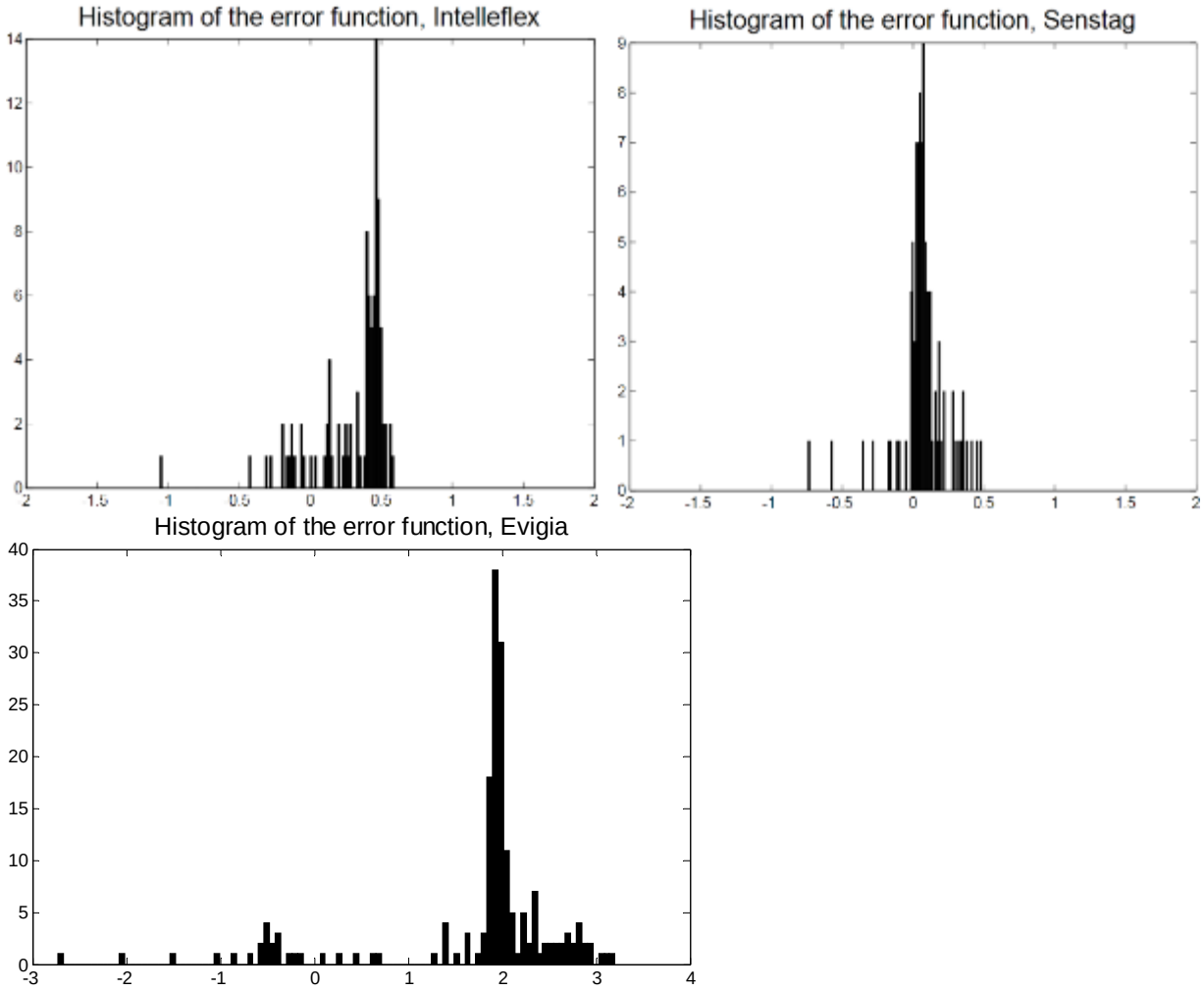


Figure 7. Histogram of the average error function for each tag during the freezing temperature test

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Table 8. Average MSE and SD during the freezing temperature test

Tag	Average MSE	Average SD
Intelleflex	0.27	0.37
SensTag	0.44	0.46
Evigia	4.2	1.1

Vibration with Temperature Requirement Range Testing

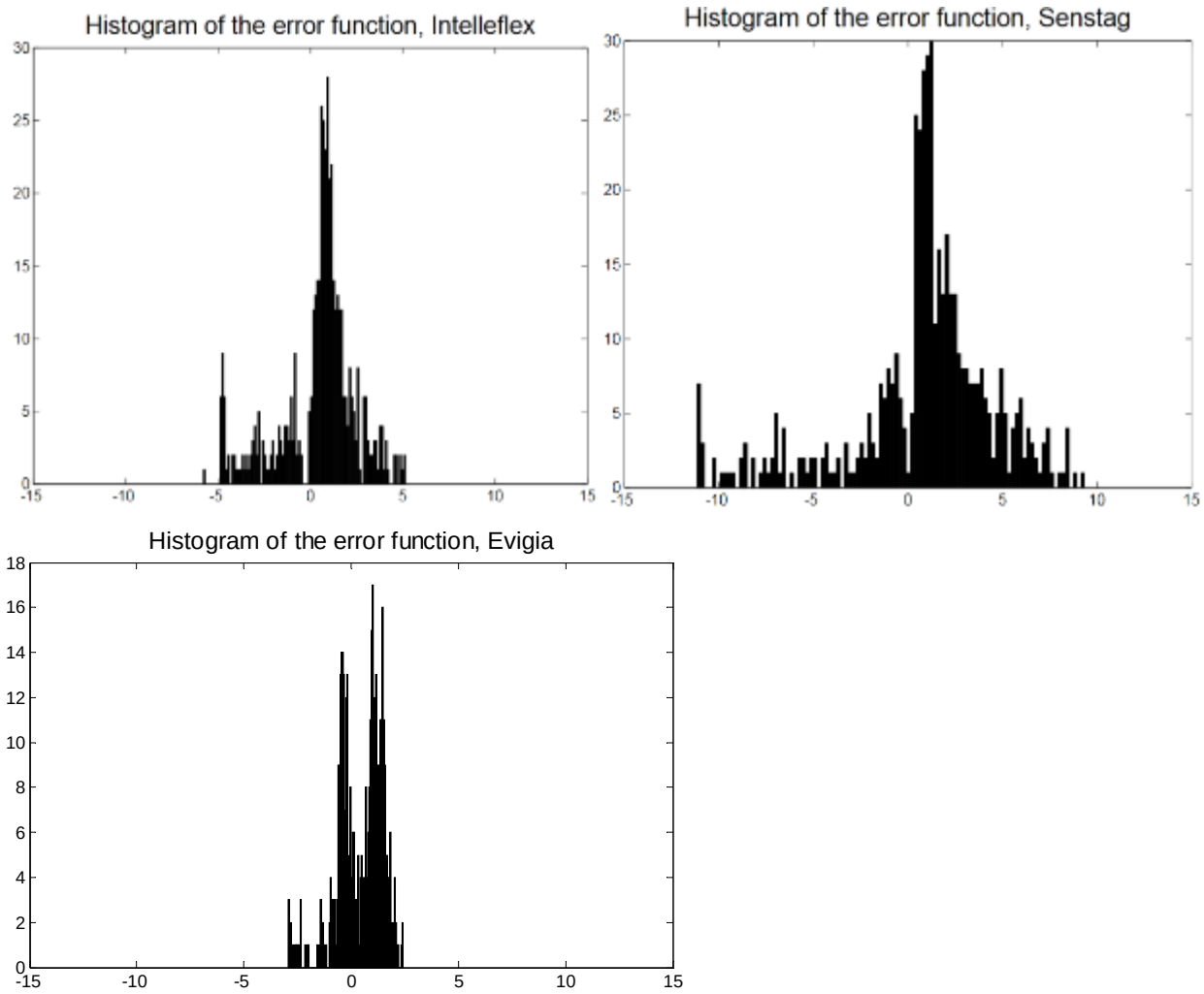


Figure 8. Histogram of the average error function for each tag during the vibration with requirement range testing

Table 9. Average MSE and SD during the vibration with requirement range testing

Tag	Average MSE	Average SD
Intelleflex	6.1	2.1
SensTag	27.9	4.3
Evigia	1.4	1.1

Vibration with Two Point Temperature Swing Test

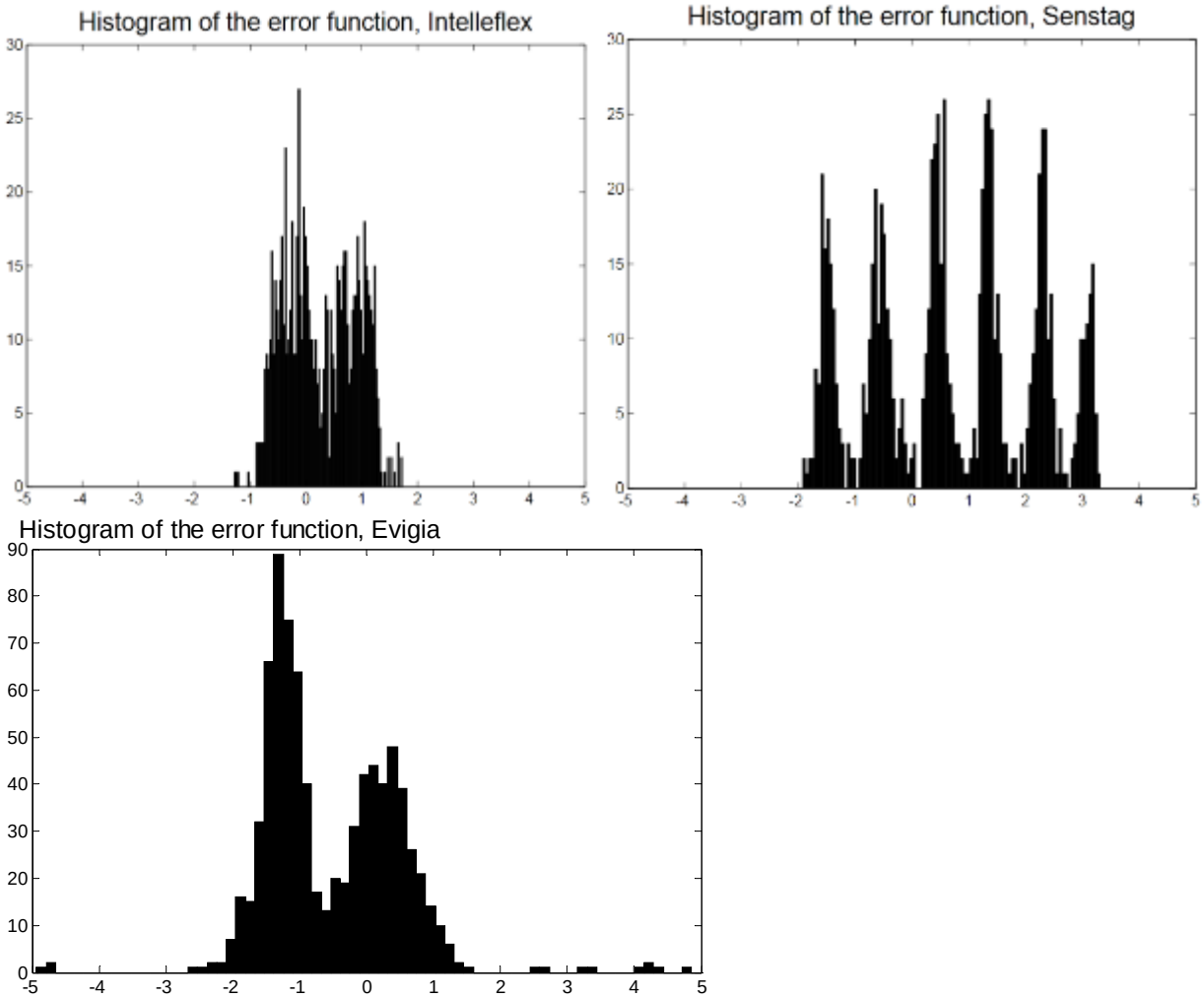


Figure 9. Histogram of the average error function for each tag during the vibration with two point swing test

Table 10. Average MSE and SD during the vibration with two point swing test

Tag	Average MSE	Average SD
Intelleflex	0.50	0.64
SensTag	4.6	1.6
Evigia	2.4	1.4

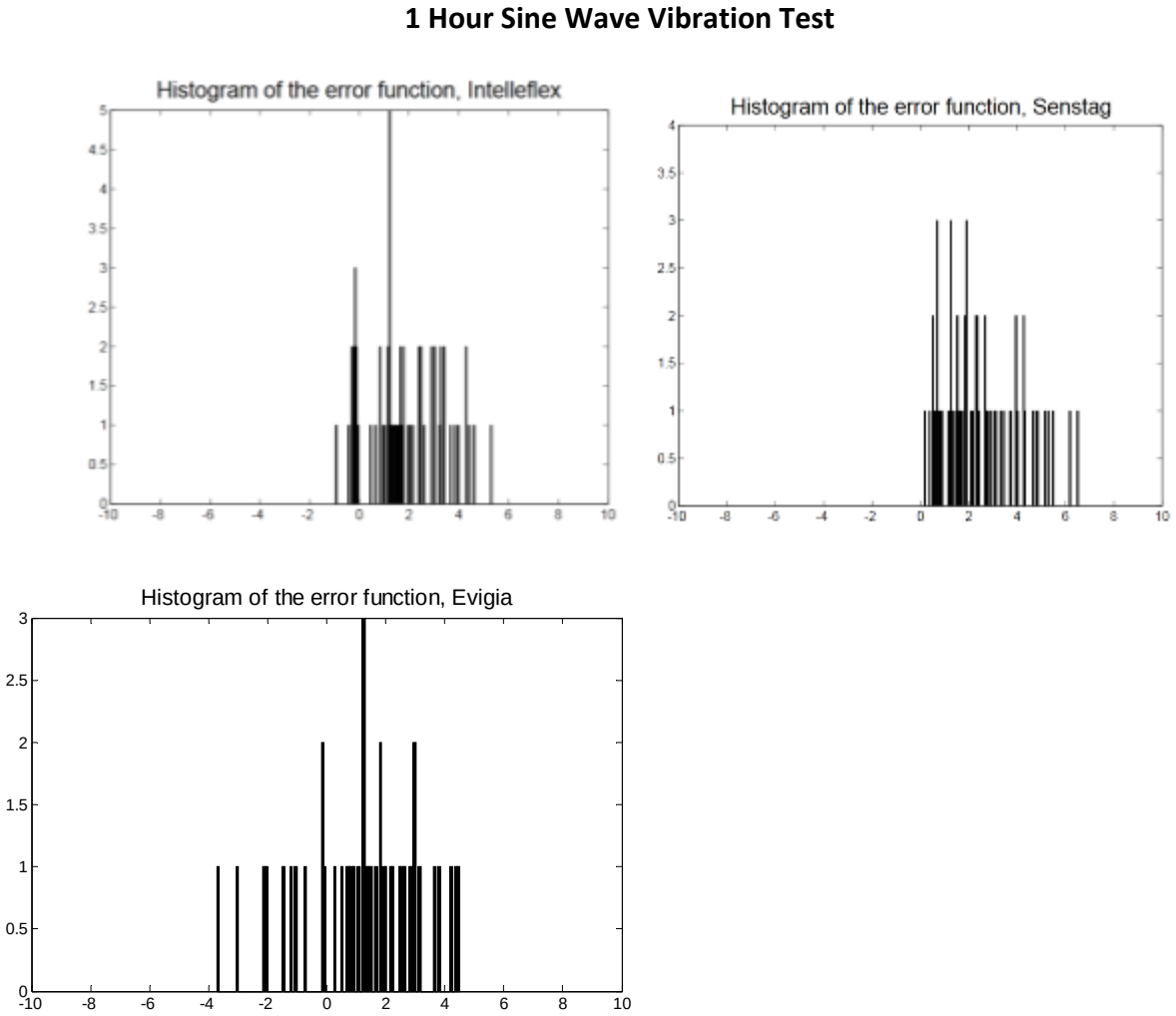


Figure 10. Histogram of the average error function for each tag during the 1 hour sine wave vibration test

Table 11. Average MSE and SD during the 1 hour sine wave vibration test

Tag	Average MSE	Average SD
Intelleflex	5.6	1.5
SensTag	10.7	1.7
Evigia	5.6	2.0

1.3.1.1 Summary Of RFID-Temperature Tag Testing Data

The average mean square error (MSE) during the temperature testing was 0.8 for Intelleflex, 3.4 for SensTag, and 2.4 for Evigia. The vibration testing produced a higher average MSE for all tags, 4.1 for Intelleflex, 14.1 for SensTag, and 3.1 for Evigia. The average standard deviation during temperature testing was 0.7 for Intelleflex, 1.3 for SensTag, and 1.1 for Evigia. Similarly to previous testing, the vibration test again generated higher deviations, 1.4 for Intelleflex, 2.5 for SensTag, and 1.5 for Evigia. The V-tags had many problems with both gathering and recording data, exhibited a much higher MSE during the initial test, and were recording much higher temperatures than the reference sensor (shown in the error histogram in Figure 4). While the Evigia tags had the highest accuracy during this phase of environmental testing, two of them failed during the temperature testing, with an additional tag failing during vibration testing. The results of the evaluation indicate the Intelleflex tags had the highest accuracy and reliability, and best overall performance, and the tags with their updated casing performed similarly to Phase I testing.

1.3.2 Communication Protocol Level Testing

In addition to temperature accuracy and environmental testing performed on sensor tags, radio frequency communication – protocol level testing was also conducted on two of the tags the RFID system was developed for; Caen model A927Z and Intelleflex model TMT-8500. In order to accomplish this, a state-of-the-art test setup was created in the lab.

National Instruments (NI) PXIe – 1062Q FPGA Hardware: This hardware is used to create an RFID reader emulator with all the variable parameters of Gen2 communication protocol used for semi-passive tags. It has an NI-PXIe 5600 down converter, 5641 transceiver and a 5610 up converter to create the RF signals to communicate with the tag while varying output power and output frequency to measure key tag characteristics. Although a Gen2 tag testing software suite was used, the flexibility of the system provides testing for not only semi-passive tags operating at 915MHz but also other frequencies and other protocols via other test suites.

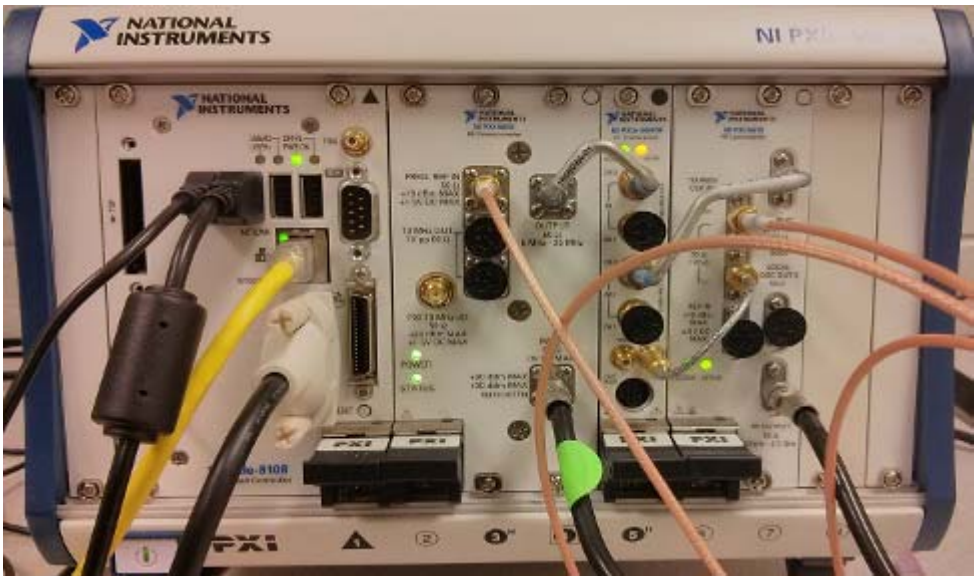


Figure 11. National Instrument hardware used in tag testing

ETS Lindgren 5240 Table Top Enclosure: This is a portable anechoic chamber which provides excellent attenuation (up to +120dB) of environmental RF noise in the range of testing (800MHz to 1GHz). It has an internal RF coupler, so the RF signals generated outside can be passed onto the inside of the chamber when it is sealed. In addition, the RF absorbent material inside prevents reflections from affecting the test results. Figure 12 below shows the portable anechoic chamber.

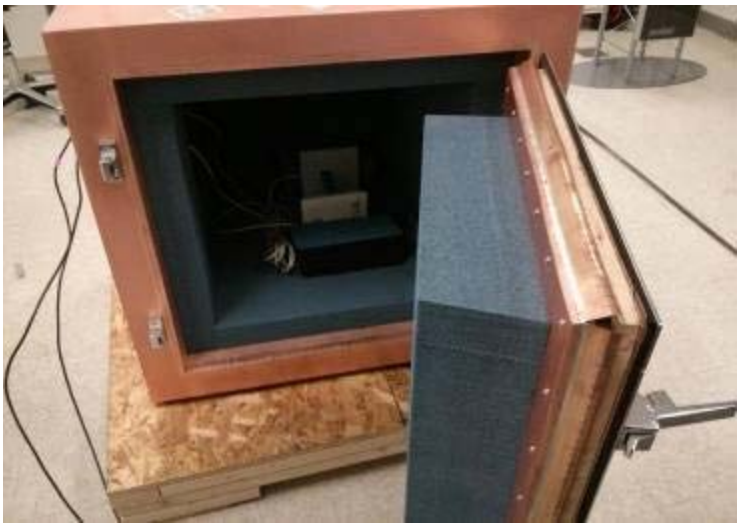


Figure 12. ETS Lindgren 5240 Anechoic Chamber

The tag was placed inside the chamber in the right orientation with respect to the transmitting and receiving antennas, which are connected to NI FPGA and carries the RF signals for communication. A typical setup inside the chamber is shown below for Caen tags from a top-down view.

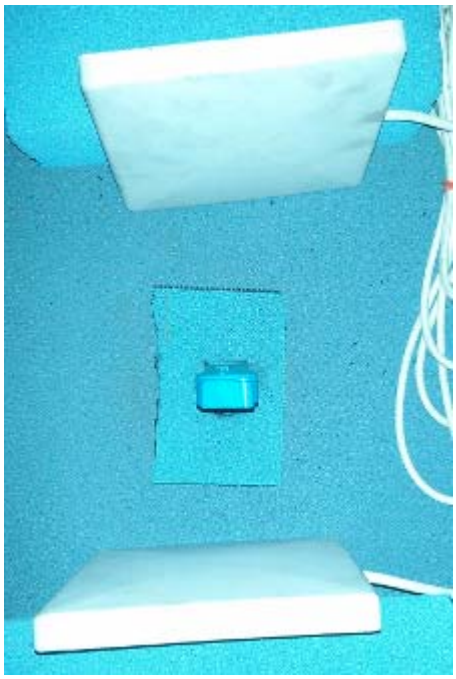


Figure 13. Top-down view of the tag-antenna orientation inside the chamber.

Nexjen 18000-6C (EPC C1G2) Tag Testing Suite: Partnering with VI Service Network, Nexjen software suite provides the necessary tools to use the National Instruments FPGA for various tag related RF performance measurements such as sensitivity, forward and backward read range, minimum carrier power, etc. The typical user interface is shown below:

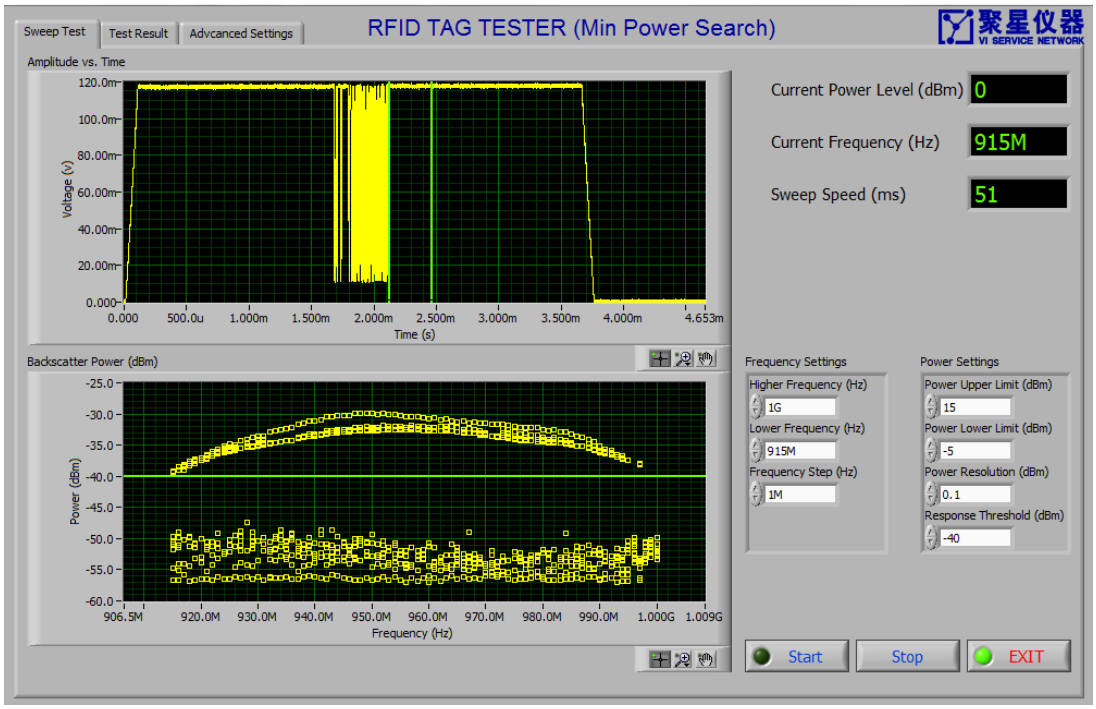


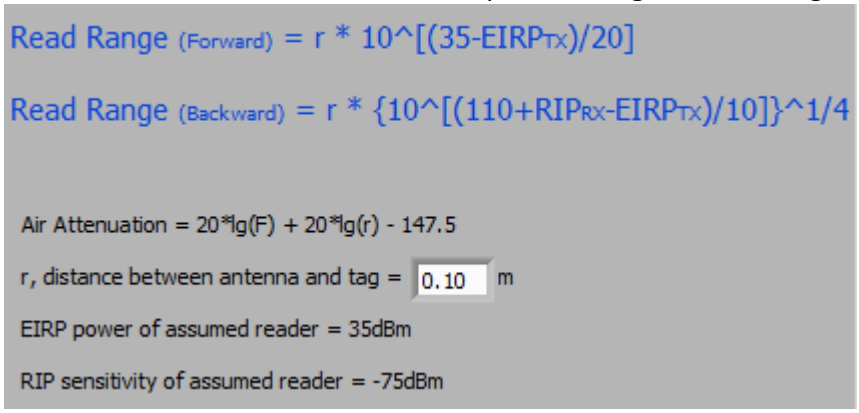
Figure 14. The user interface of the Nexjen tag testing suite

For RF performance the test setup was used to measure four important characteristics, minimum carrier power, tag sensitivity, read range forward and read range backward, for both Intelleflex and Caen tags as described below.

Minimum carrier power: This is the minimum amount of output power supplied by the reader to turn the RFID tag on at a specific frequency. Using a power sweep, the test setup is able to measure this for different frequencies within a defined interval.

Tag sensitivity: This is the minimum amount of power which needs to exist at the tag location for communicating with the tag – this is a very important performance metric which is calculated from the minimum carrier power using the distance between the antennas and the tag and path loss.

Read range (forward and backward): The forward and backward read ranges are also calculated from the minimum carrier power using the following two formulas:



Forward read range defines the distance the tag can still receive the reader signal whereas the backward range defines the distance the reader can still receive the tag signal. Generally (but not always) passive RFID systems are limited by their forward read range due to the fact that reader hardware is sophisticated enough to receive tag signals provided that the tag can power on and listen to reader signals to begin with.

Minimum carrier power and tag sensitivity comparison for Caen vs. Intelleflex: Figures 15 and 16 below compare the minimum carrier power and tag sensitivities (the lower the better) for Caen and Intelleflex tags for the UHF range 800MHz and 1GHz.

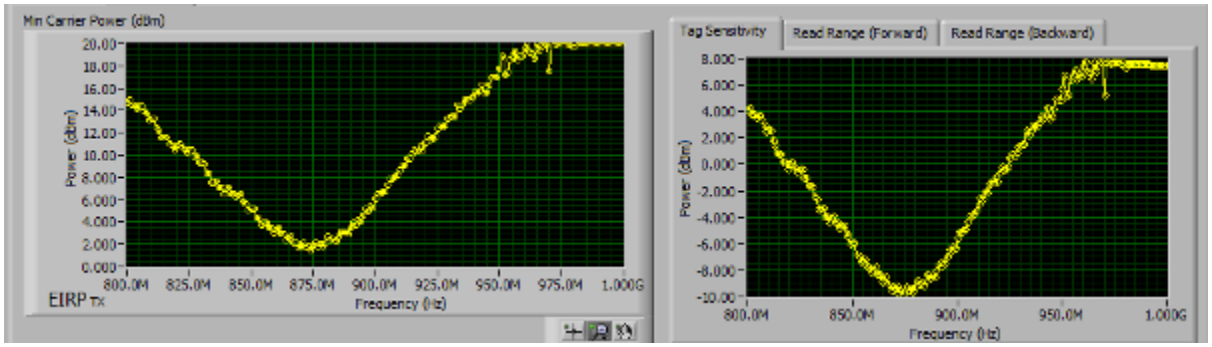


Figure 15. Min carrier power and tag sensitivity for Caen tags for frequencies 800MHz – 1GHz

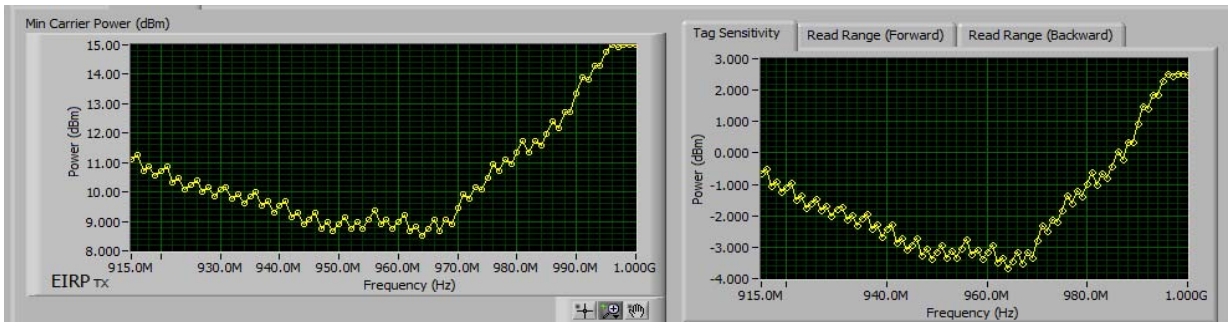


Figure 16. Min carrier power and tag sensitivity for Intelleflex tags for frequencies 800MHz – 1GHz

First thing to notice in these plots is the similar change in both quantities over frequency for both tags where it gets lower in dB as frequency increases from 800MHz, reaches a minimum point, and then starts increasing. For Caen tags, the minimum point for minimum carrier power happens around 875MHz whereas for Intelleflex tags the minimum point happens around 965MHz. It is important to note that a lower minimum carrier power means the tag is better tuned for those frequencies. Hence the results are expected as Intelleflex is a U.S. manufactured tag with expected theoretical peak around 915MHz whereas Caen is a European manufactured tag with expected theoretical peak around 868MHz.

It is also important to note that while Intelleflex tags display a slightly more flat frequency response, Caen tags have a lower minimum carrier power at their best tuned frequency (approximately 2dB for Caen vs. 8dB for Intelleflex). However, they have comparable minimum carrier powers around 915MHz (approximately 10dB for Caen vs. 11dB for Intelleflex) which is the range of operation for the system developed for this project.

As far as tag sensitivities are concerned, a similar trend can be observed as the tag sensitivity is directly calculated from the minimum carrier power taking into account the path loss from the reader antenna location to tag location. Once again, although Caen displays a lower sensitivity (which means less amount of power is required to turn on a Caen tag than an Intelleflex tag) at its minimum point, both tags have almost the same sensitivity (-2dB for Caen vs. -1dB for Intelleflex) which means their performances will be similar in a real life setting with operating frequency of 915MHz.

Forward/backward read range comparison for Caen and Intelleflex: Figures 17 and 18 below show the forward and backward read ranges calculated from the minimum carrier power using the formulas identified above.

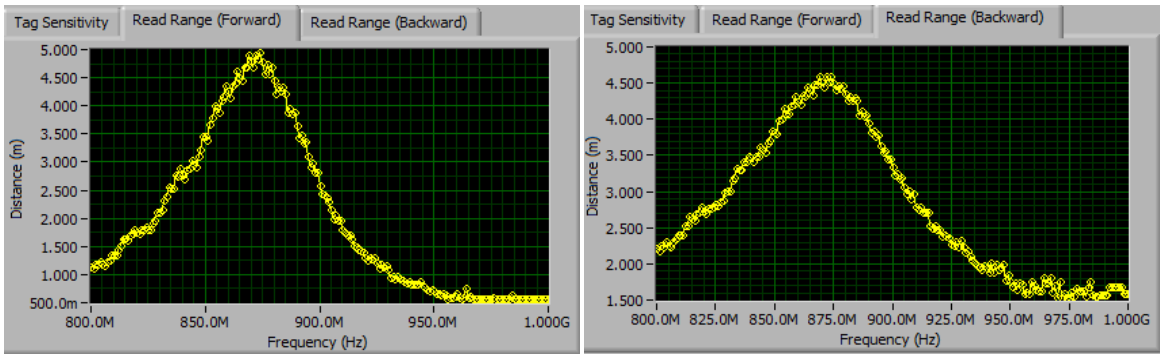


Figure 17. Forward and backward read ranges as calculated by the test software for Caen tags

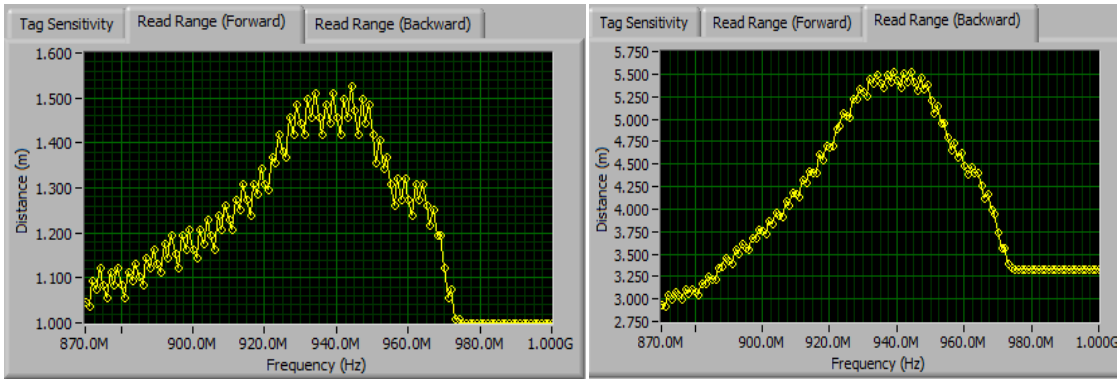


Figure 18. Forward and backward read ranges as calculated by the test software for Intelleflex tags

A quick look at the figures indicated that for Caen tags the forward and backward ranges are roughly similar and around 5m (or approximately 15 feet). This is expected and comparable to the range testing results we did in Phase I. Even though the communication range in the use-case scenario (when the tag is placed underneath the FSR/MRE pallet) is significantly shorter (around 2-3m or 6 to 9 feet) this is expected as the Nexjen test results show the range performance in free space.

For Intelleflex, the backward read range was about 1m more than Caen tags (5.5m compared to 4.5m at their maximum values) whereas the forward read range was less (1.5m compared to 5m). These findings were not consistent with our Phase I range testing results with Intelleflex – which stems from the fact that the RFID system uses an Intelleflex reader – tag duo and part of the battery is used to boost communication range. This capability is disabled when testing the tag with a 3rd party Gen2 reader software like Nexjen explaining the differences observed in real life performance.

1.4 Temperature Data And Shelf Life

One of the most important milestones in the proposal for objective 1 was the creation of a remote database with which the handheld RFID device can communicate to upload their temperature and shelf life information. Uploaded information can later be used to for supply chain logistics at a central location. In this section, we describe the specifications and how the database is designed and used for the project.

1.4.1 General Information

1.4.1.1 System Overview

The Remote Environmental Monitoring System (REMS) stores RFID temperature tag data and shelf life algorithm results that have been uploaded by a handheld device and runs supply chain simulations on the data. REMS contains a database component to store the data and user authentication information, a web interface which allows users to view the stored data and run simulations, and a web service endpoint that is used by handheld devices to authenticate users and upload temperature and shelf life data. This system is meant to serve as a proof of concept for a future system that can be used to make real-time decisions based on shelf life algorithm results and supply chain topology.

1.4.2 System Summary

1.4.2.1 System Configuration

REMS is built using ASP.NET MVC 4, targeting the .NET 4.0 runtime. The system uses a SQL Server database for storing tag data and user account information. The system has been successfully tested on a server that has Windows Server 2008 R2 Enterprise, IIS 7.5, and SQL Server 2008 R2 installed. The web service component uses ASP.NET Web API to implement a RESTful interface. The system has been deployed to a server owned by Franwell Inc. The IP address of the website is https://96.254.155.162:886/. Note that the server is using a self-signed SSL certificate, so the web browser may present a certificate error which can safely be ignored. The website has been tested using Internet Explorer 10, Chrome (latest), and Firefox (latest).

1.4.3 Getting Started

1.4.3.1 Login And Logout

The website is located at https://96.254.155.162:886/. A login screen will be presented to the user when first visiting the website. The default credentials are:

Username: admin
Password: newpass

Once logged in, the user may log out of the system by clicking the “Logout” menu item at the top right.

1.4.4 Website Functions

1.4.4.1 Pallet Status Page

Upon successfully logging in, the “Pallet Status Page” is presented to the user. This page is the starting point for accessing all functions of the website. These functions will be discussed in greater depth in later sections.

The “Pallet Status Page” displays a table of all tag data stored in the system. Each row in the table displays the following information:

- ⇨ Tag EPC: Electronic Product Code of RFID tag
- ⇨ Quality: Quality value output by shelf life algorithm
- ⇨ Shelf Life: Calculated remaining shelf life (in weeks)
- ⇨ Location: Identifier of tag’s current location in the supply chain
- ⇨ Status: Indicates whether tag is “In Transit” to final destination
- ⇨ Final Destination: The final destination that has been determined for this tag by the simulation
- ⇨ Last Scanned: Date and time of when the tag data was scanned

Clicking on a row of the data table will show a dialog that displays a graph of the temperature data over time as well as a tabular view of the shelf life data. The user may click on “Download CSV” to download a comma-separated file containing the data. The user may click anywhere outside of the dialog to dismiss it.

1.4.4.2 Adding And Removing Tag Data

Temperature data may be added to the database by either uploading to the system by the handheld device, or by randomly generating the data via the website interface. The handheld uploads the data to the /api/RESTTagData/ endpoint using an HTTP POST and includes a JSON-encoded object with the following schema:

TagEPC: <EPC of tag>,

DateScanned: <Date of scan (ISO 8601 Encoded)>,

DaysRemaining: <Number of days remaining as calculated by shelf-life algorithm>,

Quality: <Quality value calculated by shelf-life algorithm>,

TagData: <Array of objects>

DataDate: <Date of temperature reading (ISO 8601 Encoded)>

Temperature: <Temperature reading>

Note that the location of the tag is randomly generated when the tag data is uploaded to the system. In a future version of the system, each handheld would ideally provide the location at which the tag was scanned. The pallet status table is automatically updated as tag data is uploaded to the system.

Tag data may also be generated randomly using the website interface by clicking on the "Data" menu at the top of the page, entering a valid number of rows and clicking on "Insert simulated reading data". For each row generated, this function will assign a randomly generated Tag EPC starting with the string "SIM", assign a random quality value in the range [4.0…8.0], calculate the number of days remaining within the range [0…700] days which is linearly proportional to the quality value, randomly select a current location, and generate a random scan date/time that falls within the past 5 days. The temperature data for this tag will also be randomly generated, but this data has no relationship with the randomly generated quality value or number of days remaining.

The user may also delete all data from the database by clicking on the "Data" menu and then clicking "Delete All Data". Note that users with the "Admin" role are the only ones that can access this menu item.

1.4.4.3 Supply Chain Simulations

There are two different types of simulations that can be run on the tag data, First In First Out (FIFO) and First Expired First Out (FEFO). The simulation ultimately determines which tags/pallets should be selected for transport based on the simulation type (FIFO or FEFO), final destination, and number of pallets requested.

The simulation assumes a simple "notional" supply chain model predefined in the system as shown in Figure 19 below, but the decision algorithms can be extended to larger supply chain models:

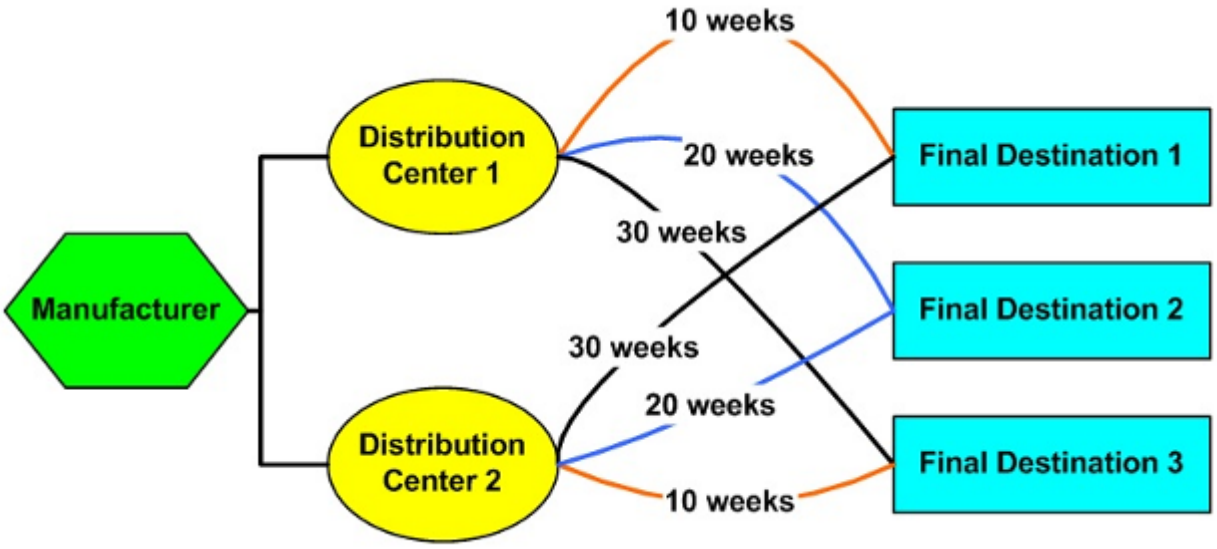


Figure 19. Basic supply chain used for supply chain distribution algorithms

The supply chain model also contains the duration it takes to travel from distribution center (DC) to final destination (FD). Note that this duration is not necessarily the time it takes to travel between the two points, but rather, the total weeks of shelf life lost during the transit – this is called "shelf life distance".

The general algorithm that the simulation executes is as follows:

1. Select a FD that is requesting tags/pallets (either randomly generated or selected by user)
2. Select the number of tags/pallets that the FD is requesting (either randomly generated or selected by user)
3. Select a simulation type, FIFO or FEFO (selected by user)
4. Inspect the tags/pallets that are not already in transit
5. Select pallets based on FIFO or FEFO algorithm
6. Mark selected pallets to be "In Transit" and set final destination

The user may trigger a round of FIFO or FEFO simulation by pressing the "Simulate FEFO" or "Simulate FIFO" buttons. These two functions will randomly select a FD and number of pallets to request in the range [1…3]. The user may also specify a final destination and number of pallets by pressing the "Request Pallets" menu and entering the appropriate data. When a pallet is selected for transport, the corresponding row in the data table is highlighted to denote that it has been selected during the last round of the simulation.

FEFO Simulation

The FEFO simulation selects pallets by determining which pallets will expire the soonest. For each pallet that is not already in transit, it calculates:

ShelfLifeAfterTransit = (RemainingShelfLife – ShelfLifeDistance(CurrentLocation, FD))

Where RemainingShelfLife equals the remaining shelf life of the pallet, and ShelfLifeDistance() is a function which references the supply chain model to look up the shelf life distance from the pallet's current location to the selected final destination.

The simulation only considers those tags/pallets that have a positive ShelfLifeAfterTransit. It then sorts the candidate tags/pallets by remaining shelf life and selects up to the top N pallets where N is the number of pallets requested.

FIFO Simulation

The FIFO simulation selects pallets by sorting the pallets that are not already in transit by the time their tags were scanned. It then selects the top N pallets where N is the number of pallets requested.

Resetting Simulation

The user may reset the simulation by clicking on the "Reset Simulation" button. This will clear the "In Transit" and "Final Destination" fields for each tag in the database. Note that this function does not delete any temperature data from the database.

1.4.4.4 User Administration

Users that are assigned the "Administrator" role may add, edit and delete users from the system. The user can select on "User Admin" at the top right to enter the administrative area. Once this menu item is clicked, the user is presented with a list of users that exist in the system. The system contains two roles, Basic and Admin. Users that are assigned the Basic role may view tag data and run simulations, but may not enter the User Administration section. Also, these users may not upload data to the system using the handheld application.

Administrators are granted full access privileges to both the website and the handheld application. Note that administrators may assign initial passwords when creating users in the system, but may not change passwords for users that already exist. Users must log into the system to change their own passwords.

1.4.4.5 My Profile

Users that are logged in may modify their profile information such as name and email address and change their passwords by clicking the "My Profile" menu item at the top right. Users are not permitted to change their usernames.

REST endpoints

The system also implements REST endpoints that are used by both the website interface as well as the handheld interface. This section describes the interface in more detail.

Endpoint	/api/RESTAuthentication
Purpose	Used by handheld devices to authenticate users
HTTP methods	POST
Request Data	{ UserName: <UserName to authenticate> Password: <Password for user>}
Response Data	Authentication Success HTTP Status Code 200 { UserName: <UserName of logged in user> Role: <Role of logged in user} Authentication Failure HTTP Status Code 401
Notes	If authentication is successfully, an authentication cookie is sent to the client. This cookie should be used in all subsequent requests by the client

Endpoint	/api/RESTPalletStatus
Purpose	Used by website interface to get pallet status data
HTTP methods	GET
Request Data	None
Response Data	JSON-encoded pallet status data

Endpoint	/api/RESTTagData
Purpose	Used by website to get temperature data Used by handheld to upload temperature data

HTTP methods	GET – used to get TagData by ID (/api/RESTTagData/:id) POST – used to upload data
Request Data	See above section for input format
Response Data	Same as input format

1.5 Shelf Life Model Integration And Handheld-Database Communication

The next important milestones in the project proposal which were accomplished in Phase II was the development of a new shelf life model for the MRE rations based on quality analysis findings of Objective 2 and integration of both shelf life prediction models into the handheld software and the backend database system.

The shelf life estimation model is a composite model that relies on taste panel sensory data. This comprehensive acceptability data is collected for each of the attributes of appearance, odor, flavor, texture and overall quality for products evaluated under controlled time/ temperature storage conditions. The data is used to determine the remaining product shelf life based on interpolation of quality index values to construct quality curves based on effects of time and temperature as applied on an iterative and recursive basis. The result is a scalable and computationally efficient model that utilizes look-up tables to enable the algorithm to run on demand and remotely on an RFID-enabled wireless handheld device while balancing accuracy and system performance.

For a more detailed description of the shelf life algorithm, please refer to the final project report from Phase I. Below is a description of the updated capabilities of the handheld system and how to use it under different modes of operation which also serves as a user-manual for the Caen handheld system.

The operation of the Intelleflex system, although using different hardware, is identical except a few user-interface changes on the handheld side. Both systems communicate with the same database so all data can be gathered in one server regardless of the front-end hardware. This creates a flexible and upgradeable setup which is independent of the changes or updates made to the RFID front-end.

1.5.1 General Information

1.5.1.1 System Overview

The Shelf-Life Monitor application is used to collect and analyze data from RFID temperature tags that are placed on pallets containing perishable goods in order to determine if the goods are viable for consumption during transit through the supply chain. The system is generally

used with a Windows Mobile RFID reader application connected to a supported RFID reader peripheral. At the start of a shipment or excursion, the user may use the application to command the tag to start the logging session. At various points throughout the supply chain, the application can be used to download and analyze temperature data read from the tags. The results of this analysis can be used to make various decisions related to supply-chain logistics. The application provides the following key features:

- Visual representation of the temperature data collected from the tags
- Runs and presents the results of the shelf life algorithm to the user
- Ability to configure the shelf-life algorithm
- Administrative functions for managing RFID tags
- Uploads temperature data to a centralized database

1.5.2 System Summary

1.5.2.1 System Configuration

The Shelf-Life Monitor application runs on a Windows Mobile device, specifically a Psion Teklogix Workabout Pro 2 handheld scanner with an attached CAEN A528 RFID reader (Figure 20). The Shelf-Life Monitor application uses the CAEN RFID reader to connect to the either the CAEN A927Z RFID or CAEN RT0005 Temperature Tags to download information and display that information to the user for analysis and as inputs into the Shelf-Life Algorithm (Figures 21 & 22). These two tags offer similar performance capability, with the CAEN A927Z temperature tag offering rugged durability, extended temperature sensor range, increased sampling size and battery life as compared to the CAEN RT005 tag, which offers an on-tag generic shelf life algorithm which is not required for this project.



Figure 20. Psion Teklogix Workabout Pro 2



Figure 21. CAEN A927Z RFID Temperature Tag



Figure 22. CAEN RT0005 RFID Temperature Tag

1.5.2.2 Contingencies And Alternate Modes Of Operation

Due to the nature of wireless RFID transmissions, the Shelf-Life Monitor application anticipates a number of error conditions that will occur when data transmissions are interrupted. Attempts are made to mitigate these error conditions by allowing a specific number of connection timeouts to occur before the software determines a tag is no longer in readable range. These timeouts could potentially degrade the performance of the software if a tag is at the edge of the RFID communication range.

The Windows Mobile device has a power setting that forces the operating system to go into sleep mode after a specified amount of time. When this mode is activated it appears that the Windows Mobile device has turned off. To bring the operating system out of sleep mode, hold the "Enter" key at the top right of the key pad for a few seconds and the operating system will go back into the state it was in before it went into sleep mode.

The Windows Mobile device does not have a way to reset the operating system from the operating system menu options. To initiate a hard reset on the Workabout Pro, hold the blue "FN" and red "Enter" keys simultaneously and wait for the hard reset to begin (about 5 seconds). The system will then reboot and the application can be used as normal.

1.5.3 Getting Started

1.5.3.1 System Startup

To start the Shelf-Life Monitor application, select the application from the Start menu on the Windows Mobile operating system. The application will power on the CAEN RFID reader and load the software taking the user to the login screen (Figure 23).

1.5.4 Login

Before the user can access the features of the handheld system, he or she must authenticate using a username and password. User credentials are stored in the Remote Environmental Monitoring System (REMS) database. Please refer to section 1.4 for more information about the REMS database.

If a user is granted the "Basic" role within REMS or logs in as a guest, he or she may download tag data and run the shelf-life algorithm, but may not administer tags, configure the shelf life algorithm, or upload tag data to REMS. Users with the "Admin" role are allowed to use all features of the system.

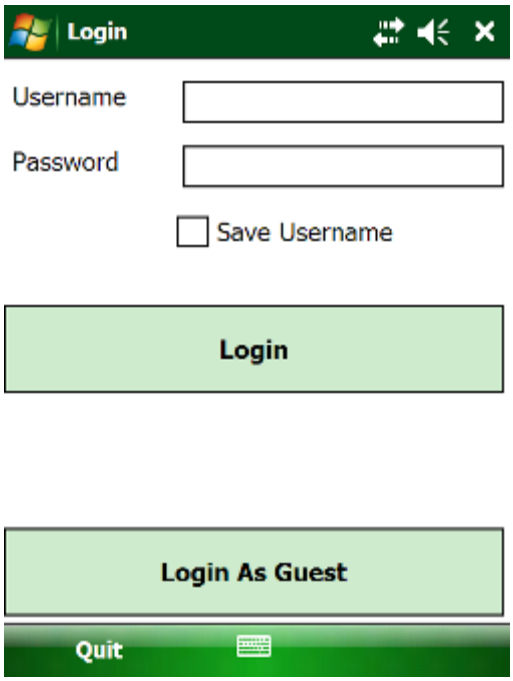


Figure 23. Login Screen

If an Internet connection is not available, the user may only log in as guest. If there is an error contacting the server for authentication, the user is automatically logged in as guest. The user may re-enter their login credentials from the Scan screen by choosing the "Login" item from the main menu.

Note that the server authentication endpoint URL is configured in the "App.config" file. Reference Section 1-5-7-2: Configuration File for more details.

1.5.5 Retrieving Tag Data

1.5.5.1 Scan For Tags

The Scan button will instruct the CAEN RFID reader to probe the area for all CAEN Temperature Tags and list their tag ID along with their current status (Figures 24 and 25). If the reader was unable to find any tags within range an error message will be displayed. The user may also press the trigger key on the RFID reader to start a scan. If the Scan button is pressed while tags are pre-existing in the "Found Tags" table, tags which have had their data downloaded will not be removed, even if they are out of range. Any tags marked as "Not Downloaded" will be removed if the most recent scan was unable to find them. This feature allows a user to analyze the data from tags that have been downloaded when they are out of range and informs the user which tags are available for downloading based on the most recent scan.



Figure 24. Scan Screen

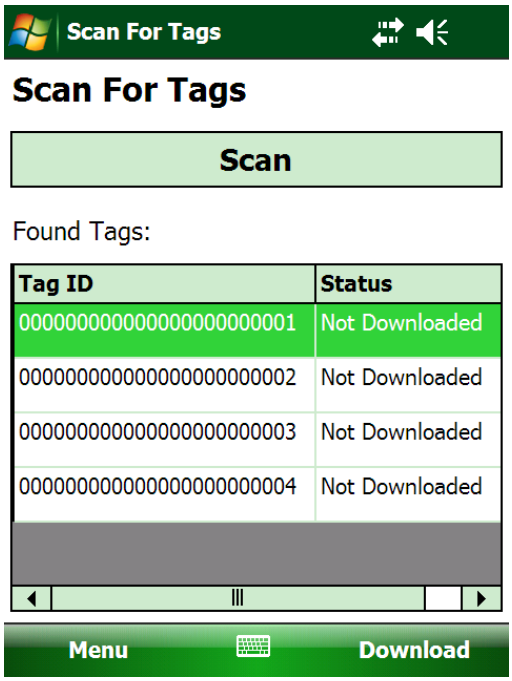


Figure 25. Main Screen with Found Tags

1.5.5.2 Download Data

Once a tag has been found the user can then download the temperature data from that tag. This is achieved by selecting the tag from the "Found Tags" table and clicking the Download button. The user will then be presented with a progress screen where the data download progress is shown and the user is given the option to cancel the download (Figure 26). If the user chooses to cancel the download a warning message is shown to inform the user that the partially downloaded data will be saved with this tag (Figure 27). If the user chooses "Yes" to continue the cancellation, then the incomplete data can be used in the Shelf-Life Algorithm. If the user chooses "No", then the download operation continues as normal. If the user chooses "Cancel" then the download is stopped and the user is taken back to the main screen.

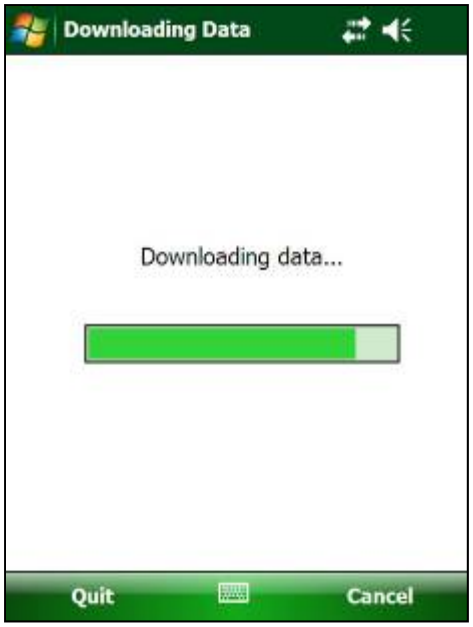


Figure 26. Download Progress Screen



Figure 27. Incomplete Data Warning

1.5.5.3 View Data

If a tag's status is set to any status other than "Not Downloaded", the tag data can be viewed from the main screen by selecting the tag and choosing "Menu" -> "View Data". This will present the user with the algorithm result and chart screen.

1.5.5.4 Remove / Remove All

To remove an individual tag from the "Found Tags" table a user can either press and hold on the tag entry and click "Remove From List" or select the tag and choose "Menu" -> "Remove". To clear the table of all tags a user can select "Menu" -> "Remove All".

1.5.6 Running Shelf-Life Algorithm

1.5.6.1 Run Shelf-Life Algorithm

Once the tag data has been downloaded, the shelf-life algorithm is automatically run to determine if the product is good or expired. Once the algorithm completes, the status is displayed and updated on the main screen (Figures 28 and 29). The visual representation of the temperature data is shown in the center for visual analysis. Depending on the configuration settings, the application will send the status update along with the raw temperature data to the email addresses specified in the configuration file (Reference section 1.5.7.2 Configuration File).

The user also has the option to save the data log which contains the raw temperature data to a file on the Windows Mobile file system. This is done by pressing the "Save Data Log" button on

the algorithm result screen. To access this file, connect the Windows Mobile device to a Windows based computer, open the ActiveSync program, choose the explore button, double-click on “My Windows Mobile-Based Device” -> “Program Files” -> “shelflifemonitor”. In here you’ll find all of the data logs along with application specific files. The data logs are named “DataLog” followed by the tag ID and the date the log was created. Copy and paste the log from the shelflifemonitor file onto the computer. Once the log has been copied over it can be viewed with the text editor (i.e. Notepad). The log can also be viewed directly from the Windows Mobile device by opening the File Explorer and navigating to the directory containing the logs. Note: If the algorithm result is displayed with a “*” next to it, it’s because this tag’s data was run through the Shelf-Life Algorithm with partially downloaded data. In order to display the status without the “*”, the tag’s data will need to be fully downloaded from the main screen.

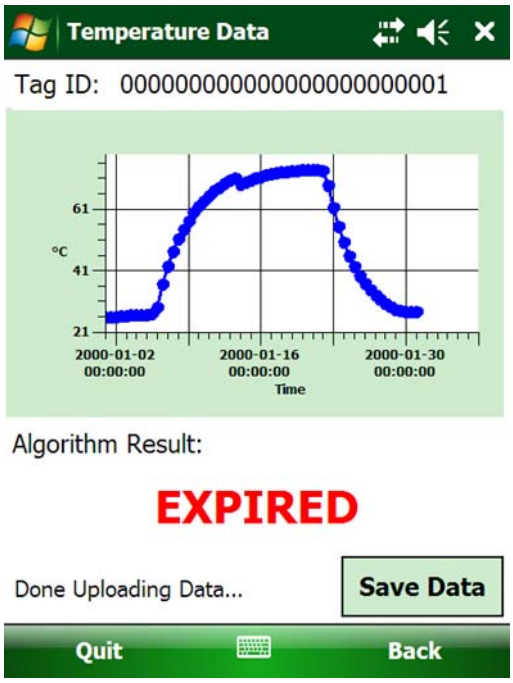


Figure 28. Algorithm Result Post Shelf-life Algorithm for an Expired Product

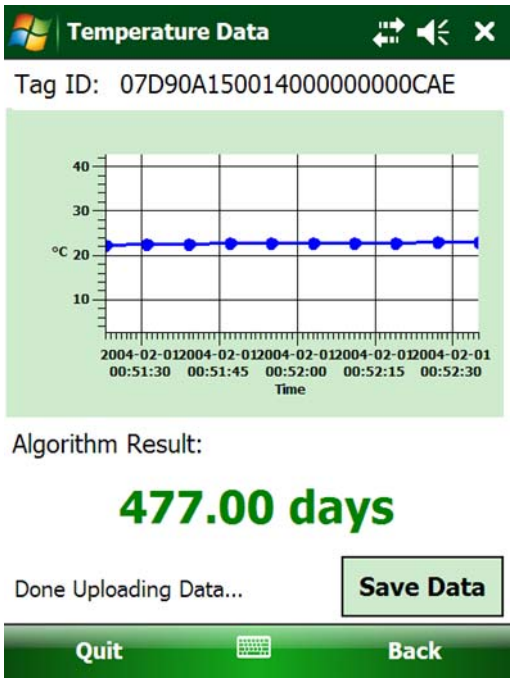


Figure 29. Algorithm Result Post Shelf-Life Algorithm for a Non-expired Product

1.5.6.2 Upload Tag Data

If the user is logged in and the user’s account contains the “Admin” role, the system will automatically upload the temperature tag data and algorithm results to REMS. If the user’s session has timed out due to inactivity, data may not be uploaded and the user will be presented with the login screen. Once logged in successfully, the user may upload the data by selecting the tag and choosing “Menu” -> “View Data” and then pressing the “Upload” button on the “View Data” screen.

1.5.6.3 Configure Algorithm

The parameters of the shelf life algorithm may be configured by the user by navigating to the main screen and choosing the option “Menu” -> “Admin Menu” -> “Configure Algorithm”.

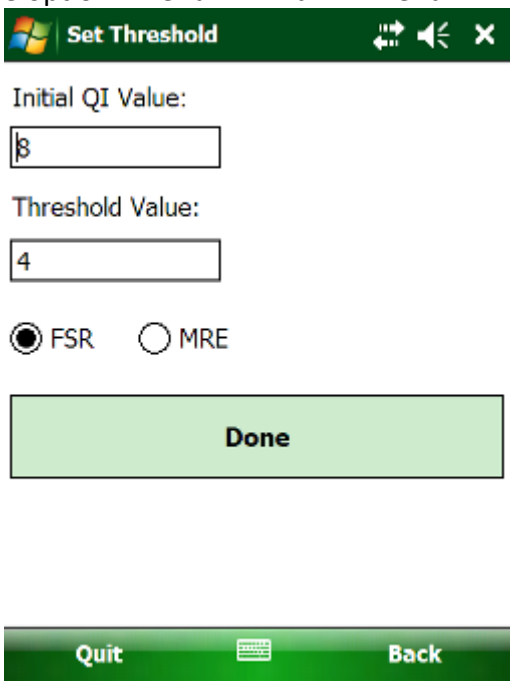


Figure 30. Choosing the shelf life algorithm based on the product

The Configure Algorithm screen allows the user to set the Initial Q Value, Threshold, and matrix type (FSR or MRE) (Figure 30).

Once the user is finished setting the parameter values, select “Done” to save the changes. These values are stored in the application’s configuration file which can be accessed via Active Sync for manual updating (Reference Section 1-5-7-2: Configuration File for more information).

1.5.7 Administration

1.5.7.1 Administration Tags

Overview

The Shelf-Life Monitor application contains a module for administering the CAEN temperature tags which provides functionality for starting and stopping the logs and setting the sampling interval. This module is accessed by selecting a tag from the main screen then navigating to “Menu” -> “Admin Menu” -> “Tag Admin” (Figure 31). On the tag administration screen the user will be presented with the following tag information (Figure 32):

- Tag ID – The ID of the tag current being administered

- Logging Status – Informs the user as to whether this tag is currently logging data or not logging any data.
- Number of Samples – The total number of samples that have been logged by this tag.
- Log Start Time – The time that this tag's logging session was started.
- Sampling Interval – The interval which each temperature sample is logged for this tag.

Start Logging

To commission the tag for logging the user must choose the sampling interval, click on the "Start Logging" button and agree to erase the tag's current temperature log. The tag log can only be started if the tag is not currently logging.

The CAEN RFID temperature tag supports the ability for a log to be stopped and started without erasing the log; however, because the Shelf-Life Monitor implementation does not log timestamps, the temperature data timestamps would be calculated incorrectly. The application calculates the timestamps based on start time and sampling interval and any gaps between temperature samples would not be identified if the log was not erased upon restart.
Once the tag log has been started, the tag administration screen will be updated to reflect the new information such as sampling interval, start time, and number of samples.

Note: The tag's log does not have to be stopped for a user to download the tag's data and run it through the Shelf-Life Algorithm.

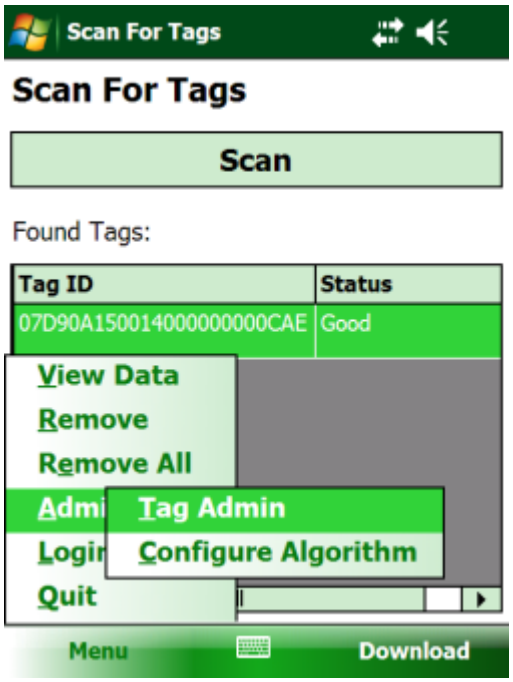


Figure 31. Tag Admin Menu Option

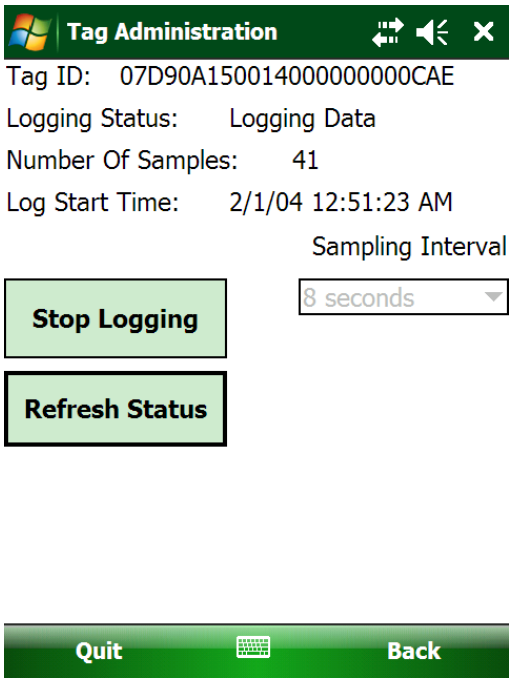


Figure 32. Tag Admin Screen

Stop Logging

To stop the tag's current logging session, the user must click the "Stop Logging" button and agree to finalize this tag's logged temperature data. The tag log can only be stopped if the tag is currently logging.

As explained above, the purpose of finalizing the tag's logging session is due to the fact that the timestamps cannot be accurately calculated if there are gaps in the temperature logs. This warning is informing the user that when this tag's log is restarted the currently logged data will be erased and a new logging session will be started.

Once the tag log has been stopped, the tag administration screen will update the logging status. Note: This tag's data can still be downloaded and run through the Shelf-Life Algorithm after the log has been stopped. Once the log is restarted the data will be lost.

1.5.7.2 Configuration File

The Shelf-Life Monitor application reads parameters from a configuration file that can be edited on the device through the Windows Mobile ActiveSync application. To access the configuration file, ensure the device is connected to a Windows based computer, open Microsoft ActiveSync, select Tools ->Explore Device. This should open a new Windows Explorer window into the device. Double click on "My Windows Mobile-Based Device" -> "Program Files" -> "shelflifemonitor". Copy and paste the configuration file "App.config" from the device onto the computer (the file cannot be edited directly on the device). Open the configuration file in a text editor (i.e. Notepad).

The configuration file contains the following parameters:

- AlgorithmThreshold – Sets the threshold of the Shelf-Life Algorithm. This can also be done via the Shelf-Life Monitor application Admin section
- InitialQValue – Sets the initial Q value before executing the shelf life algorithm
- FSR_QIMatrixFile – Filename of FSR QI matrix data
- MRE_QIMatrixFile – Filename of MRE QI matrix data
- MatrixMode – Determines which matrix the algorithm will use. Valid values are "FSR" and "MRE"
- SendEmailEnabled – Whenever the Shelf-Life Algorithm is run on temperature data, an email is sent containing the tag ID, status, and data log file. This parameter enables and disables that email from being sent. Setting the parameter to 1 enables emailing and 0 disables emailing.
- EmailAddressRecipients – Determines the recipients for the Shelf-Life Algorithm email sent stated above. Must be in a semi-colon delimited string (i.e. email1@domain.com;email2@domain.com).

- PocketOutlookAccountName – The name of the email account provider that has been setup on the device for sending the Shelf-Life Algorithm status emails. This email account must be setup on the device for the Shelf-Life Monitor application to send the status emails. For more information on setting up email accounts on Windows Mobile 6.1, see http://www.microsoft.com/windowsmobile/en-us/help/v6-0/Send-Receive-Email-touch.aspx
- SavedUsername – Saved username if user selected "Save Username" on login screen
- PrintAlgorithmRunTime – Whether or not to print the time it took to run the shelf life algorithm to the output file. Possible values are 1 (enabled) or 0 (disabled)
- DataUploadTimeout – Number of seconds to wait while uploading data before declaring the data upload a failure
- PalletStatusServerAddress – Address of REMS system
- PalletStatusServerPort – TCP port of REMS system

Once these parameters have been set, save the configuration file (must be named "App.config"). Copy and paste the saved configuration file from the computer back onto the device from the same location you retrieved the file from. When the application is reopened, the new configuration parameters will be used.

1.5.8 Error Conditions

It is important for the user to understand the error conditions that occur when the Shelf-Life Monitor application attempts to connect to the CAEN RFID temperature tag and the connection has been lost. This section explains the different error conditions, how they can be mitigated, and their significance in operating the application and tags.

1.5.8.1 CAEN RFID Temperature Tag Memory

The CAEN RDID temperature tag contains memory for storing the temperature data that has been logged since the logging session was started. This memory is a fixed size and will eventually be filled up once the device has logged enough data. Whenever the memory is full, the tag will erase a block of old data and begin storing the new data in its place. Deleting temperature data renders the algorithm result unusable because all historical data is needed to determine if the product is good or expired. Therefore, the Shelf-Life Monitor application informs the user that a tag with full memory cannot be checked with the Shelf-Life Algorithm. The tag will need to be restarted so the old log can be deleted.

1.5.8.2 Scan For Tags

The Shelf-Life Monitor application attempts to scan for tags by probing the area multiple times for CAEN RFID temperature tags. If there are no tags available then the user is informed with an error message. Given the range of RFID transmissions, it is important for a user to aim the

handheld in the general direction of the tag that the user is trying to scan. The user could potentially press the "Scan for Tags" button and point the handheld at multiple tags in an effort to gather as many tags as possible in one sweep.

1.5.8.3 Download Data

When a user begins downloading data from a selected tag, the RFID transmission could be interrupted due to interference or the tag going out of range. The Shelf-Life Monitor application tries to reconnect to the tag multiple times before displaying an error message that the tag's connection has been lost. If the download has not completed, the user will be directed back to the main screen where the download can be retried. The user could begin the download and then point the handheld in the direction of the tag that the user is trying download data from in an effort to keep the connection open long enough to gather all of the data.

1.5.8.4 Tag Admin

When a user chooses the "Tag Admin" option for a selected tag, the Shelf-Life Monitor application will attempt to connect to the tag and download all of the status information such as logging status and start time. If the application cannot connect to the tag initially, an error message will be displayed and the user will remain at the main screen. Otherwise the tag is connected and the status is read and the user is presented with the tag administration screen. The options available to the user from the tag administration screen are start logging, stop logging, and refresh status. When a user starts the logging session, the application sends commands to the tag to delete its current log, reset the start time and sampling interval, and begin a new logging session. When a user stops the logging session, the application sends commands to the tag to simply stop the logging session. During these operations the application needs to connect to the tag multiple times. At the beginning of the start and stop commands the application connects to the tag to send it start and stop command information then attempts to update the status information on the admin screen. There is a possibility that the commands were sent to the tag without errors, but the connection was lost when the status information was attempting to be refreshed. In this case, the application will inform the user that the start or stop action was completed successfully, but the connection was lost to refresh the status. The tag administration screen will show "Error" for all fields accept the "Logging Status". If the application was unable to send the initial start or stop command information, then the application will inform the user that a connection to the tag could not be made and the state of the tag has not been changed. In cases when the data was not downloaded completely from the tag, the result of the shelf life algorithm will be displayed with an "*"sign next to the result (Table 12)

Table 12. Tag Status Descriptions

Status	Description
Not Downloaded	The data has not yet been downloaded from the tag.
Partially Downloaded	The data has been partially downloaded from the tag due to the user

	cancelling the download midway through the downloading process.
Fully Downloaded	The data has been completely downloaded from the tag.
Expired	The Shelf-Life Algorithm has been run on fully downloaded data from the tag and has determined the product is expired.
Expired*	The Shelf-Life Algorithm has been run on partially downloaded data from the tag and has determined the product is expired.
Good	The Shelf-Life Algorithm has been run on fully downloaded data from the tag and has determined the product is good.
Good*	The Shelf-Life Algorithm has been run on fully downloaded data from the tag and has determined the product is good.

1.6 Product Temperature Estimation Using Ambient Temperature Recorded By RFID Temperature Tags

1.6.1 Introduction

Another important milestone outlined in the proposal which was accomplished in this phase was to develop tools to use the acquired data in the database for more accurate analysis using adaptive learning systems and to facilitate informed decision making in the supply chain. This is accomplished by:

1) Extending the pallet temperature estimation algorithm to container level with the help of adaptive learning systems such as artificial neural networks to study how to use minimum number of wireless sensors to predict product temperature throughout the container accurately.

2) Simulating a basic perishable supply chain to highlight the differences between first-in-first-out (FIFO) and first-expired-first-out (FEFO) which takes into account shelf life prediction, equipment failure and delays, and random arrival and product request times.

We will start with describing the temperature estimation studies we carried out at the container level and the work to understand temperature behavior in a container.

Based on the former studies of temperature estimation on a First Strike Ration pallet at the case level, it was decided to perform similar studies in more realistic scenarios, i.e. a refrigerated sea container, since the potential benefit of having a system capable of predicting the temperature along any period of time with a reduced number of sensors, not only in just one per pallet but in the entire container were recognized. In this case due to lack of available FSR pallets to fill a container, mixed pallets of synthetic perishables (oranges and strawberries) were used. Criteria under evaluation included; (1) a refrigeration system failure, when the product is stabilized at 2°C, (2) the temperature behavior during a regular, non-cloudy day profile at both pallet level and container level, and lastly testing use of various temperature estimation methods.

In this experiment three types of temperature profiles were used: (1) the step profile, (2) refrigeration failure profile, and (3) the 2-day cycle profile. These temperature profiles were evaluated in four different situations, (a) empty container, (b) one pallet at the end of the container, (c) one half load with four pallets, and (d) eight pallets, which represents the full load of our 20 foot refrigerated sea container. The most significant data are concentrated on the full load configuration; therefore we will only analyze these results in this report. The other configurations were used with the goal to achieve the best RFID tag location and the best temperature profiles.

The refrigeration failure and the 2-day profile scenarios are representative of commonly occurring situations and therefore serve as a very good way to optimize the test to obtain valuable data.

A refrigeration system breakdown has the potential to occur at any stage and /or time resulting in a significant loss of product. It can be caused by a lack of power supply to the refrigerators or by an accidental unplug. In these instances a proper characterization of the temperature trend, including during breakdown, is essential.

The 2-day profile is representative of temperature throughout the container when the refrigeration system is disconnected; which will be necessary to estimate the shelf life of the product for optimal decision-making across the supply chain after prolonged storage.

Finally the step profile is used to define the dynamic behavior of the temperature in the container, where it is possible to obtain a time constant necessary to use one of the temperature estimation methods, namely the Capacitor method as explained in detail in the Phase I final report.

The most important data relates to the fully loaded configuration. As one can see in Figure 33, the temperature distribution along the container and among the pallets is not homogeneous. From this figure we can see that the four pallets at the right of the image represent the closest pallets to the cold air steam with lower temperatures compared to the other four that are closest to the door. One can also observe temperature differences within each pallet as well.

In this configuration the air flows from right to the left of the image, traversing the bottom of the container. For this reason we observe the lower parts of the pallets being colder than the upper parts, since the time instant shown in the image is with the cold air flowing in the container. This is the reason the top of the container shows a very different temperature compared to the pallet temperature. This particular container happens to have an internal temperature sensor located very close to the upper right corner of the container as shown as location 1 in Figure 33). An RFID tag was placed adjacent to the sensor which provided source data used in some of the estimation methods.

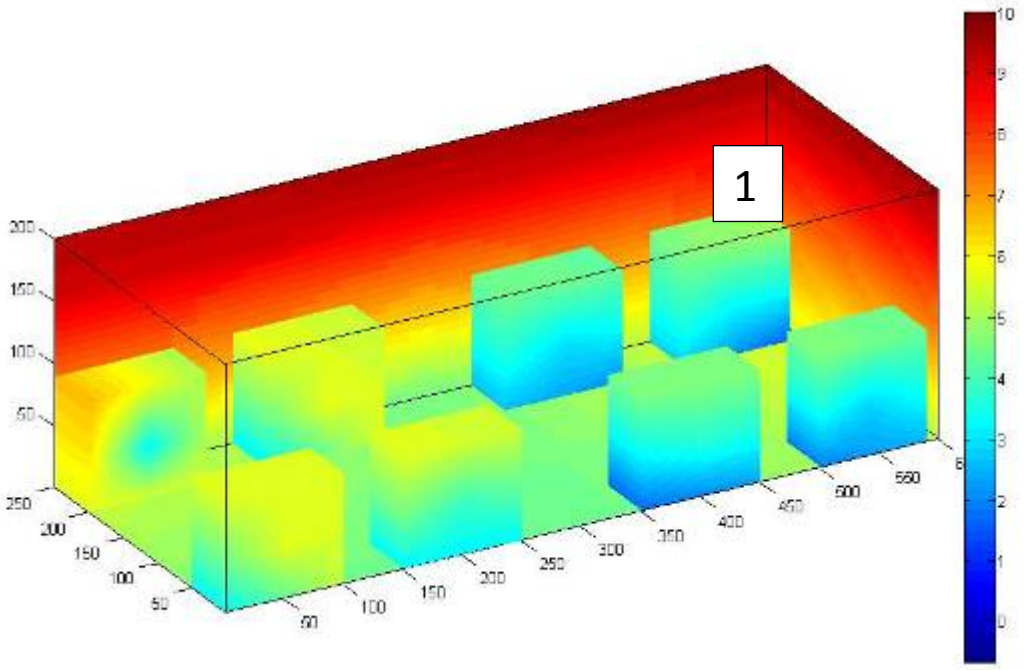


Figure 33. 3D temperature distribution observed in a sea container with 8 pallets

1.6.2 Materials And Methods

The distribution of the sensors was key to this study. An example of the load procedure and the sensors on the container is represented in Figure 34. The materials utilized in this study were (1) Intelleflex XC3 and Caen temperature loggers used in the project, (2) a 20 foot long sea container with a refrigeration system and (3) eight pallets of synthetic produce.



Figure 34. Pallet distribution inside of the container

The procedure to carry out the experiment was to place five RFID tags in each pallet along the pallet diagonal. The distribution is shown in Figure 35 where each tag is represented by a colored dot and each color represents a single pallet. Eighteen Intelleflex tags were put in the container (hanging from the ceiling as shown in Figure 34) to record the container temperature during different phases of the experiment. After the set up we executed the temperature estimation techniques described in the following sections.

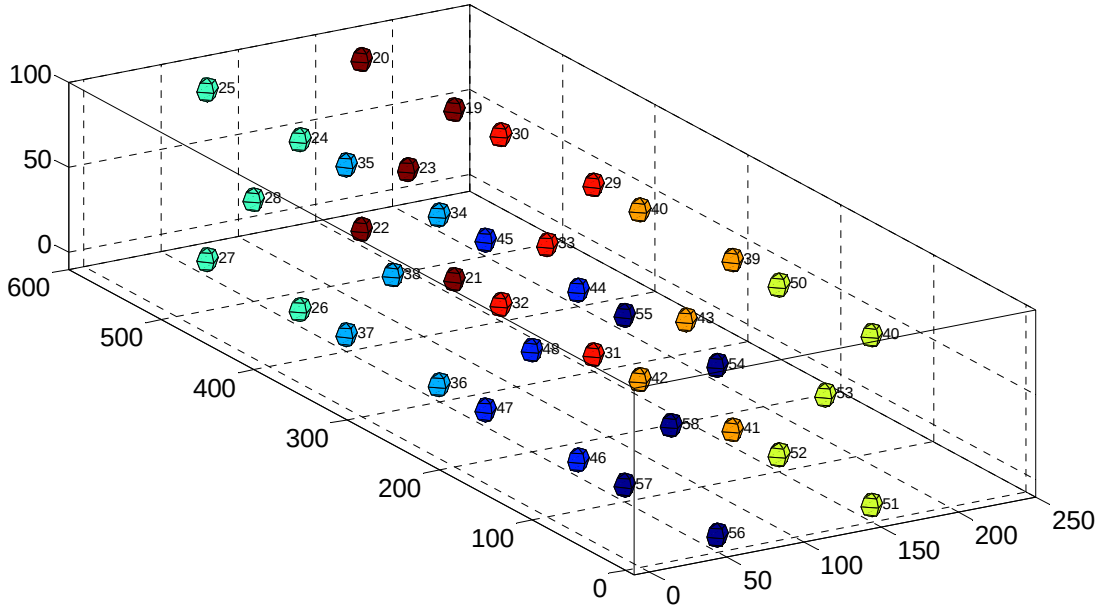


Figure 35. Sensors distribution on the container

1.6.2.1 Temperature Estimation Methods

Similar to the previous study, the goal for all the temperature estimation methods is to predict the product temperature better than using only the reference sensor, which measures the ambient temperature. This effort examines estimation performance of three different algorithms looking at three distinct temperature profiles.

Capacitor method

This method is explained in detail in the Phase I final report. Briefly, the capacitor method attempts to overcome liquid and metal performance limitations of RFID technology and tag placement to more accurately estimate the dynamic heating and cooling cycles typically found within tightly stacked pallets of rations as found inside containers. The capacitor effect results in slowed heating and cooling cycles as compared to ambient temperature cycles. The temperature changes inside the pallet are modeled as end-results of a capacitive model with the environmental temperature as input. The increasing and decreasing temperatures are modeled with different time constants. The system is trained with prior data to find these time

constants and the relationship between the estimated temperature and the environmental temperature can be described as follows:

$$If\, T_{environmental} > (T-1)_{pallet}, \text{ then...}$$

$$T_{pallet} = (T-1)_{pallet} + \left(T_{environmental} - (T-1)_{pallet}\right)\left(1 - e^{\frac{-t}{\tau_{rising}}}\right)$$

$$If\, T_{environmental} < (T-1)_{pallet}, \text{ then...}$$

$$T_{pallet} = (T-1)_{pallet} + \left(T_{environmental} - (T-1)_{pallet}\right)\left(1 - e^{\frac{-t}{\tau_{falling}}}\right)$$

Kriging

The Kriging method has previously been used in environmental estimation problems defined within a continuous feature space (such as temperature inside a homogenous container) *(Reiner Jedermann, Javier Palafox-Albarrán, Pilar Barreiro, Luis Ruiz-García, Jose Ignacio Robla, Walter Lang "Interpolation of spatial temperature profiles by sensor networks", IEEE, 2011)* There are various linear interpolation methods that multiply the measured values at the source points with a set of weighting factors in order to estimate the value at a destination point. The weighting factors can be set by a heuristic approach proportional to the inverse squared distance or by—statistically more solid—Kriging method. The Kriging method is based on an analysis of the spatial correlation of the measurements. This method uses the Variogram, which gives the expected difference of the physical quantity between two points as a function of their distance (*Jedermann et al*). The first step in Kriging is to calculate the experimental Variogram from the data set and estimate the parameters of a theoretical model (in this case the Gaussian model) to approximate the experimental function. Using this function one can calculate the weights of the destination points, and then estimate the temperature inside the pallet from the environmental temperature. The way we apply Kriging is with the script obtained from the official web page of Mathworks developed by Wolfgang Schwanghart in October, 2010. This script also needs the scripts Variogram and Variogramfit to calculate the estimated points. First it calculates the variances between the source points in accordance with the different distances using the previously mentioned script Variogram that uses the variance statistic formula below to estimate the variance.

$$\mathrm{Var}(X) = \frac{1}{n}\sum_{i=1}^{n}(x_i - \mu)^2$$

Then the Variogramfit script is used with the Gaussian model to achieve the experimental semivariogram to obtain the coefficients to calculate the weights (w). With these weights w_{ij} it is possible to calculate the estimated temperature z_i from the environmental temperature as source points s_j using the equation below.

$$z_i(k) = \sum_{j=1}^{N_s} s_j(k) \cdot w_{ij}$$

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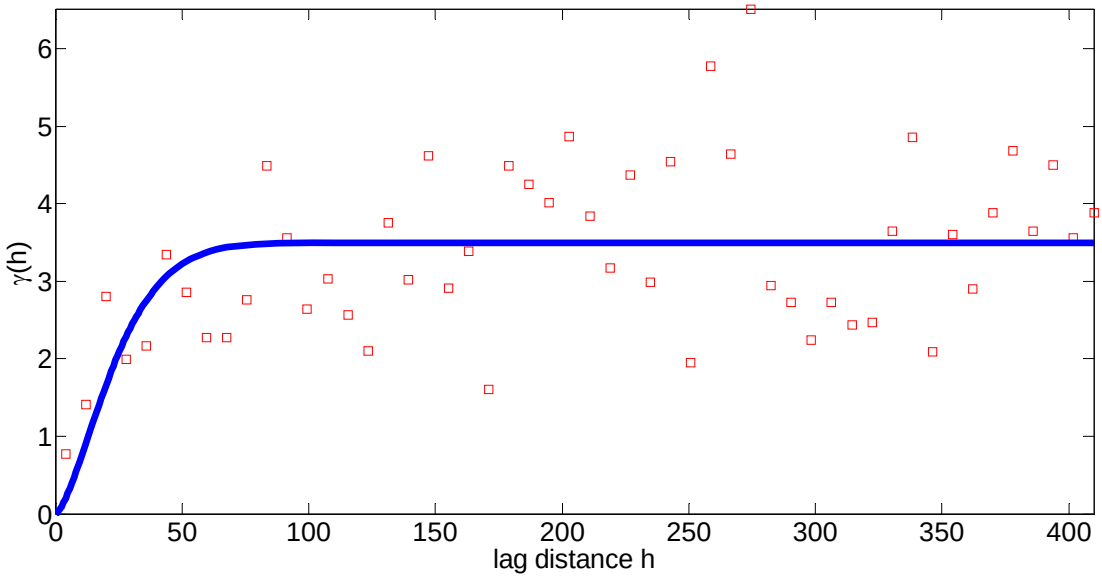


Figure 36. Semivariogram 12 source sensors Sea Container

The semivariogram above (Figure 36) shows the distribution of the variances of the temperatures as a function of the distance between them. From this figure one can appreciate sensors with distances larger than 100 cm has little correlation between their recordings as the fitted curve (in blue) becomes constant. This signifies that source sensors at distances greater than 100 cm are going to have a common weight, which will be multiplied by their recordings before being summed up to yield the temperature estimation.

Artificial Neural Network

Finally, as the third estimation algorithm, we assume that the inherently non-linear relationship between the product temperature inside a pallet and the air temperature can be modeled by an artificial neural network (ANN) as shown in Figure 37 below. Input to the network consists of time-temperature data provided by the sensor(s) placed outside the pallets whereas output is the estimated time-temperature data for products placed inside the pallets. Hidden layers consist of artificial neurons which weigh and sum their inputs as they propagate their outputs to the next hidden layer. ANNs need to be trained with part of the temperature data to learn how to estimate the non-linear relationship between its input and target output.

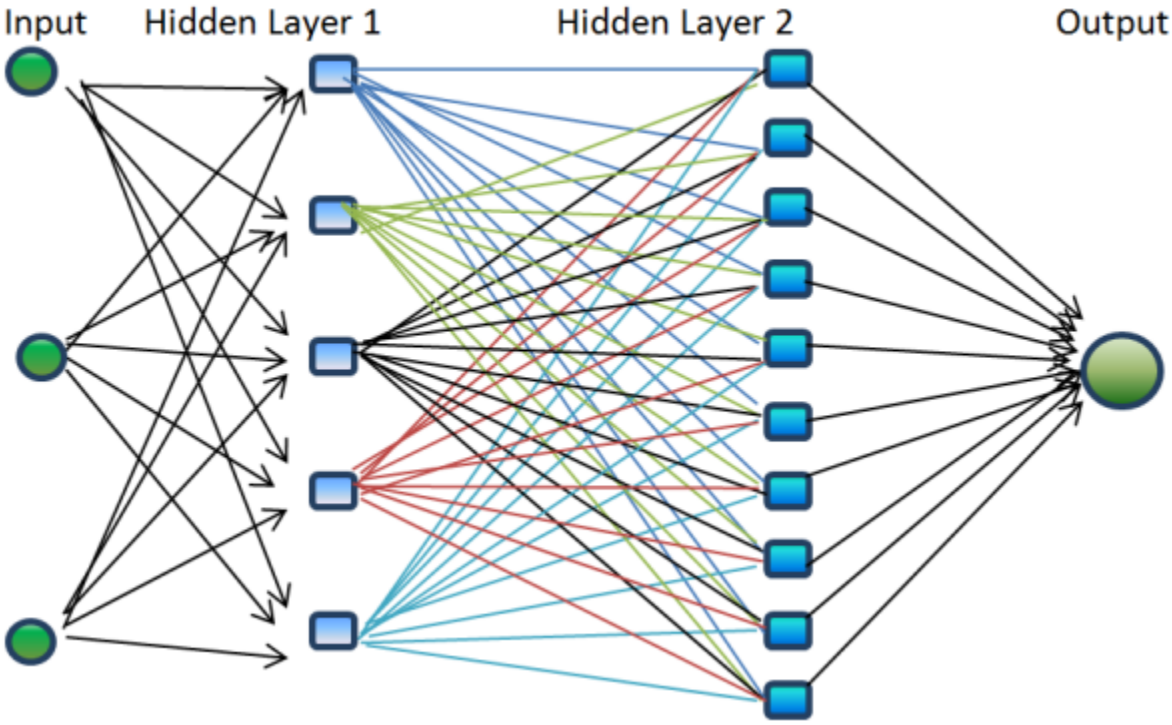


Figure 37. The structure of an artificial neural network to estimate temperature dynamics

In order to do a comparative analysis of the different estimation algorithms, we looked at the average root-mean-squared-error (RMSE) performance between actual and estimated temperatures for each box inside the pallet and the air temperature for a number of temperature profiles as shown below.

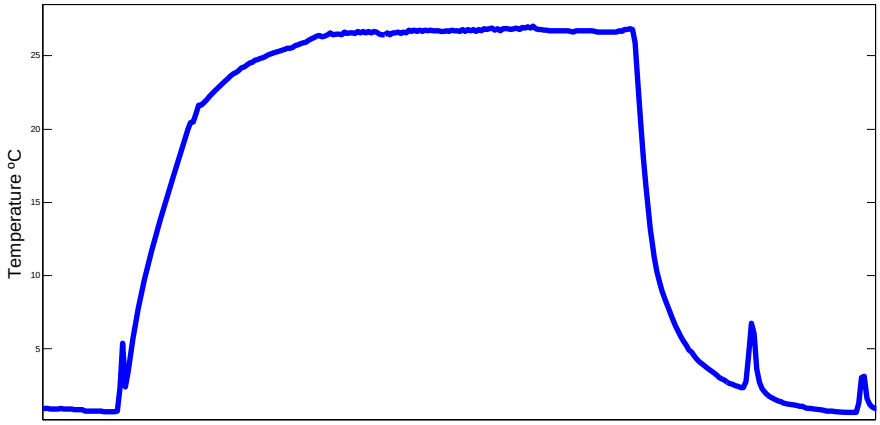


Figure 38. Step profile

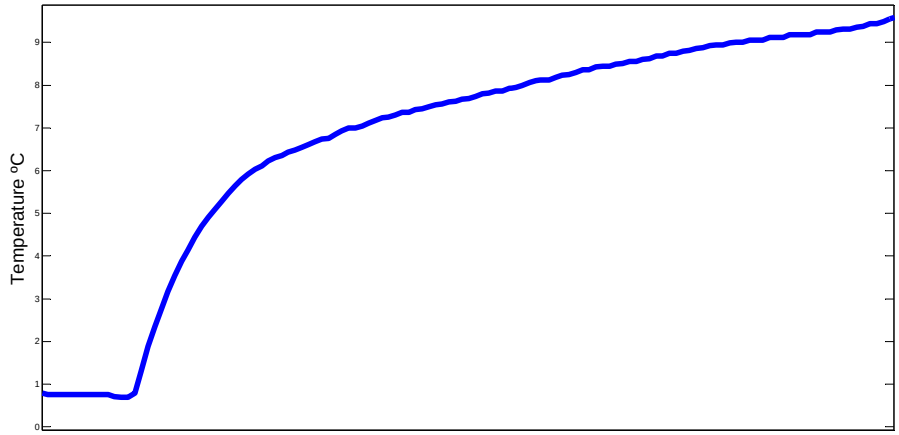


Figure 39. Refrigeration failure profile

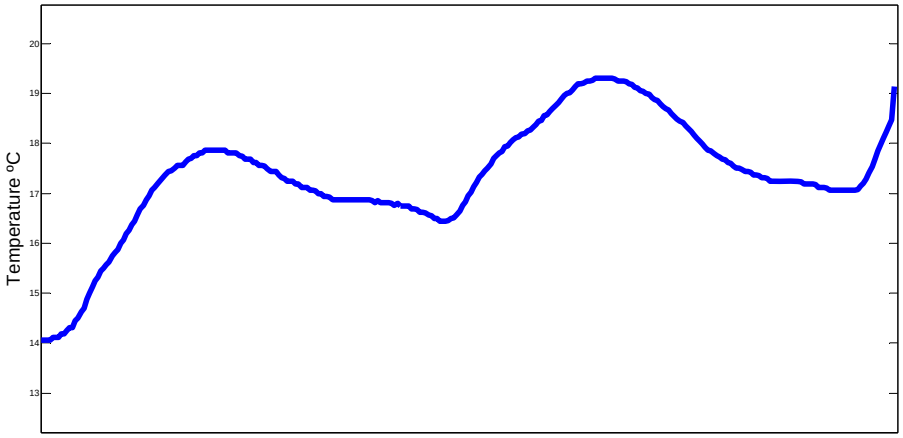


Figure 40. Two day cycle profile

1.6.3 Results

The results are divided into two parts. In the first phase we tried the profiles and verified the ability to conduct the experiment with the materials on hand while extracting the necessary parameters to run the test again using only the source sensors, such as time constant *tau* for capacitor method, the data weights structure of Kriging method, and training parameters for the neural network for every point. In order to simplify the results report, we will only refer to the refrigeration failure scenario, as the RMSE results are similar for the 2-day profile.

1.6.3.1 Phase Testing

Kriging

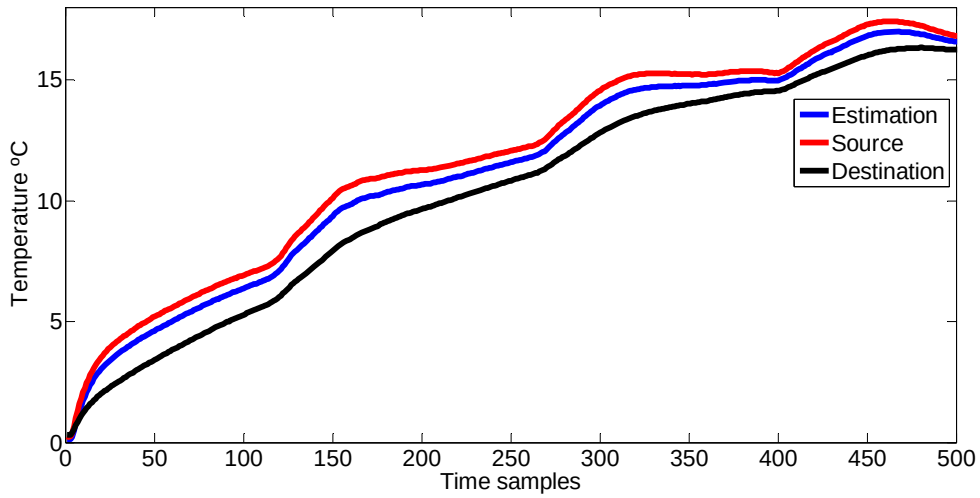
To measure the performance of Kriging we used two different combinations for source sensors. First, we used the source sensors placed at both middle and bottom layers for estimation. Second, we used only the source sensors placed at the bottom layer. Results are tabulated and plotted below (Tables 13, 14 and Figure 41).

Table 13. RMSE for Kriging for refrigeration failure profile – bottom and middle layers

Kriging bottom and middle layers (°C)					
Temperature estimation of the entire profile	Average RMSE 1.41	**Temperature estimation pallet by pallet**	Average RMSE 1.88	RMSE Pallet1	1.24
				P2	1.38
				P3	0.79
				P4	2.23
	RMSE with Source sensors 3.97		Average RMSE with Source sensors 2.93	P5	2.88
				P6	3.22
				P7	2.64
				P8	3.57

Table 14. RMSE for Kriging for refrigeration failure profile – bottom layers

Kriging Errors (°C) bottom layer source sensor					
Temperature estimation of the entire profile	Average RMSE 1.48	**Temperature estimation pallet by pallet**	Average RMSE 1.32	RMSE Pallet1	1.13
				RMSE P2	0.95
				RMSE P3	0.97
				RMSE P4	1.29
	RMSE with Source sensor 3.97		RMSE with Source sensor 2.93	RMSE P5	1.48
				RMSE P6	1.55
				RMSE P7	1.48
				RMSE P8	1.72



F

Figure 41. Temperature estimation average for the refrigeration failure using Kriging method

Capacitor

Capacitor works with only one source sensor as a reference and applying a particular time constant called “tau” to each destination point. This “tau” is the time response constant characteristic of a first order system, which correspond to our sensors. The constant is calculated from the profile shown in Figure 38 and as described in Phase I final report. Results are tabulated and plotted below (Table 15 and Figure 42).

Table 15. RMSE for Capacitor

Capacitor Errors (°C)			
Temperature estimation pallet by pallet	Mean RMSE 1.28	RMSE Pallet1	1.36
		RMSE P2	0.71
		RMSE P3	1.43
		RMSE P4	1.004
	RMSE Container sensor 3.97	RMSE P5	1.08
		RMSE P6	1.15
		RMSE P7	1.53
		RMSE P8	2.02

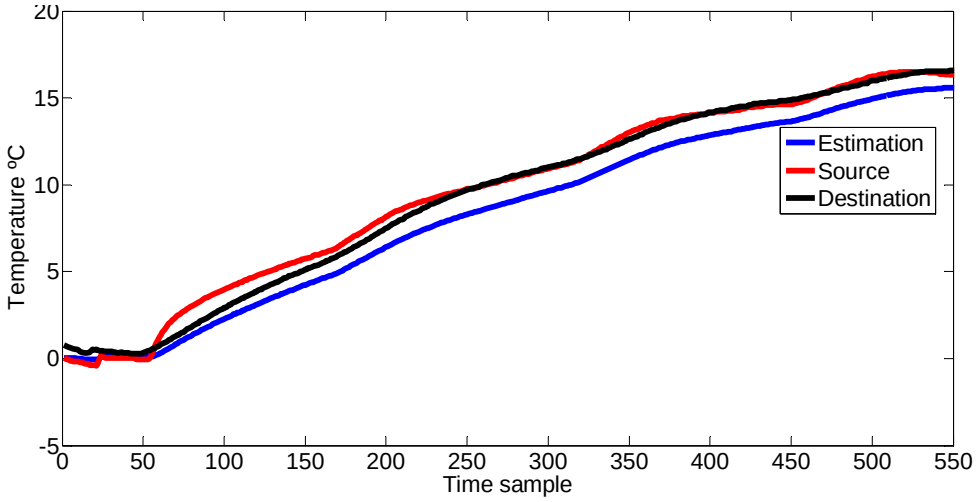


Figure 42. Temperature estimation average for the refrigeration failure using Capacitor method

Artificial Neural Network (ANN)

Artificial neural networks are used for system classification or estimation purposes when the goal is to estimate a specific output value given an input value. In this case the input values are obtained as the time-temperature recordings of source sensors and the desired output values are the destination sensors. The only challenge in training a neural network is the fact that there are many parameters, from the number of layers to number of neurons in each layer to

minimum performance gradient. Because of this, we had to test many different possibilities and measure RMSE errors in every case. The results are tabulated below (Table 16):

Table 16. RMSE for Artificial Neural Network

Neural Net (°C)							
	[555] layers Mu 0.01	[555] layers Mu 0.001	[555] layers Mu 0.0001	[10] layers Mu 0.01	[10] layers Mu 0.001	[10] layers Mu 0.0001	1 To 1
MeanRMSE	1.4279	1.4281	1.4779	1.0204	1.0009	0.94	2.4510
Pallet 1	1.2123	1.4587	1.5151	1.1688	1.0382	0.87	1.8543
Pallet 2	1.5821	0.8839	1.2752	0.8334	0.8775	1.05	1.5336
Pallet 3	1.3444	0.9588	1.6047	1.1488	1.1131	0.64	1.6389
Pallet 4	1.2880	1.7055	1.4411	1.4568	0.8471	0.85	2.9431
Pallet 5	1.5370	1.3848	1.6260	0.9432	1.0256	0.97	2.7209
Pallet 6	1.5534	1.6961	1.2619	0.9555	0.9616	1.15	2.2953
Pallet 7	1.6515	2.0079	1.4400	0.7222	0.9698	1.03	2.1469
Pallet 8	1.2548	1.3292	1.6596	0.9345	1.1743	0.95	4.4751
RMSE Source	3.97						

As can be seen from these numbers, the minimum RMSE was obtained using a single layer with 10 neurons and a performance gradient of 0.0001. An RMSE of 0.95 in this case, shows a 50% better estimation performance compared to Kriging and Capacitor methods, but this is not unexpected considering the fact that ANN is a much more complicated estimator with higher system resource needs.

Since in this case the estimated temperature profile is very close to the desired output, plotting the two curves in the full time scale is not very helpful. Thus we zoom in on the curves to highlight the relative differences between source/estimated/desired (destination) temperature curves as shown in Figure 43. As expected the estimated temperature curve is a much better approximation of the product temperature than just using the ambient temperature which would, in theory, results in better prediction performance.

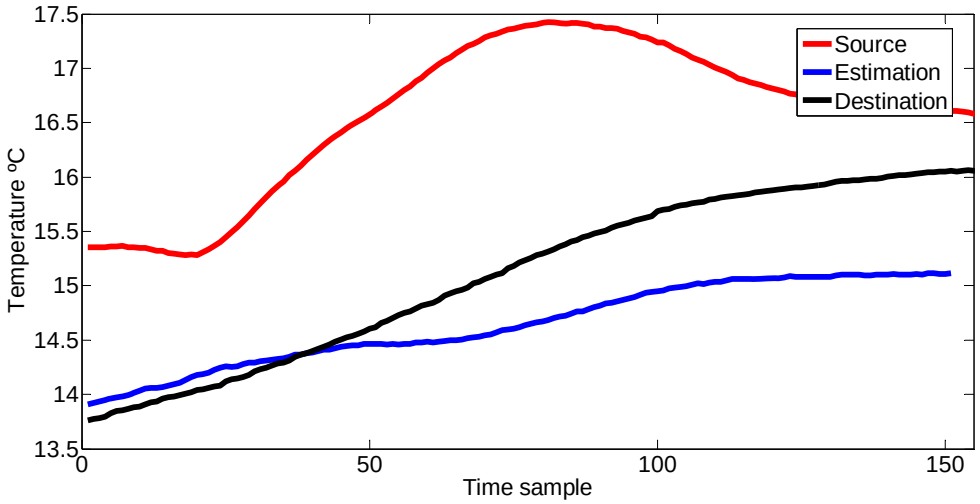


Figure 43. Neural network source, estimation and destination average temperatures

1.6.3.2 2nd Phase Testing

With the results and data obtained in the 1st phase of testing, it was deemed necessary to test the estimation methods with new and unknown data, very much like the validation study we performed for shelf life prediction. Since all three methods have training and testing phases we decided to use the 1st phase testing data for training and the new data for testing.

Kriging

Kriging method had an average RMSE of 3°C compared to the ambient temperature RMSE of 3.2°C, hence the approximation of the product temperature in this case is almost negligible. One of the reasons for this is the fact that Kriging method is primarily developed for sensors placed in a continuous variable environment, such as a homogenous medium. In our case, the transition from the air surrounding the perishable pallet to the inside of the pallet is anything but homogenous, so Kriging displays a worse performance compared to the other two methods.

Capacitor

The results of the capacitor method in this phase were obtained with the constants tau from the previous phase. The average RMSE for all the estimated product temperatures was 2.26°C. Even though this is higher than the results we obtained in the first phase of the study, considering the RMSE of the source point is 3.20°C, it is still a significant improvement over simply using the ambient temperature for shelf life prediction. Figure 44 shows the average estimated temperature data in comparison to source and desired temperature data.

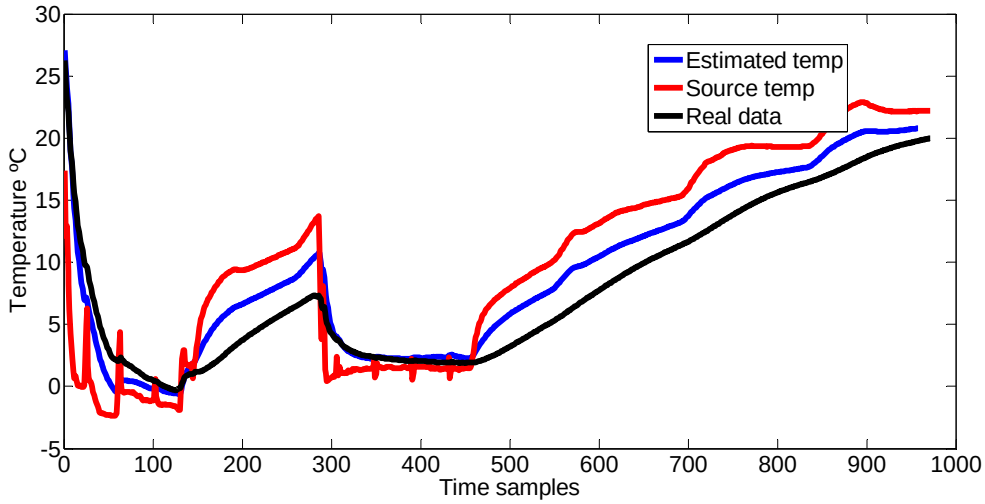


Figure 44. Average temperatures for the capacitor method in the second phase

Artificial Neural Network (ANN)

The trained network parameters from Phase 1 of testing were used to estimate the product temperatures using testing data obtained in Phase 2 which was never seen before by the network. We also tried a combination of sensor configurations to identify the minimum number of sensors that can be used for reliable estimation of product temperature. The results are significant because even using a single container sensor, as input, we estimated a temperature profile closer to the product temperature than the ambient temperature. This implies that even in a scenario where no wireless temperature RFID loggers are used, one can still get some level of insight into product temperature rather than just using ambient temperature.

Results are tabulated below for different source sensor configurations:

Table 17. Neural Network RMSE

NN configuration	Mean RMSE estimated °C	Mean RMSE source sensor °C
NFtool [5 10] + mu = 0.0001 + 8 source sensors	0.1304	3.8500
NFtool [5 10] + mu = 0.001 + 8 source sensors	0.1131	
NFtool [5 10] + mu = 0.001 + 4 bottom source sensors	0.3251	3.9370
NFtool [5 10] + mu = 0.001 + Container Sensor + 2 bottom sensors	0.4485	
NFtool [5 10] + mu = 0.001 + Container Sensor + 2 top sensors	0.3769	
NFtool [5 10] + mu = 0.001 + 4 top source sensors	0.7113	
NFtool [5 10] + mu = 0.001 + Container Sensor + 1 bottom + 1 top sensor	0.4277	
NFtool [5 10] + mu = 0.001 + Container Sensor	1.7943	

The lowest RMSE achieved when using two layers with 5 and 10 neurons at each layer and the full set of 8 source sensors. The temperature curves are shown in Figure 45. As can be expected the estimated temperature profile is a very good approximation of the product temperature when compared with the real temperature.

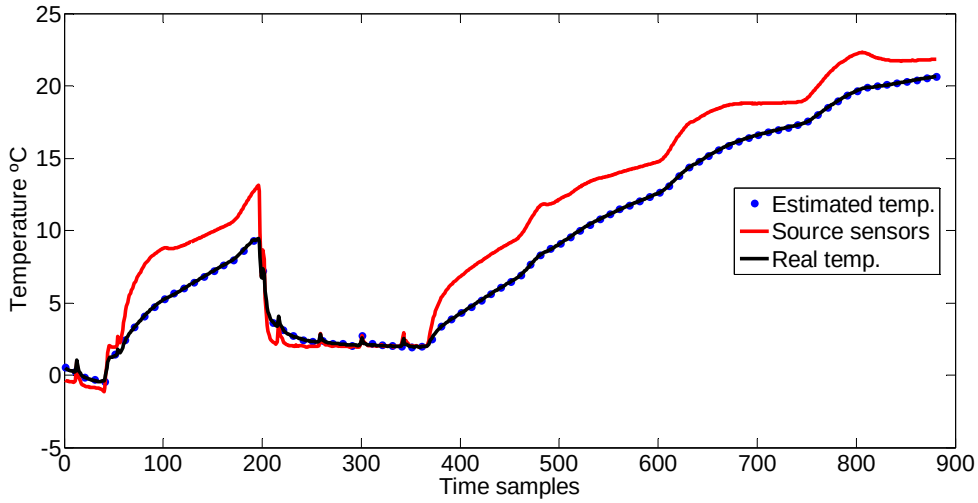


Figure 45. Average temperatures for the ANN method in the second phase

1.6.4 Conclusion

In this part of Objective 1e, we were able to continue the work from Phase 1 and prove that it is theoretically possible to estimate the product temperature in a real refrigerated sea container using sensors placed strategically inside the container. This estimation can be done even with one sensor (the container sensor) in the case of ANN estimation method, and the estimation error will still be lower than the error of the ambient temperature.

It is important to note that, each temperature estimation method investigated as part of this study is better than not using any estimation at all for the product temperature prior to being used in shelf life prediction. ANN performed better than the others but it also requires extensive training and more system resources to operate.

1.7 Analysis Of FEFO Vs. FIFO In Smart Supply Chain Logistics

1.7.1 Introduction

In order to enable smart and informed decision making in the supply chain, one needs to define a set of tools and rules that govern the acquired data through the use of the RFID system and the corresponding predicted shelf life. In order to assist us in developing these tools such as first-in-first-out (FIFO) and first-expired-first-out (FEFO) we created a basic supply chain that consists of a single manufacturer (or the source), two distribution centers and three final destinations. Although this constitutes a generic supply chain, the distribution logic remains

the same for larger supply chains as long as the link between the manufacturer and the final destination follows a similar path: Manufacturer -> Distribution Point 1 -> Distribution Point 2 -> … -> Final Destination. The description of the simulation tool and adjustable parameters are described below.

The first step to use the simulation model is to import the data. Data can be imported from an Excel sheet created by saving the existing temperature and shelf life data on the database server. All the models will be using the following raw data:

- Shelf life
- Quality

As an example, the 3-dimensional representation of the simulation model used for FEFO is shown below in Figure 46:

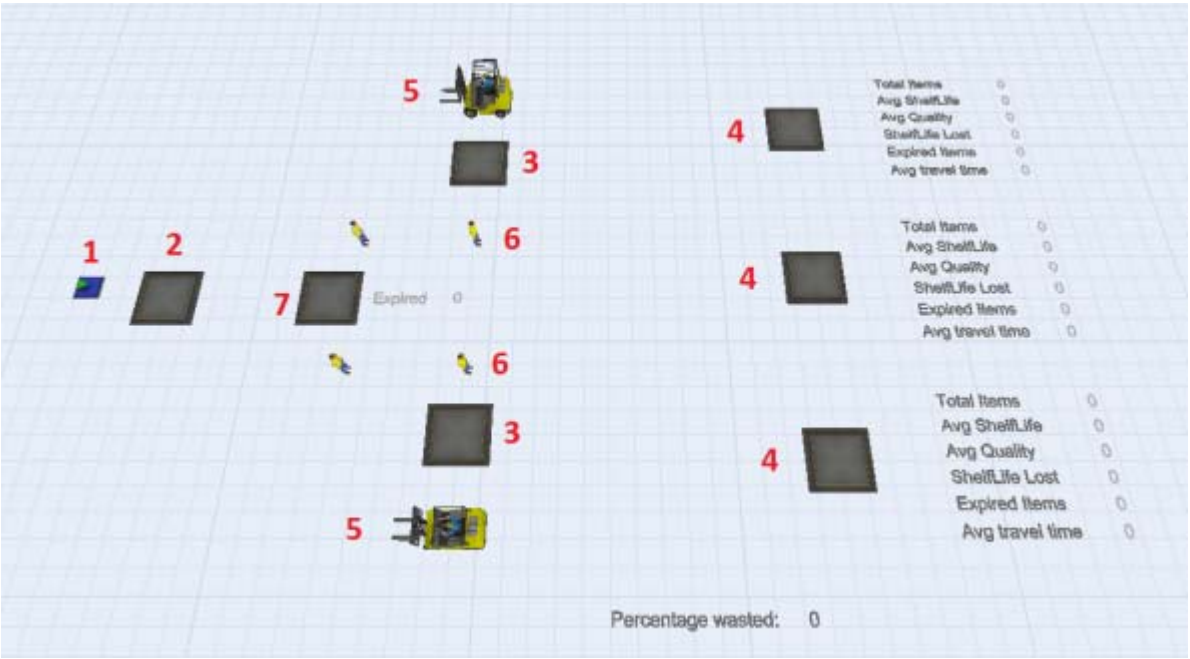


Figure 46. An overview of the simulation model used for FIFO vs. FEFO analysis

In the 3D view model, we can see the simulation preview.

1. Manufacturer where the items are produced or assembled
2. Storage location for the manufacturer
3. Warehouses/Distribution centers (DC) (we have 2 DCs in this case)
4. Final destinations (FD) (we have 3 FDs in this case)
5. Transporters that carry items between manufacturer and the distribution centers
6. Transporters that carry items between distribution centers and the final destinations

7. Storage place for the items that are expired in the distribution centers (Note that this may not be present in some of the models like FIFO, service in random order (SIRO) etc.

Beside each final destination, simulation statistics are displayed corresponding to each final destination. When the simulation is run, stats like total number of items received, average shelf life of the items, average quality, and number of expired items etc. can be seen here. Percentage of total items that are expired can be seen at the bottom. These performance statistics can later be analyzed to make decisions on which distribution algorithm would reduce waste and improve food quality for a given set of temperature/ shelf life data and the specifics of the supply chain which can be adjusted as described below.

1.7.2 Simulation Settings And Parameters

1.7.2.1 Distribution Logic

The data can be analyzed using two different types of FEFO settings as shown in Figure 47 below.

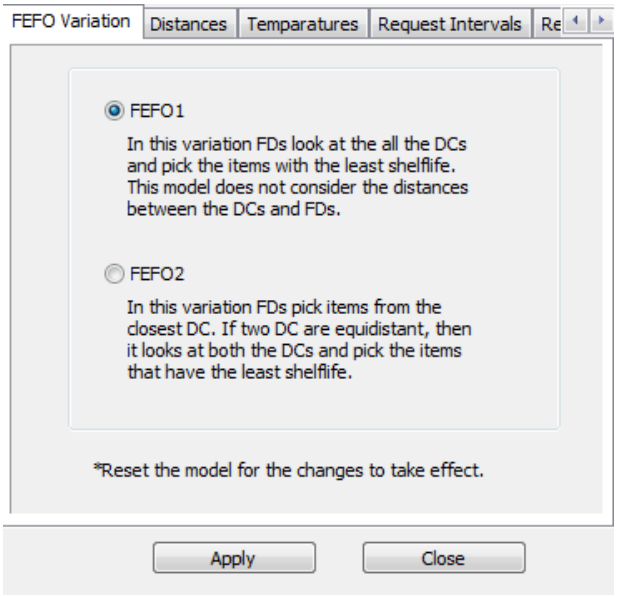


Figure 47. Different distribution schemes for FEFO (or FIFO)

In the first variation, when the final destinations pick items, they look at all the distribution centers and pick the desired items. In this variation there is no specific preference for any particular distribution center. In the second variation, the final destination will always look at the closest distribution centers for the products and pick the desired products. If two distribution centers are equidistant from the final destination, then both the distribution centers are looked at and then the desired products are selected. (Note that when we say desired products it means that the products are selected based on the model running. For example if the model is FIFO, the desired products are the ones that are produced first. If it is FEFO the desired products are the ones with the least shelf life etc.)

1.7.2.2 Distances

You can specify the distance between two points in the supply chain in terms of simulation time steps (Figure 48). We can specify the distances between the source to the distribution centers and from the distribution centers to the final destinations. The distance supplied here is the number of days it takes to travel between locations.

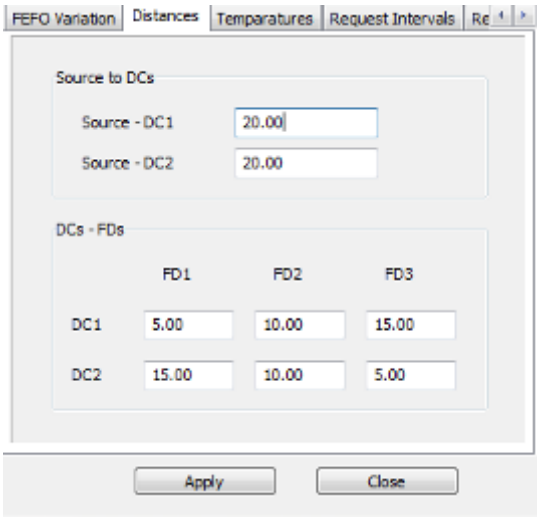


Figure 48. Adjusting distances between points in the supply chain

1.7.2.3. Temperatures

We can create random temperature profiles for both transportation and storage in the supply chain. In order to do that, we can set a minimum and maximum temperature point and uniformly distribute time-temperature data between these two points as shown in Figure 49 below.

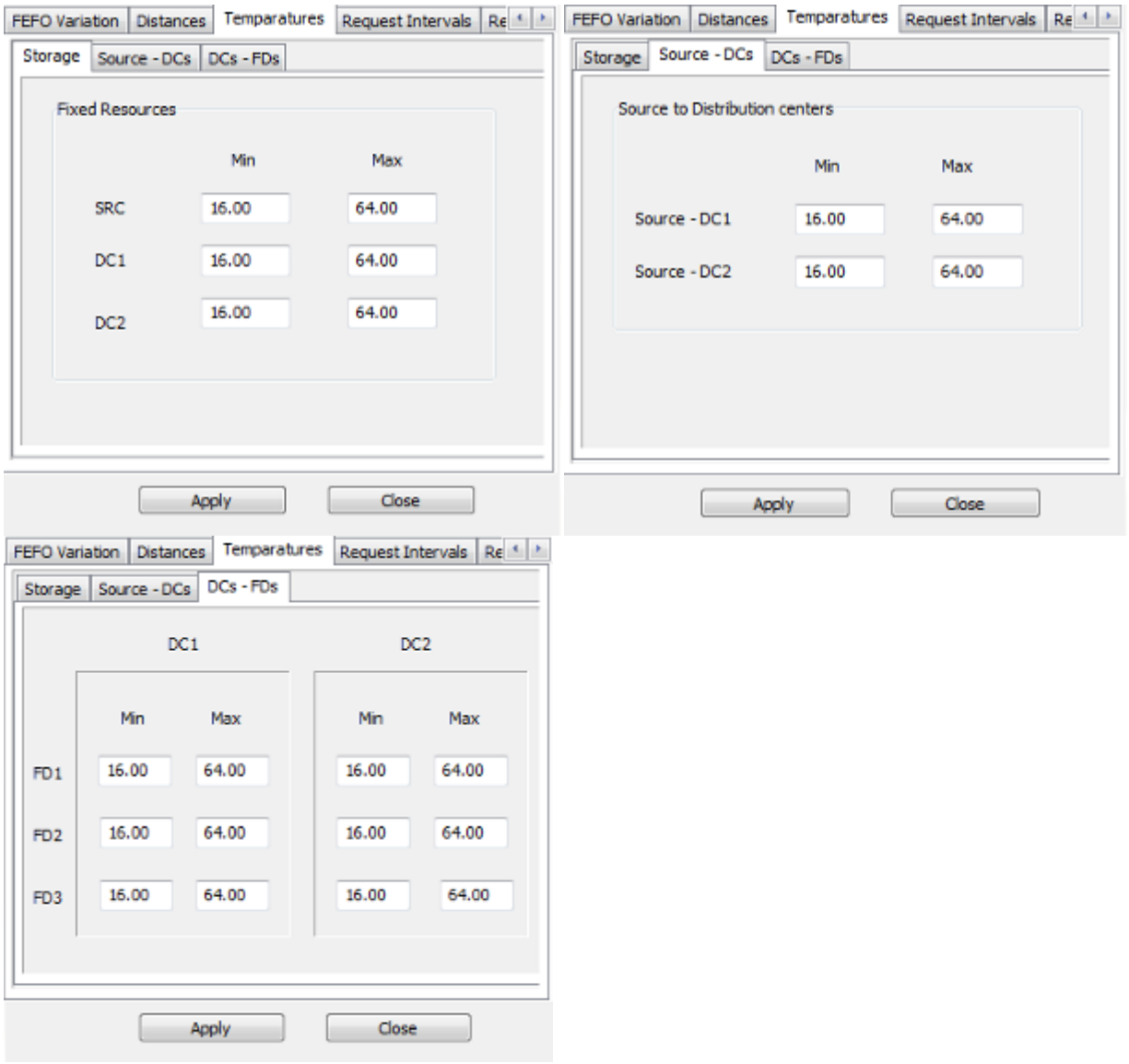


Figure 49. Adjusting temperature distributions between points in the supply chain

In the Storage sub-tab, we can set the temperature in the Source and the distribution centers. Min is the minimum temperature possible, and max is the maximum temperature possible. A random value is chosen between min and max and applied to the item. Similarly in the Source-DCs tab, temperatures during the transportation between the source and the distribution centers are specified. In the DCs-FDs tab, temperatures during the transport between the distribution center and the final destination are specified. The temperature supplied here should be in Celsius.

1.7.2.4 Request Intervals

Here we can enter the frequency of the product requests made by the final destinations i.e. number of days between two consecutive requests as shown in Figure 50 below. We have two

variations. In the first, the final destinations make requests independently i.e. any final destination can request for products irrespective of when the other final destination requested for products. In the second variation, all the products request at the same time. Min indicates the minimum duration in days between the successive requests. Max indicates the maximum duration in days between the successive requests. A random value between the min and max is chosen and the desired number of products is requested based on the simulation variation.

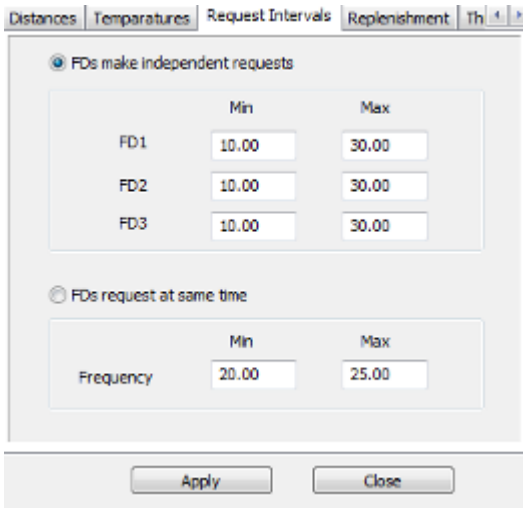


Figure 50. Adjusting product request intervals and frequency by final destinations

1.7.2.5 Replenishment Policy

In the replenishment section we can set the parameters related to replenishment policy. We can set the order point (if the number of items falls below this value, items will be ordered from the source) and the order quantity (number of items requested from the source during the replenishment) for different distribution centers as shown in Figure 51 below.

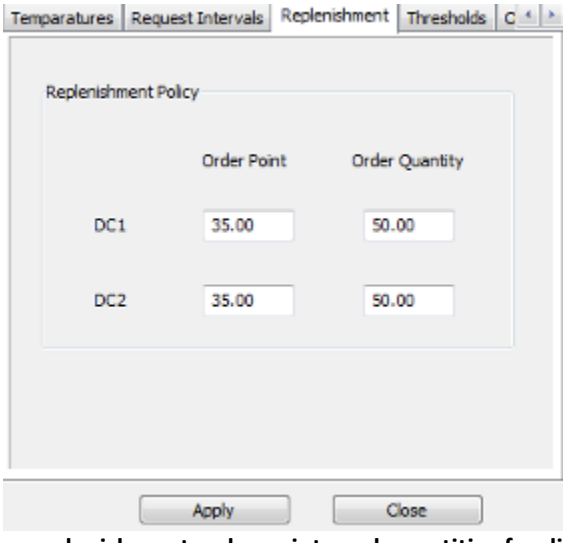


Figure 51. Adjusting replenishment order points and quantities for distribution centers

1.7.2.6 Thresholds

Here we can specify the minimum shelf life in days that the items need to have when they reach the final destination (Figure 52). Since, this is just the desired shelf life, sometimes there may be items with less shelf life than the desired shelf life. This is possible when the temperature during the journey goes beyond the predicted value or if there is any vehicle break down (due to randomness in the model).

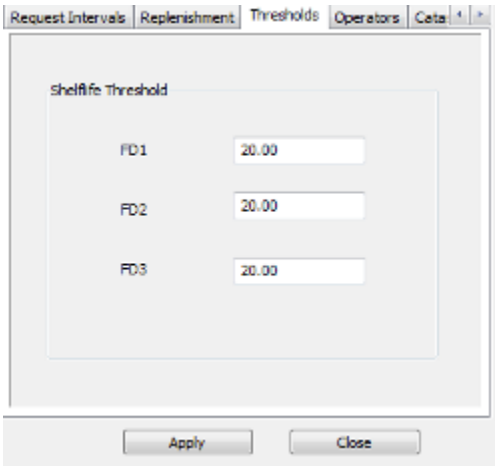


Figure 52. Adjusting minimum desired shelf life threshold per final destination

1.7.2.7 Operators

Here we can set the number of operators to be used for each distribution center (Figure 53). To the left we can see the maximum number of operators available for the simulation. This is a non-editable field and depends on the number of models assigned during the creation of the model. To the right we can set the number of operators to be used for this simulation. Note that this number should be less than the maximum number of operators available.

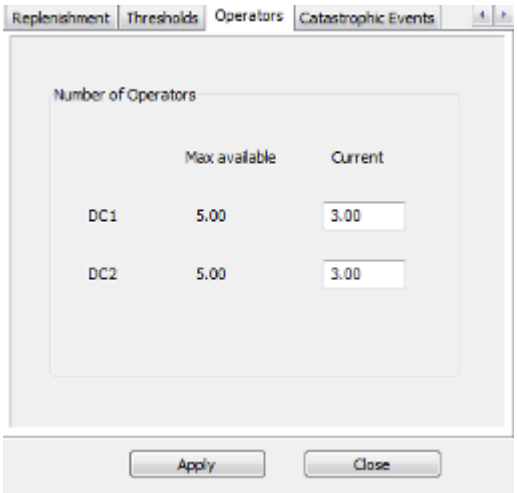


Figure 53. Adjusting the number of transporters in the simulation

1.7.2.8 Catastrophic Events

Here we can set the parameters related to catastrophic events which happen rarely (Figure 54). For simulation purposes we define two different types of events: a refrigeration equipment failure inside the transporting truck or a vehicle delay due to vehicle breakdown or traffic. In the temperature failures tab, we can set how often the temperature failure happens in the transporters (source to distribution centers or from distribution centers to final destinations) during the transport. In the vehicle delays tab, we can specify how frequently the vehicle carrying the items breakdown. The frequency is in terms of number of trips before the failure happens.

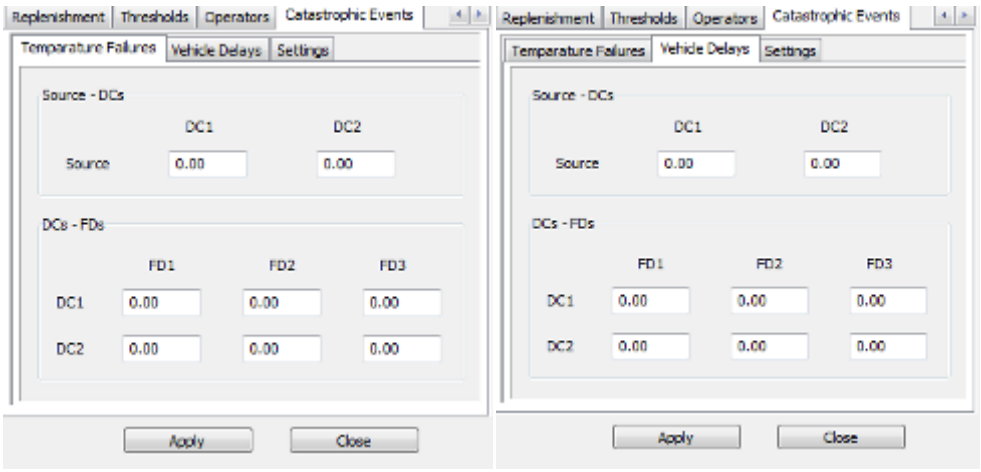


Figure 54. Adjusting rates for different types of failure scenarios

In the settings tab, we can specify the failure settings (Figure 55). Failure duration is the amount of duration in days it takes to fix the breakdown (temperature/ vehicle). Temperature increase is increase in temperature (in Celsius) over the normal temperatures when there is a breakdown. Vehicle delay duration is the number of times the regular duration it takes to transport. For example, if the value shown here is 2, it indicates that the vehicle now takes twice the amount of time compared to a normal case.

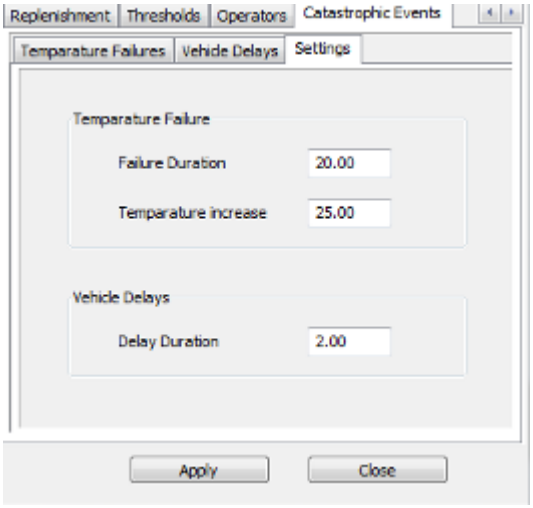


Figure 55. Adjusting the settings for different types of failures

1.7.3 Simulation Results

1.7.3.1 Simulation Of FIFO Distribution Logic

With the different settings and parameters described above, we can create enough randomness in the model to test for different scenarios and determine the best distribution practices for any given warehouse stock. As an example, we ran the simulation in FIFO mode using the default settings as described above and experimental data pulled from the REMS database with a random distribution of FSR/ MRE items with shelf lives ranging from a couple of weeks to 100 weeks. At the end of a 1000-step simulation we obtained the following statistical performance results using FIFO (Figure 56).

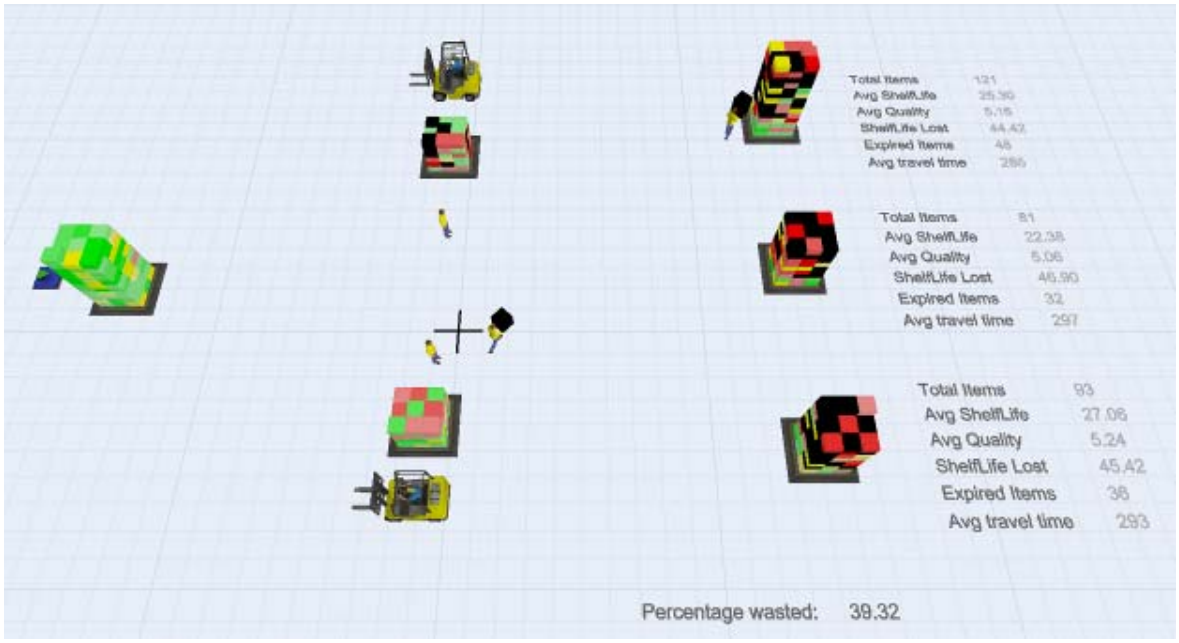


Figure 56. Simulation results after 1000 time steps for FIFO distribution logic using entire FSR inventory

The quality of each pallet is color-coded where green corresponds to fresh items and the color changes to red as the item loses its usable shelf life. Expired items are denoted in black. Since FIFO model pulls items from the distributing warehouses only in the order they receive the items, it doesn't have insight into the product quality and whether or not it will expire prior to reaching their final destination. This results in the following observations:

- **Total Items:** This gives the total number of items received by the particular FD. For example, in this particular simulation FD1 received 121 items, whereas FD2 received 81 items.

- **Average Shelf Life:** This gives the average shelf life of all the items that a particular FD received. For this simulation, the average shelf life of the items that FD1 received was 25.30 weeks. This value will be significantly low (as in this case) when most of the items received are already expired or they are about to expire when they are received.

- **Average Quality:** This value gives the average quality of the items received and is calculated based on the shelf life model developed for the project. A value close to 4 indicates that the items received have a very poor quality. And a value close to 8 indicates that the items are received with high quality. For FD1, we have average quality of 5.14. This indicates that the items are received with relatively low quality.

- **Shelf Life Lost:** This value gives the average shelf life lost during the journey of the items. For FD1 this value is 44.77. This indicates that on an average, items lost about 45 days of shelf life before they reached FD1.

- **Expired items:** This value gives the number of expired items a particular final destination receives. The bigger this number is, the worse the decision made in choosing the DC from which items are requested. In this case FD1 has received 48 items that were already expired when they reached FD1 compared to the total number of 121 items that were received by FD1.

- **Average travel time:** This value gives the time difference between the day when the item is manufactured and the day it is received by the FD. The bigger this value is, the more the shelf life lost. In this case, the average time difference between the date of manufacturing to the date of receipt by FD1 was around 285 days.

Finally we have Percent wasted figure at the bottom of the model. This value serves as an overarching indicator of how well the supply chain was managed with given parameters by providing the percentage of the total products that are expired before the items reach the final destination. Higher values indicate a poor supply chain. Note that the results will vary for each run of the same simulation due to the randomness in the models. In this case, using FIFO with the given set of temperature and shelf life data and simulation parameters resulted in a 39.32% loss in the supply chain.

1.7.3.2 Simulation Of FEFO Distribution Logic

To highlight the importance of choosing the right distribution logic, we simulated the same supply chain with the same inventory data (same temperature/ shelf life data) using FEFO for the distribution logic. The results are shown below (Figure 57):

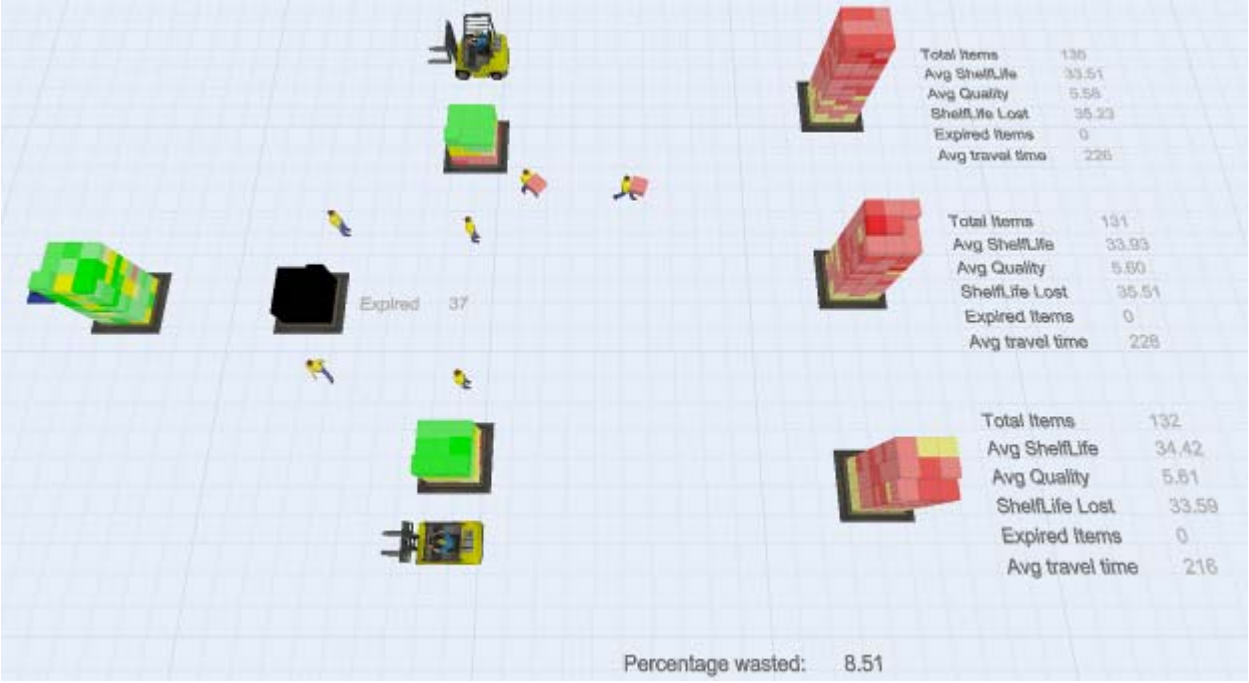


Figure 57. Simulation results after 1000 time steps for FEFO distribution logic using entire FSR inventory

The difference in performance stats between FIFO and FEFO are significant. Whereas all final destinations received the same number of products, overall waste percentage was reduced to 8.51% compared to 39.32%. Furthermore, there is a slight increase in the average product quality from an average of 5.2 to 5.6. Most importantly, final destinations received no expired products, which results in significant cost savings as expired products are discarded prior to transportation (in the expired queue.

Further optimizations are possible. For instance, when the final destinations are instructed to choose from the closest warehouses instead of looking at the entire shelf life inventory, the waste is further reduced to 6.78% as shown below (Figure 58).

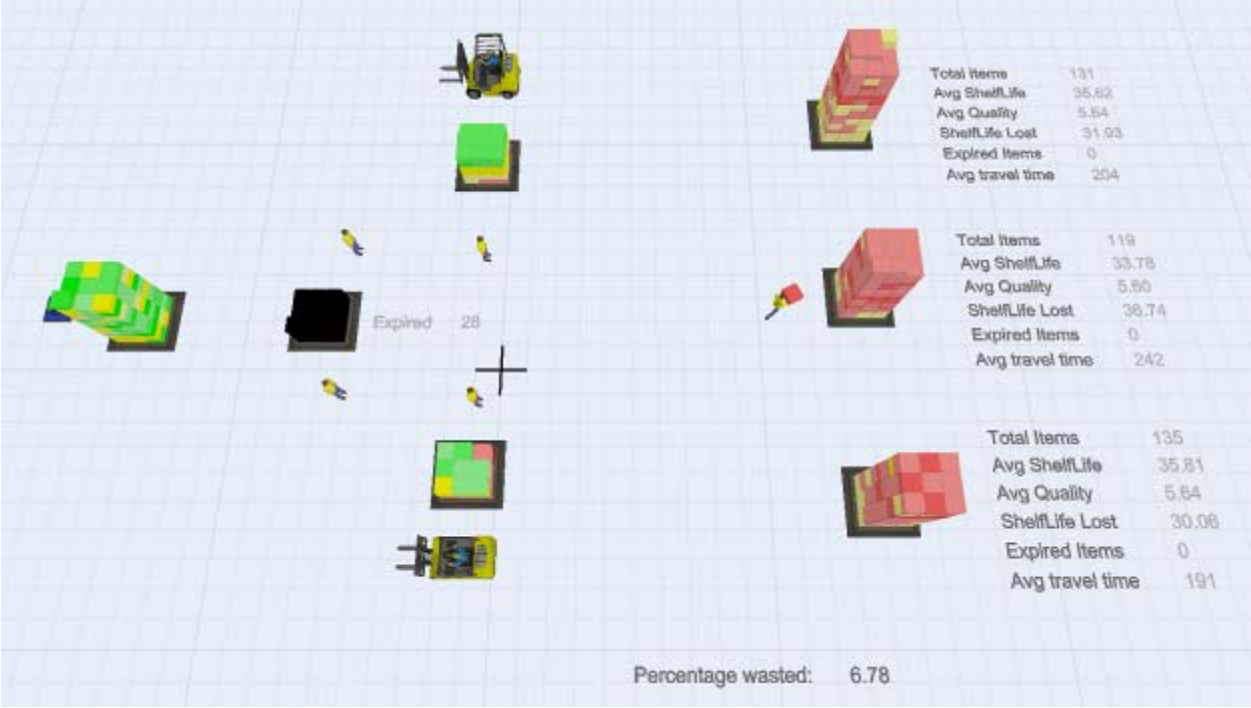


Figure 58. Simulation results after 1000 time steps for FEFO distribution logic using closest FSR inventory

These observations and simulations were taken into account when developing the pulling strategies implemented on the database server for FEFO and FIFO logistics.

2 Physical And Compositional Attributes Of FSR Items During Storage At Different Temperatures

2.1 Introduction

The First Strike Ration (FSR) is comprised of several food items designed to be consumed by Warfighters during short duration high intensity combat operations. The FSR is intended to enhance consumption, nutritional intake and mobility. Although it is known that the FSR has a minimum 2-year shelf-life when stored at 80°F, and 6 month shelf life at 100°F, there is more limited information about the quality and shelf-life of these rations when exposed to extreme ambient temperatures such as those commonly found in desert-like areas. It is important to more fully examine the physical and compositional characteristics of selected food components to understand the reaction kinetics of food deterioration and how it impacts ration serviceability.

This part of the Phase II project was a continuation of storage research that began in Phase I for FSR menu items that had not reached the end of their shelf life by the end of Phase I.

The objectives in this part of the project were: 1) to study the effect of different storage temperatures: refrigerated (40°F), ambient (80°F) and extreme (100, 120 and 140°F) temperatures, which are temperatures within the range normally encountered in temperate and warm regions of the world (i.e., subtropical, tropical or arid areas), on the physical and compositional quality of nine selected items from three FSR menus; and 2) to generate quantitative data to validate the sensory data used in the design of the shelf-life predicting model.

2.2 Materials And Methods

2.2.1 FSR Items

From the three currently available FSR menus, nine individual menu items were selected (Table 18). From Menu 1 the following items were selected: Filled French Toast Pocket (1), Bacon Cheddar Pocket Sandwich (2), Wheat Snack Bread (3), Beef Snack, Sweet BBQ (4), and Applesauce CHO Enhanced (5); from Menu 2: Italian-Style Sandwich (6) and Tortillas (7); and from Menu 3: Honey BBQ Beef Sandwich (8) and Dessert Bar, Chocolate Banana Nut (9). From these nine items, two were common items to all three FSR menus, namely Applesauce, CHO Enhanced (Zapplesauce) and Beef Snack, Sweet BBQ; and Tortillas were common to Menus 2 and 3.

These nine menu items were identified by the NSRDEC Combat Feeding Directorate as having been previously determined to be the most shelf-life-sensitive among all FSR menu items.

Table 18. First Strike Ration Menus (source: NSRDEC)

Menu 1	Menu 2	Menu 3
Filled French Toast Pocket	Brown Sugar Cinnamon Toaster Pastry	Lemon Poppy Seed Pound Cake
Bacon Cheddar Pocket Sandwich	Italian-Style Sandwich	Honey BBQ Beef Sandwich
Pepperoni Pocket Sandwich	Chunk Chicken (Tyson, 7 oz)	Albacore Tuna (Starkist, 3 oz)
	Tortillas	Tortillas
Cheese Spread, Jalapeno	Peanut Butter	Cheese Spread, Plain
Wheat Snack Bread	Cracker, Plain	Cracker, Plain
ERGO Drink	ERGO Drink	ERGO Drink
ERGO Drink	ERGO Drink	ERGO Drink
Mini HooAH! Mocha	Mini HooAH! Apple Cinnamon	Mini HooAH! Mocha
Mini HooAH! Chocolate	Mini HooAH! Cran-Rasp	Mini HooAH! Cran-Rasp
Dessert Bar, Peanut Butter	Dessert Bar, Mocha	Dessert Bar, Choc Banana Nut
Beef Snack, Sweet BBQ	Beef Snack, Sweet BBQ	Beef Snack, Sweet BBQ
Beef Snack, Teriyaki	Beef Snack, Teriyaki	Beef Snack, Teriyaki
Applesauce, CHO Enhanced	Applesauce, CHO Enhanced	Applesauce, CHO Enhanced
FSR Nut Fruit Mix, Type III	FSR Nut Fruit Mix, Type III	FSR Nut Fruit Mix, Type III
Gum, Stay Alert	Gum, Stay Alert	Gum, Stay Alert
	Mayonnaise, Fat Free	Mayonnaise, Fat Free
	Hot Sauce	Hot Sauce

Filled French Toast Pocket consists of flour, corn syrup, hydrogenated vegetable shortening, glycerol, sugar, dextrose, imitation maple syrup, yeast, salt, tapioca starch, corn starch, sucrose ester, artificial and natural flavor, gum arabic, calcium sulfate, xanthan gum, cinnamon, cocoa, lecithin, sorbic acid, FD&C yellow #5, locust bean gum.

Nutrition Facts: serving size 99 g (3.5 oz), 240 calories (30 calories from fat), 3.5 g total fat (2 g from saturated fat), 350 mg sodium, 49 g total carbohydrates (2 g dietary fiber, 20 g sugars) and 6 g protein.

Bacon Cheddar Pocket Sandwich is prepared from bread and cured bacon, and contains the following ingredients: bread (enriched flour [wheat flour, niacin, reduced iron, thiamine mononitrate, riboflavin, folic acid], water, cheddar flavored flakes [hydrolyzed vegetable oil, corn syrup solids, wheat flour, milk, maltodextrin, salt, lactic acid, enzyme modified cheese; milk, salt, enzyme, natural flavors, sodium citrate, sodium carbonate, disodium phosphate, annatto as a color agent], partially hydrogenated soybean and cottonseed oil, glycerol, yeast, salt, sucrose ester, dough conditioners [dextrose, flour diacetyl tartaric acid esters of mono-

and diglyceride, mono- and diglycerides, ***ascorbic acid***, fungal alpha amylase, L-cysteine hydrochloride, azodicarbonamide], gum arabic, butter flavor [modified food starch, maltodextrin, natural and artificial flavors, partially hydrogenated soybean oil, water, soy lecithin], glucono-delta-lactone, calcium sulfate, xanthan gum, sorbic acid) and bacon (cured with water, salt, hickory smoke flavor, sugar, dextrose, sodium erythorbate, sodium nitrite).

Nutrition Facts: serving size 1 package (88 g), 320 calories (140 calories from fat), 15 g total fat (5 g from saturated fat, 3 g trans-fat, 20 mg cholesterol), 580 mg sodium, 31 g total carbohydrates (3 g dietary fiber) and 11 g protein.

Wheat Snack Bread is composed of enriched bleached flour (bleached flour, malted barley flour, niacin, reduced iron, thiamine mononitrate, riboflavin, folic acid), water, partially hydrogenated soybean and cottonseed oils, glycerol, sugar, wheat bran, contains 2% or less: hydrated monoglycerides, polysorbate 60, salt, extract of malted barley and corn, wheat starch, silicon dioxide, hydroxylated soy lecithin, soy flour, calcium sulfate, enzymes, sodium stearoyllactylate, leavening (sodium aluminum phosphate, baking soda), xanthan gum, gum arabic, corn syrup, sorbic acid, yeast, sorbitanmonostearate.

Nutrition Facts: serving size 1 piece (57 g), 180 calories (50 calories from fat), 6 g total fat (1.5 g from saturated fat, 1.5 g trans-fat, 10 mg cholesterol), 580 mg sodium, 30 g total carbohydrates (2 g dietary fiber, 3 g sugars) and 4 g protein.

Beef Snack, Sweet BBQ is made up of beef, water, hydrolyzed soy protein, sugar, salt, brown sugar, dextrose, corn syrup, flavorings, monosodium glutamate, smoke flavoring, extract of paprika, sodium erythorbate, sodium nitrite.

Nutrition Facts: serving size 1 package (26 g), 70 calories (20 calories from fat), 2.5 g total fat (1 g from saturated fat, 20 mg cholesterol), 460 mg sodium, 4 g total carbohydrates (2 g sugars) and 7 g protein.

Applesauce, CHO Enhanced, known as Zapplesauce, consists of apples, maltodextrin, water sugar and ascorbic acid as vitamin C source. It was originally designed to increase the endurance of the soldiers by adding higher amounts of maltodextrin, which can preserve glycogen in the muscles and liver.

Nutrition Facts: serving 4.5 oz (128 g), 130 calories (0 calories from fat), 0 g total fat (0 g from saturated fat, 0 mg cholesterol), 0 mg sodium, 33 g total carbohydrates (2 g dietary fiber, 19 g sugars) and 0 g protein.

Italian Style Sandwich, which is prepared from bread, tomato sauce, marinated cooked sausage, pepperoni, and mozzarella cheese powder, contains following ingredients: bread (enriched flour [wheat flour, niacin, reduced iron, thiamine mononitrate, riboflavin, folic acid], water, cheddar-flavored flakes [hydrolyzed vegetable oil, corn syrup solids, wheat flour, milk,

maltodextrin, salt, lactic acid, enzyme modified cheese; milk, salt, enzyme, natural flavors, sodium citrate, sodium carbonate, disodium phosphate, annatto as a color agent], partially hydrogenated soybean and cottonseed oil, glycerol, yeast salt, sucrose ester, dough conditioners [dextrose, flour diacetyl tartaric acid esters of mono- and diglyceride, mono- and diglycerides, ascorbic acid, fungal alpha amylase, L-cysteine hydrochloride, azodicarbonamide], gum Arabic, butter flavor [modified food starch, maltodextrin, natural and artificial flavors, partially hydrogenated soybean oil, water, soy lecithin], glucono-delta-lactone, calcium sulfate, xanthan gum, sorbic acid); tomato sauce (tomato paste [tomatoes, tomato juice, salt, citric acid], glycerol, parmesan/Romano cheese [pasteurized cow's milk, culture, salt, enzymes], olive oil, sugar, garlic powder, dried onions, spices, salt); marinated cooked sausage (Italian sausage [pork, salt water, dextrose, spices and flavorings, monosodium glutamate, sodium nitrite], rice syrup, glycerol, water, salt, spices); pepperoni (pork, beef, salt, water, dextrose, paprika, spices and flavorings, lactic acid starter culture, oleoresin of paprika, sodium erythorbate, sodium nitrite, BHA, BHT); mozzarella cheese powder (mozzarella cheese [pasteurized milk, cultures, salt, enzymes], disodium phosphate). The Italian-Style Sandwich has a high source of protein made up of about 21% meat.

Nutrition Facts: serving 1 sandwich (100 g), 340 calories (130 calories from fat), 14 g total fat (4.5 g from saturated fat, 2.5 g trans-fat, 15 mg cholesterol), 750 mg sodium, 32 g total carbohydrates (3 g dietary fiber, 2 g sugars) and 10 g protein.

Tortillas consists of ingredients including bleached flour (wheat flour, niacin, reduced iron, thiamine mononitrate, riboflavin, folic acid), water, vegetable shortening (partially hydrogenated soybean and/or cottonseed oil), glycerin, mono- and diglycerides, baking powder (corn starch, sodium acid pyrophosphate, sodium bicarbonate, and monocalcium phosphate), sugar and/or corn syrup, salt, fumaric acid, potassium sorbate, calcium propionate, sodium stearoyllactylate.

Nutrition Facts: serving 2 tortillas (62 g), 220 calories (70 calories from fat), 8 g total fat (2 g from saturated fat, 1 g trans-fat, 0 mg cholesterol), 320 mg sodium, 34 g total carbohydrates and 4 g protein.

Honey BBQ Beef Sandwich, which is prepared from bread and barbecued beef, contains the following ingredients: bread (enriched flour [wheat flour, niacin, reduced iron, thiamine mononitrate, riboflavin, folic acid], water, cheddar-flavored flakes [hydrolyzed vegetable oil, corn syrup solids, wheat flour, milk, maltodextrin, salt, lactic acid, enzyme-modified cheese, milk, salt, enzyme, natural flavors, sodium citrate, sodium carbonate, disodium phosphate, annatto as a color agent], partially hydrogenated soybean and cottonseed oil, glycerol, yeast, salt, sucrose ester, dough conditioners [dextrose, flour diacetyl tartaric acid esters of mono- and diglyceride, mono- and diglycerides, ascorbic acid, fungal alpha amylase, L-cysteine hydrochloride, azodicarbonamide], gum arabic, butter flavor [modified food starch, maltodextrin, natural and artificial flavors, partially hydrogenated soybean oil, water, soy lecithin], glucono-delta-lactone, calcium sulfate, xanthan gum, sorbic acid), barbecued beef

(beef tomato paste [tomato paste, salt, citric acid], brown sugar, mustard, glycerol, honey, molasses, spices, and flavorings, beef broth, partially hydrogenated soybean oil, salt, partially polished brown rice syrup, vinegar flavor [sodium diacetate, citric acid, potassium citrate, glucona-delta-lactone], Worcestershire sauce [distilled vinegar, molasses, corn syrup, water, salt, caramel coloring, sugar, spices, anchovies, flavoring, tamarind, dried onions, smoke flavoring, sodium phosphate]). The Honey BBQ Beef Sandwich provides a high source of protein and contains about 21% meat.

Nutrition Facts: serving 1 package (100 g), 320 calories (80 calories from fat), 9 g total fat (3 g from saturated fat, 2.5 g trans-fat, 40 mg cholesterol), 700 mg sodium, 29 g total carbohydrates (3 g dietary fiber, 2 g sugars) and 21 g protein.

Dessert Bar, Chocolate Banana Nut is composed of sugar, cream powder (cream, nonfat milk, dipotassium phosphate, silicon dioxide), chocolate chips (sugar, chocolate liquor, cocoa butter, dextrose, soy lecithin, vanillin), partially hydrogenated soybean and cottonseed oil, cocoa (processed with alkali), nonfat dry milk, contains 2% or less of: artificial flavor, spray-dried coffee, ascorbyl palmitate, BHA, mixed tocopherols.

Nutrition Facts: serving 1 bar (40 g), 230 calories (140 calories from fat), 15 g total fat (7 g from saturated fat, 0 g trans-fat, 120 mg cholesterol), 25 mg sodium, 21 g total carbohydrates (1 g dietary fiber, 18 g sugars) and 2 g protein.

2.2.2 Storage Conditions

Three replicated samples/packages per individual FSR item were used for initial quality evaluation, and a total of 1,269 packages were distributed among five temperature-controlled rooms that were set at 40°F (control-refrigerated conditions), 80°F, 100°F, 120°F and 140°F (i.e., 486 samples/packages were stored at 40°F, 162 samples/packages were stored at 80°F, 216 samples/packages were stored at 100°F, 189 samples/packages were stored at 120°F and 216 samples/packages were stored at 140°F). Physical and compositional attributes were evaluated during a maximum 112-week storage period following the schedule shown in Table 19. Samples stored at 40°F (refrigerated control) were evaluated every time samples from another temperature were evaluated.

Depending on the FSR item and temperature, the evaluation times were: eight weeks for all nine FSR items stored at 140°F; 14 weeks for all nine FSR items stored at 120°F; 36 weeks for Beef Snack Sweet BBQ, Italian-Style Sandwich, Filled French Toast Pocket, Applesauce CHO Enhanced, Honey BBQ Beef Sandwich and Bacon Cheddar Pocket Sandwich stored at 100°F; 42 weeks for Tortilla, Dessert Bar Chocolate Banana Nut and Wheat Snack Bread stored at 100°F; 100 weeks for Tortillas, Dessert Bar Chocolate Banana Nut, Wheat Snack Bread, and Beef Snack Sweet BBQ stored at 40 or 80°F; and 112 weeks for Honey BBQ Beef Sandwich, Italian-Style Sandwich, Filled French Toast Pocket, Applesauce CHO Enhanced and Bacon Cheddar Pocket Sandwich stored at 40 or 80°F.

The schedule used for the physicochemical evaluations was synchronized with the sensory panel schedule so that when the panelists considered the samples unacceptable we would be able to terminate the experimental part for the physicochemical analysis. Therefore, some FSR items stored at 80 and 100°F were evaluated after 36 or 42 weeks, depending on the "expiration" of their sensory quality.

Table 19. Physical and Compositional Evaluation Schedule

Schedule	Weeks	40°F Control	80°F 112 weeks (every 16 weeks)	100°F 36 weeks (every 6 weeks)	120°F 14 weeks (every 2 weeks)	140°F 8 weeks (every week)	NOTES
Nov 10	0	X					Start 2009
Nov 17	1	X				X	
Nov 24	2	X			X	X	
Dec 1	3	X				X	
Dec 8	4	X			X	X	
Dec 15	5	X				X	
Dec 22	6	X		X	X	X	
Dec 29	7	X				X	
Jan 5	8	X	(X)	(X)	X	X	End of 140°F 2010
Jan 12	9						
Jan 19	10	X			X		
Jan 26	11						
Feb 2	12	X		X	X		
Feb 9	13						
Feb 16	14	X	(X)	(X)	X		End of 120°F
Feb 23	15						
Mar 2	16	X	X				
Mar 9	17						
Mar 16	18	X		X			
Mar 23	19						
Mar 30	20						
Apr 6	21						
Apr 13	22						
Apr 20	23						
Apr 27	24	X		X			6 months
May 4	25						
May 11	26						
May 18	27						
May 25	28						
Jun 8	29						
Jun 15	30	X		X			
Jun 22	31						
Jun 29	32	X	X				
Jul 6	33						
Jul 13	34						
Jul 20	35						
Jul 27	36	X	X	X			End of 100°F
Aug 3	37						
Aug 10	38						
Aug 17	39						
Aug 24	40						
Aug 31	41						
Sep 7	42						
Sep 14	43						
Sep 21	44						

Sep 28	45						
Oct 5	46						
Oct 12	47						
Oct 19	48						
Oct 26	49						
Nov 2	50						
Nov 9	51						
Nov 16	52	X	X				12 months
Nov 23	53						
Nov 30	54						
Dec7	55						
Dec 14	56						
Dec 21	57						
Dec 28	58						
Jan 4	59						2011
Jan 11	60						
Jan 18	61						
Jan 25	62						
Feb 1	63						
Feb 8	64						
Feb 15	65						
Feb 22	66						
Mar 1	67						
Mar 8	68	X	X				
Mar 15	69						
Mar 22	70						
Mar 29	71						
Apr 5	72						18 months
Apr 12	73						
Apr 19	74						
Apr 26	75						
May 3	76						
May 10	77						
May 17	78						
May 24	79						
May 31	80						
Jun 7	81						
Jun 14	82						
Jun 21	83						
Jun 28	84	X	X				
Jul 5	85						
Jul 12	86						
Jul 19	87						
Jul 26	88						
Aug 2	89						
Aug 9	90						
Aug 16	91						
Aug 23	92						
Aug 30	93						
Sep 6	94						
Sep 13	95						
Sep 20	96						
Sep 27	97						
Oct 4	98						
Oct 11	99						
Oct 18	100	X	X				
Jan 10	**112**	**X**	**X**				**End of 40-80°F 28 months**

Note: each (X) corresponds to three samples/packages per FSR item

2.2.3 Quality Evaluation

Physical quality attributes were evaluated for all nine items, and composition was evaluated according to the major components that were considered to be more susceptible to changes and therefore would be good indicators of deterioration. Changes in color, texture, water activity, moisture content, pH acidity, soluble solids content (SSC) and sugar profile were measured in all nine FSR items. Ascorbic acid content was measured only in Bacon Cheddar Pocket Sandwich, Beef Snack Sweet BBQ, Apple Sauce CHO Enhanced, Italian-Style Sandwich and Honey BBQ Beef Sandwich, because these products are enriched with ascorbic acid (AA) to act as an antioxidant and/or to increase their nutrient content. Lipid oxidation was measured in all items except in Applesauce due to its low content in lipids. Before the evaluation, samples were removed from their respective temperatures and held under ambient conditions until they all reached the same temperature.



Figure 59. Physical and compositional evaluation (from left to right: color and texture analysis, sample preparation and soluble solids content measurements).

2.2.3.1 Physical Evaluation

Color. Surface color measurements were taken on three replicated samples of each FSR sample, at five different points, with a handheld tristimulus reflectance colorimeter (Model CR-300, Minolta Co., Ltd., Osaka, Japan) equipped with a glass light-protection tube with an 8 mm aperture (CR-A33a, Minolta Co., Ltd., Osaka, Japan) using standard illuminant D65 (Figure 59). Color was recorded using the CIE-L*a*b* uniform color space (CIE-Lab), L* (lightness), a* (redness) and b* (yellowness) values. The numerical values of a* and b* were converted into hue angle ($h°_{ab} = \tan^{-1}b^*/a^*$) and chroma ($C^*_{ab} = ((a^*)^2+(b^*)^2)^{1/2}$).

Texture. Textural analysis of each FSR sample was performed using the TA.XT Plus Texture Analyzer (Texture Technologies Corp., Scarsdale, NY) (Figure 59). Maximum peak force for compression and shear testing was expressed as kg-force (kgf).

Filled French Toast Pocket, Bacon Cheddar Pocket Sandwich, Wheat Snack Bread, Honey BBQ Beef Sandwich, Italian-Style Sandwich, and Chocolate Nut Dessert Bar were sheared using a knife probe for 25 mm distance at a speed of 10 mm/s with a 1 g contact force. Maximum peak

force was obtained from five readings on each of the three replicated samples per temperature.

Textural analysis of Beef Snack, Sweet BBQ was performed using the TA.XT Plus Texture Analyzer (Texture Technologies Corp., Scarsdale, NY). Beef Snack, Sweet BBQ was sheared using a craft knife probe for 25 mm distance at a speed of 10 mm/s with a 1 g contact force. Maximum peak force was obtained from five readings on each of the three replicated samples per temperature.

The texture of Applesauce was evaluated using a flat probe, which compressed 50 mL of Applesauce in a 100 mL plastic container for 50 mm distance at a speed of 10 mm/s with a 1 g contact force. Maximum peak force was obtained by taking five readings on each of the three replicated samples per temperature.

The texture of tortillas was evaluated using a tortilla fixture with a cone type probe for 50 mm distance at a speed of 10 mm/s with a 1 g contact force. Maximum peak force was obtained from four readings of three replicates of each tortilla per temperature.

2.2.3.2 Compositional Analysis

Moisture Content. Moisture content was determined by the standard gravimetric method. A 5 g homogenized sample was spread evenly over the bottom of a metal dish, weighed and dried 24 h at 80°C in a laboratory oven (Model: 40GC, Quincy Lab Inc., Chicago, IL). Dry samples were cooled in desiccators and then weighed, and the final weight was subtracted from the initial weight to obtain the moisture content. Triplicates were taken from three FSR samples per temperature.

Water Activity. Water activity was performed using the dew point technique with an AquaLab 4TE water activity meter (Decagon device Inc., WA, USA). A 2 g homogenized sample was weighed in a disposable plastic cup and placed into the chamber of the water activity meter for measurement. Three replicates per item per temperature were used.

Titratable Acidity, Soluble Solids Content (SSC) and pH. Samples were homogenized using a handheld homogenizer (BioMixerBamix, Biospec, Switzerland) or a commercial blender (Model HBB908, Hamilton Beach Inc., NC, USA). A 5 g aliquot of each sample was mixed thoroughly with 45 mL deionized water in a 50 mL polypropylene screw cap tube. After vortexing for 30 s, samples were centrifuged at 6500 rpm for 20 min in a centrifuge (Hermle Z200A, Labnet, Edison, NJ, USA). The supernatant was decanted from the centrifuge tubes for TA, SSC and pH measurements. Then 6 g of each supernatant was weighed into 50 mL beakers and diluted with 50 mL distilled water. The titratable acidity was determined by titration with 0.1 N NaOH to an end point of pH 8.1 with an automatic titrimeter (Titroline 96, SCHOTT-GERÄTE GmbH, Germany). The pH of the samples was determined using a pH meter (Accumet model 15, Fisher Scientific, CO, USA), previously calibrated with a pH of 4 and 7. The soluble solids content (SSC)

of the resulting clear samples was measured with a digital refractometer (Palette PR-101, 0-45 Brix, Atago Co. LTD, Tokyo) (Figure 59).

Quantification of Ascorbic Acid (Vitamin C) by HPLC. This procedure was only performed on samples that contained significant amounts of ascorbic acid: Applesauce, Bacon Cheddar Pocket Sandwich, Italian-Style Sandwich, and Honey BBQ Beef Sandwich. Samples were homogenized using a handheld homogenizer (BioMixerBamix, Biospec, Switzerland) or a commercial blender (Model HBB908, Hamilton Beach Inc., NC, USA). Then 2 g of each homogenized sample was weighed into a 50 mL plastic bottle, and 20 mL metaphosphoric acid mixture (6% HPO_3, containing 2 N acetic acid) was added. The samples were filtered (0.22 µm filter) prior to HPLC analysis. Ascorbic acid analysis was conducted using a Hitachi LaChromUltra UHPLC system with a diode array detector and a LaChromUltra C18 4.6µm column (2 × 50 mm) (Hitachi, Ltd., Tokyo, Japan). The analysis was performed under isocratic mode at a flow rate of 1 ml/min with a detection of 254 nm. The sample injection volume was 5 µL. The mobile phase used was buffered potassium phosphate monobasic (KH_2PO_4, 0.5%, w/v) at pH 2.5, with metaphosphoric acid (HPO_3, 0.1%, w/v). The retention time of ascorbic acid peak was 2.48 min. After comparison of retention time with the ascorbic acid standards, the peak was identified. The amount of total ascorbic acid was quantified using calibration curves obtained from different concentrations of ascorbic acid standards. Three samples per item per temperature were used with duplicated HPLC injections.

***Quantification of Individual and Total Sugar Profile by HPLC*.** This procedure was the same for all FSR samples except for Applesauce, for which the ether and boiling steps were omitted. The procedure used for Applesauce can be found in the second paragraph below.

An aliquot of 5 g from each homogenized sample was mixed thoroughly with 45 mL petroleum ether in a 50 mL polypropylene screw-cap tube. After vortex for 30s, samples were centrifuged at 6000 rpm for 10 min. The ether was discarded and 45 mL distilled water was added. The samples were placed into a bath of boiling water for 25 min, and vortexed every 5–7 min. Subsequently, the samples were cooled to room temperature and centrifuged at 6000 rpm for 10 min. The supernatant was decanted from the centrifuge tubes and filtered through a 0.45 µm nylon syringe into labeled amber glass vials. Individual and total sugar analyses were conducted using a Hitachi HPLC system with a RI-refractive index detector and a 300 mm × 8 mm Shodex SP0810 column (Shodex, Colorado Springs, CO) with an SP-G guard column (2 mm x 4 mm). An isocratic solvent delivery of water was run at 1.0 mL/min. The sample injection volume was 5 µL. Several standards, including maltodextrin, sucrose, glucose and fructose, were run to identify sample peaks. After comparison of retention time with standards, the peaks were identified. The amount of total sugar was quantified using calibration curves obtained from different concentration of standards. Three samples per FSR item per temperature were used with duplicated HPLC injections.

An aliquot of 5 g per Applesauce sample was mixed thoroughly with 45 mL distilled water in a 50 ml polypropylene screw-cap tube. After vortexing or mixing for 30 s, samples were

centrifuged at 6000 rpm for 10 min. The supernatant was decanted from the centrifuge tubes and filtered through a 0.45 µm nylon syringe into labeled amber glass vials. Individual and total sugar analyses were conducted using a Hitachi HPLC system with an RI-refractive index detector and a 300 mm × 8 mm Shodex SP0810 column (Shodex, Colorado Springs, CO) with an SP-G guard column (2 mm × 4 mm). An isocratic solvent delivery of water was run at 1.0 mL/min. The sample injection volume was 5 µL. Several standards, including maltodextrin, sucrose, glucose and fructose, were run to identify sample peaks. After comparison of retention time with the standards, the peaks were identified. The amount of total sugar was quantified using calibration curves obtained from different concentrations of standards. Three samples per Applesauce item per temperature were used with duplicated HPLC injections.

Lipid Oxidation. Lipid oxidation was determined for all FSR samples except for Applesauce samples, which had practically no lipid content. The Peroxide Value (PV) method was used to measure the primary oxidation products and as an index to quantify the amount of hydrogen peroxide in FSR products (note that this method measures only primary oxidation products that do not cause rancid flavors). For sandwiches that contained a defined bread and meat part, such as Bacon Cheddar, Beef BBQ and Italian, the PV was measured in the whole sandwich and in the meat part of the sandwich.

Approximately 1 g of each homogenized item was transferred to a 15 ml disposable glass test tube, homogenized for 1 min with a 3 mL chloroform/methanol (2:1) mixture using a Biohomogenizer, and a 7 mL chloroform/methanol (2:1) mixture was added and mixed with 3 mL of 0.5 % NaCl solution. The mixture was vortexed for 30 s and then centrifuged at 2000 rpm for 10 min in a cold room at 5°C. The chloroform phase was removed, and a 2 mL volume was brought to 10 ml using a chloroform/methanol (2:1) mixture. A 50 µl aliquot of thiocyanate/Fe^{2+} solution was added to the sample, which was then inverted three times. The thiocyanate/Fe^{2+} solution was prepared immediately before use by mixing 1 volume of thiocyanate solution (3.94 M ammonium thiocyanate) with 1 volume of Fe^{2+} solution (obtained from the supernatant of a mixture of 3 ml of 0.144 M $BaCl_2$ in 0.4 M HCl and 3 ml of freshly prepared 0.144 M $FeSO_4$). The samples were incubated for 10 min at room temperature, and the absorbance was measured at 500 nm. A standard curve was prepared using cumenehydroperoxide.

Although there is no certain threshold for PV in the literature, others have reported that the level of PV depends on the type of food analyzed. For example, the limiting PV values reported to be critical for acceptability of roasted peanuts or peanut oil were 20–30 meq/kg (Evranuz, 1993; St. Angelo et al., 1977; Balasubramanyam et al., 1983; Narasimhan et al., 1986); crude fish oil was 7–8 meq /kg (Huss, 1988); bread sticks were 11.4–14.2 meq/kg (Calligaris, 2008); and biscuits were 13–18 meq/kg (Calligaris, 2007).

2.3 Results

2.3.1 Filled French Toast Pocket

2.3.1.1 Physical Characteristics

Appearance and Color

In general, as the storage temperature increased, the color of the samples turned from a light to a dark brown (Figure 60). Brown color development took place after an eight-week storage period for samples stored at 120 and 140°F and was aggravated by time and temperature exposure. The reaction that caused the color change could have resulted from non-enzymatic browning due to the exposure to extreme temperatures.



Figure 60. Changes in the appearance of Filled French Toast Pocket during storage at 40, 80, 100, 120 and 140°F.

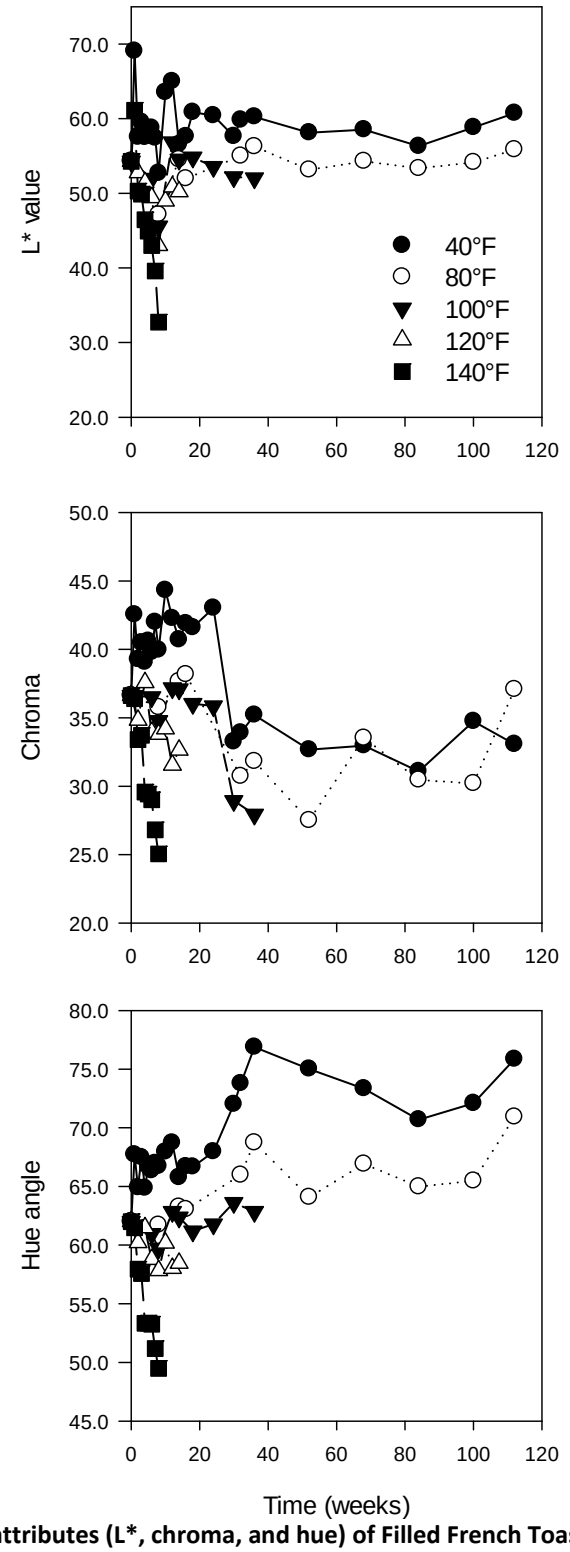


Figure 61. Changes in color attributes (L*, chroma, and hue) of Filled French Toast Pocket during storage period 40, 80, 100, 120 and 140°F.

French Toast samples exposed to 120°F and 140°F for eight weeks showed a sharp decrease in L* value, chroma and hue angle, and mainly for samples stored at 140°F (Figure 61). For example, after eight weeks, the L* value, chroma and hue angle of samples stored at 140°F showed a decrease of approximately 40, 32 and 20%, respectively. L* values of samples stored at 40 and 80°F remained quite stable up to 112 weeks of storage, while chroma values decreased (less vivid) and hue angles increased (more dark-brownish color).

Texture

Overall, firmness significantly decreased in samples stored at temperatures higher than 80°F, meaning that French Toast samples became softer with increasing temperature and exposure time (Figure 62). After 112 weeks, samples stored at 40 and 80°F showed only slight changes in their texture when compared to their initial values, whereas French Toast Pocket samples became much softer after eight weeks at 100, 120 and 140°F.

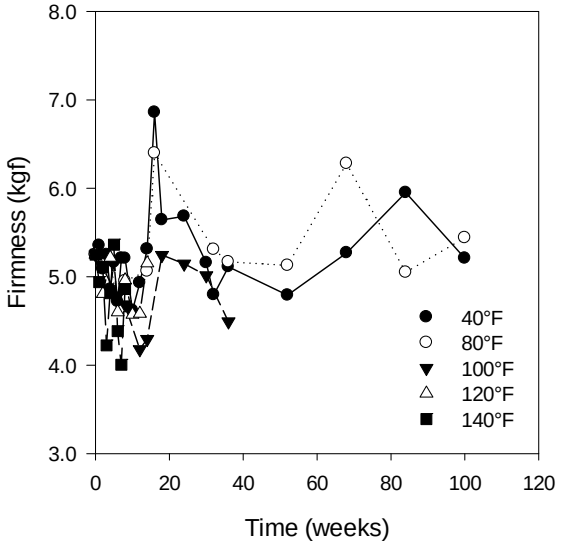


Figure 62. Changes in the texture of Filled French Toast Pocket during storage at 40, 80, 100, 120 and 140°F.

2.3.1.2 Compositional Analysis

Titratable Acidity, Soluble Solids Content, and pH

The pH of Filled French Toast Pocket samples showed a decreasing trend, regardless of the temperature (Figure 63). During a 36-week storage period, the pH decreased for all storage temperatures, but the pH of samples stored at higher temperatures decreased more rapidly, especially for samples stored for eight weeks at 140°F. After 112 weeks, the pH of samples stored at 40 and 80°F also decreased but never reached the levels observed for samples stored at 140°F.

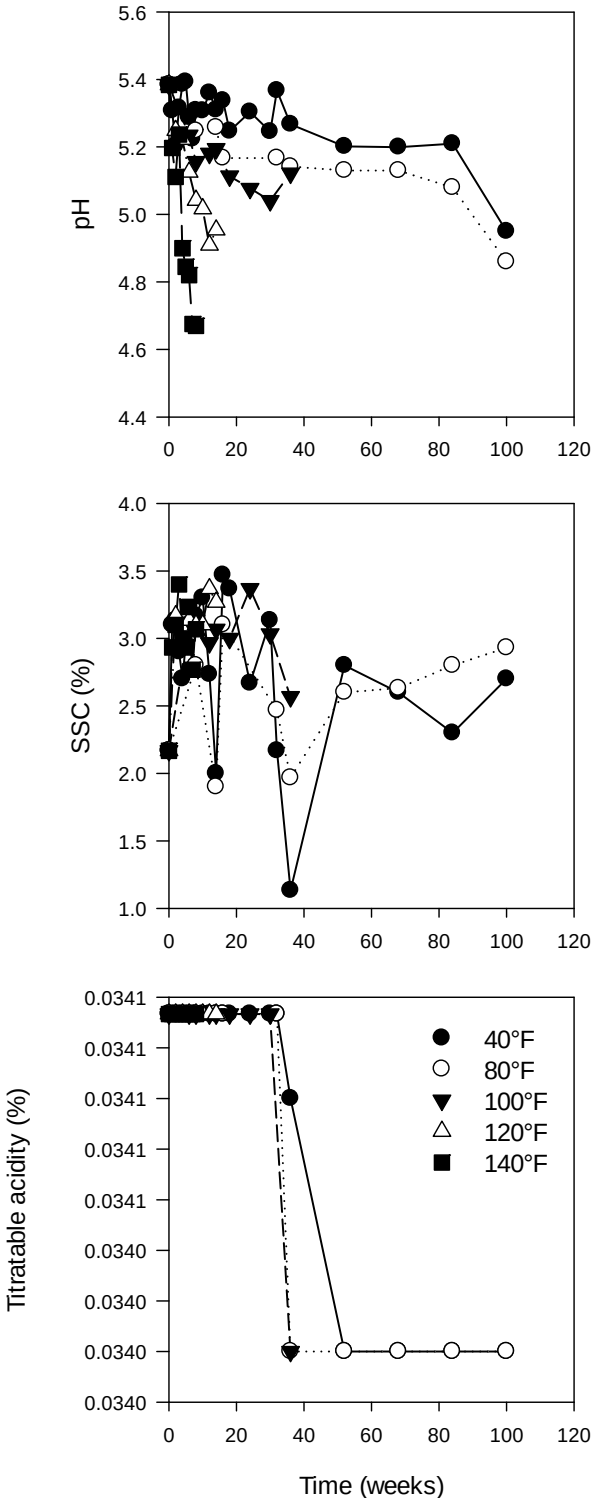


Figure 63. Changes in pH, titratable acidity and soluble solid contents of Filled French Toast Pocket during storage at 40, 80, 100, 120 and 140°F.

After 36 weeks of storage, there were no changes in the titratable acidity of samples, regardless of the temperature (Figure 63). However, after 36 weeks there was a decrease in the pH of samples stored at 40 and 80°F. The soluble solids content of the samples fluctuated during storage, regardless of the temperatures (Figure 63). However, at the end of each respective storage period, SSC was generally higher than the initial values.

Water Activity and Moisture Content

Water activity increased during storage regardless of temperature (Figure 64). This might have been caused by the fact that at the end of each respective storage period there was more free water in the food matrix or that water migrated from one layer of the product to the other. However, after eight weeks, samples stored at 140°F had the lowest water activity as well as the lowest moisture content compared to the samples stored at lower storage temperatures (Figure 64). After 112 weeks, samples stored at 40 and 80°F showed only a slight increase in water activity (approximately 10%) and moisture content (approximately 4%) compared to initial values.

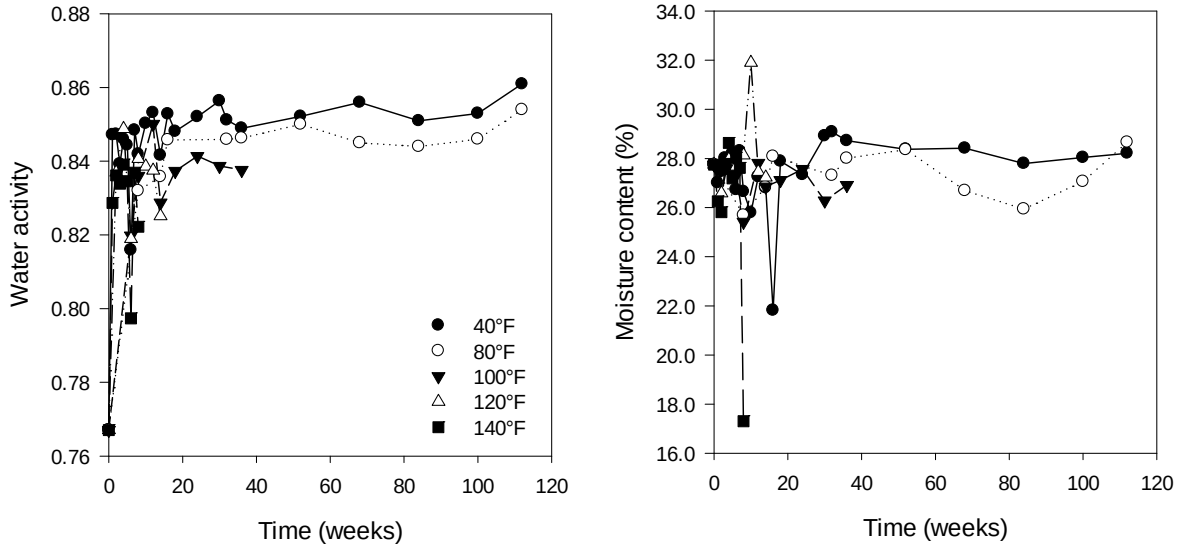


Figure 64. Changes in moisture content and water activity of Filled French Toast Pocket during storage at 40, 80, 100, 120 and 140°F.

Individual and Total Sugar Profiles

Sucrose was the major sugar measured in Filled French Toast Pocket (Figure 65). While sucrose concentration decreased, the glucose and fructose concentration increased for samples stored at 100°F or higher. Exposure to high temperatures resulted in hydrolysis of sucrose into fructose and glucose. Although after eight weeks the total sugar concentration of Filled French Toast Pocket stored at 140°F was comparable to that of samples stored at lower temperatures, maltodextrin, glucose and fructose were higher in samples stored at 140°F, while sucrose was higher in samples stored at lower temperatures. Therefore, sucrose hydrolysis and conversion

into fructose and glucose was most likely accelerated when samples were exposure to higher temperatures.

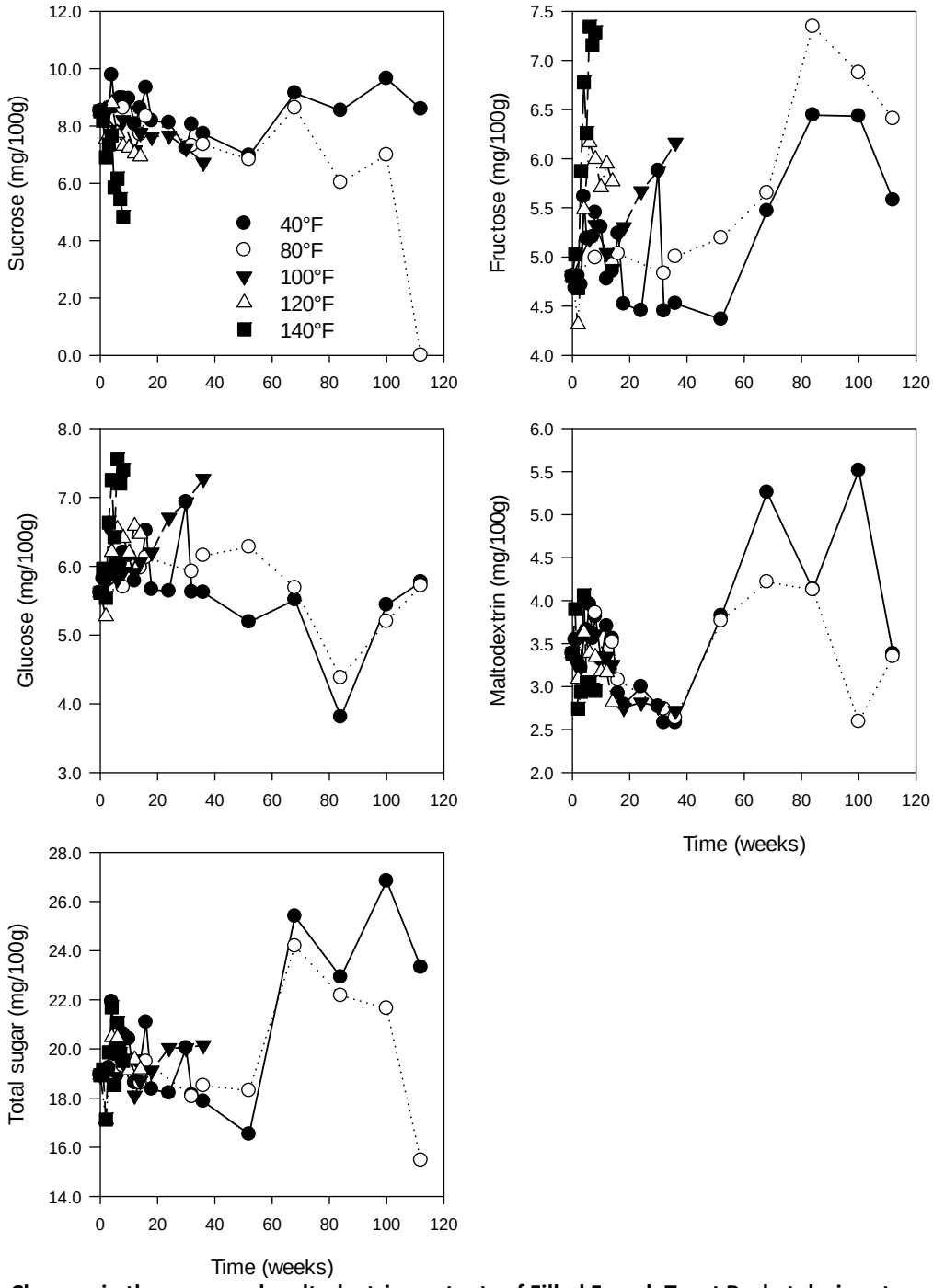


Figure 65. Changes in the sugar and maltodextrin contents of Filled French Toast Pocket during storage at 40, 80, 100, 120 and 140°F.

Maltodextrin concentration fluctuated for all temperatures regardless of storage time (Figure 65). However, after eight weeks of storage, the maltodextrin content of samples stored at

140°F was lower than that of samples stored at lower temperatures, mostly likely due to its hydrolysis to simple sugars such as glucose. After 112 weeks at 40 and 80°F there was no significant difference in the levels of maltodextrin between the two temperatures, and the values were comparable to the initial values measured.

Lipid Oxidation

The degree of lipid oxidation was measured using the peroxide value (PV) assay to monitor the primary oxidation products formed. Figure 66 shows the level of PV in Filled French Toast Pocket during storage at 40, 80, 100, 120 and 140°F. After 52 weeks of storage, the level of lipid oxidation was reasonably low for all temperatures. The degree of lipid oxidation fluctuated regardless of the storage time and temperature, but it tended to decrease during storage. In terms of overall quality, the lipid oxidation that occurred during storage of Filled French Toast Pocket was not considered critical, as the levels remained quite low (0.60 to 1.74 meq/kg), considering a range of 7–30 meq/kg as the limit of acceptability reported in the literature for different foods (in Materials and Methods).

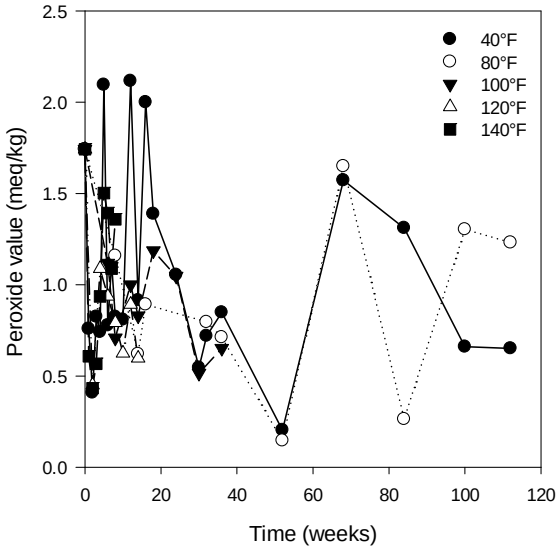


Figure 66. Changes in the peroxide value of Filled French Toast Pocket during storage at 40, 80, 100, 120 and 140°F.

2.3.1.3 Summary Of The Results For Filled French Toast Pocket

Below is a summary of the changes that occurred in the appearance (Table 21) and in the different physical (Table 22) and compositional attributes (Tables 23 and 24) measured in Filled French Toast Pocket samples at the beginning and end of storage:

- L* value: increased in samples stored at 40 and 80°F, and decreased (darker color) in samples stored at 100, 120 and 140°F.
- Chroma: decreased for all temperatures (duller color).

- Hue: increased in samples stored at 40, 80 and 100°F, and decreased in samples stored at 120 and 140°F (deeper color).
- Texture: decreased (softening) for all temperatures.
- pH: decreased for all temperatures.
- Acidity: no significant changes.
- Soluble solids content: increased for all temperatures.
- Moisture content: increased in samples stored at 40 and 80°F, and decreased in samples stored at 100, 120 and 140°F.
- Water activity: increased for all temperatures (more free water).
- Sucrose: decreased in samples stored at 80, 100, 120 and 140°F, and slightly increased in samples stored at 40°F.
- Glucose: increased for all temperatures (resulted most likely from the hydrolysis of sucrose).
- Fructose: increased for all temperatures (resulted most likely from the hydrolysis of sucrose).
- Total sugars: increased in samples stored at 40, 100, 120 and 140°F, and decreased in samples stored at 80°F (most likely as a result of the increase in glucose and fructose).
- Maltodextrin: maintained approximately the same levels in samples stored at 40°C, and decreased in samples stored at 80, 100, 120 and 140°F (hydrolysis of maltodextrin may have contributed to the increase in simple sugars such as glucose).
- Peroxide value: decreased for all temperatures.

2.3.2 Bacon Cheddar Pocket Sandwich

2.3.2.1 Physical Characteristics

Appearance and Color

As the temperature increased, the color of Bacon Cheddar Pocket Sandwiches changed from a light to a darker brown (Figure 67). Overall, development of browning occurred after eight weeks of storage at 120 and 140°F and was intensified with exposure to time and temperature. The development of the brown color could have been due to non-enzymatic browning caused by exposure of the samples to high temperatures. Samples stored at 40 and 80°F maintained an acceptable color comparable to that before storage (week 0), even after 112 weeks of storage.

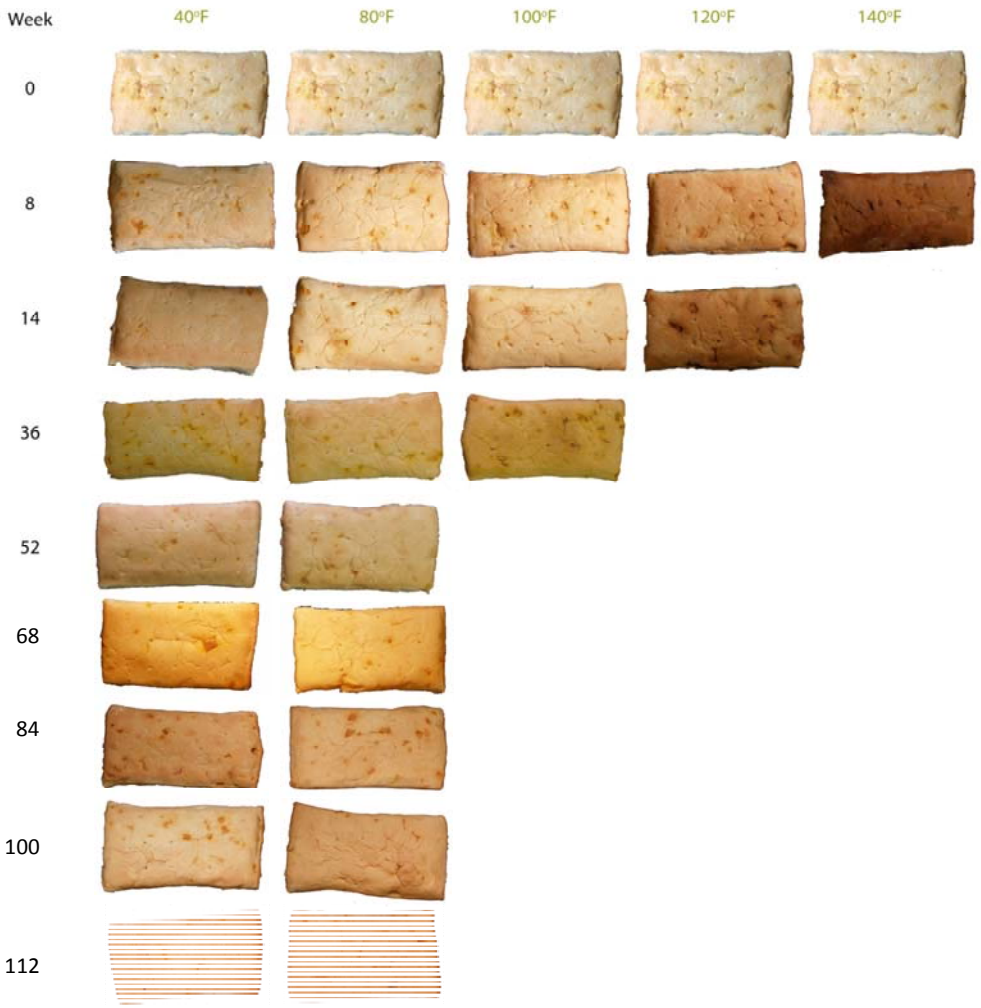


Figure 67. Changes in the appearance of Bacon Cheddar Sandwich during storage at 40, 80, 100, 120 and 140°F.

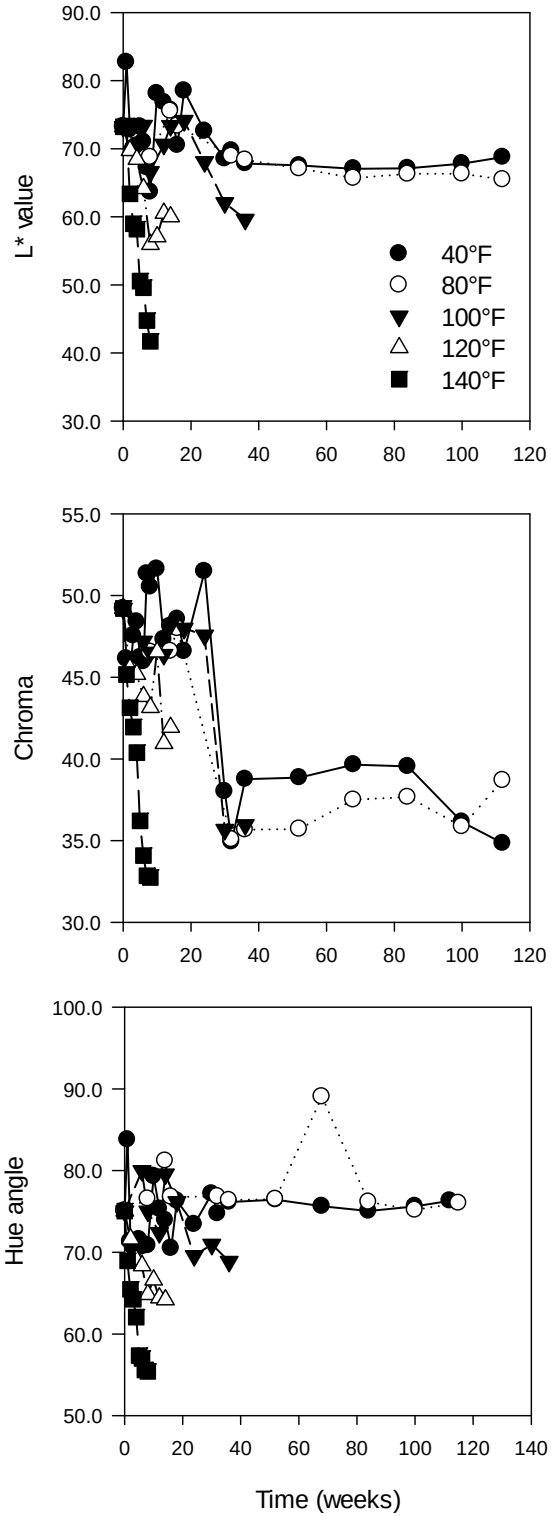


Figure 68. Changes in the color attributes (L*, chroma and hue) of Bacon Cheddar Sandwich during storage period 40, 80, 100, 120 and 140°F.

Development of the brown color on Bacon Cheddar Sandwich was faster at 140°F when compared to lower temperatures. L* values, hue angle and chroma values decreased as the temperature increased but changed slightly for samples stored at 80 and 40°F (Figure 68). Exposure to extreme temperatures (120 and 140°F) during storage contributed to a sharp decreased in L* values (darker color), hue angle (more brownish) and chroma values (less vivid) when compared to exposure to lower temperatures.

Texture

The most important effect of temperature was seen on the firmness of samples stored at temperatures higher than 100°F, as shown by a sharp decrease toward the end of an 8–36-week storage period (Figure 69). However, after 112 weeks, samples stored at 40 and 80°F showed only slight changes in their firmness compared to initial values before storage.

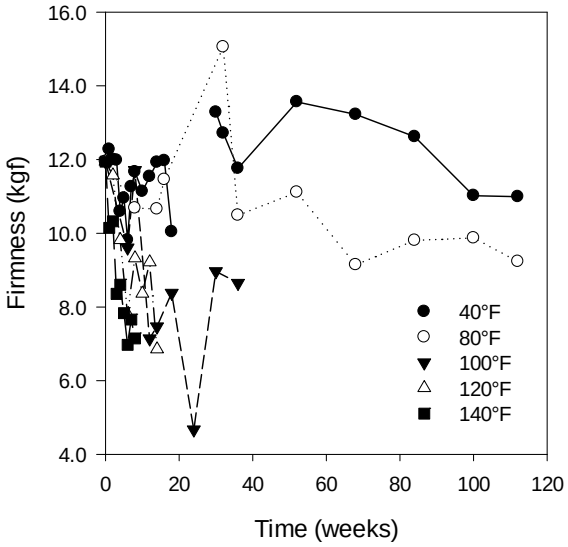


Figure 69. Changes in the texture of Bacon Cheddar Sandwich during storage at 40, 80, 100, 120 and 140°F.

2.3.2.2 Compositional Analysis

Titratable Acidity, Soluble Solids Content and pH

Overall, the pH of Bacon Cheddar Sandwich showed a decreasing trend (Figure 70); whereas titratable acidity showed an increasing trend during storage, regardless of the temperature. The pH slightly decreased for all temperatures during storage, but in samples stored at higher temperatures, the pH decreased rapidly after eight weeks of storage, primarily for samples stored at 140°F. The titratable acidity increased over time for all samples, but the increase was intensified as storage temperatures increased.

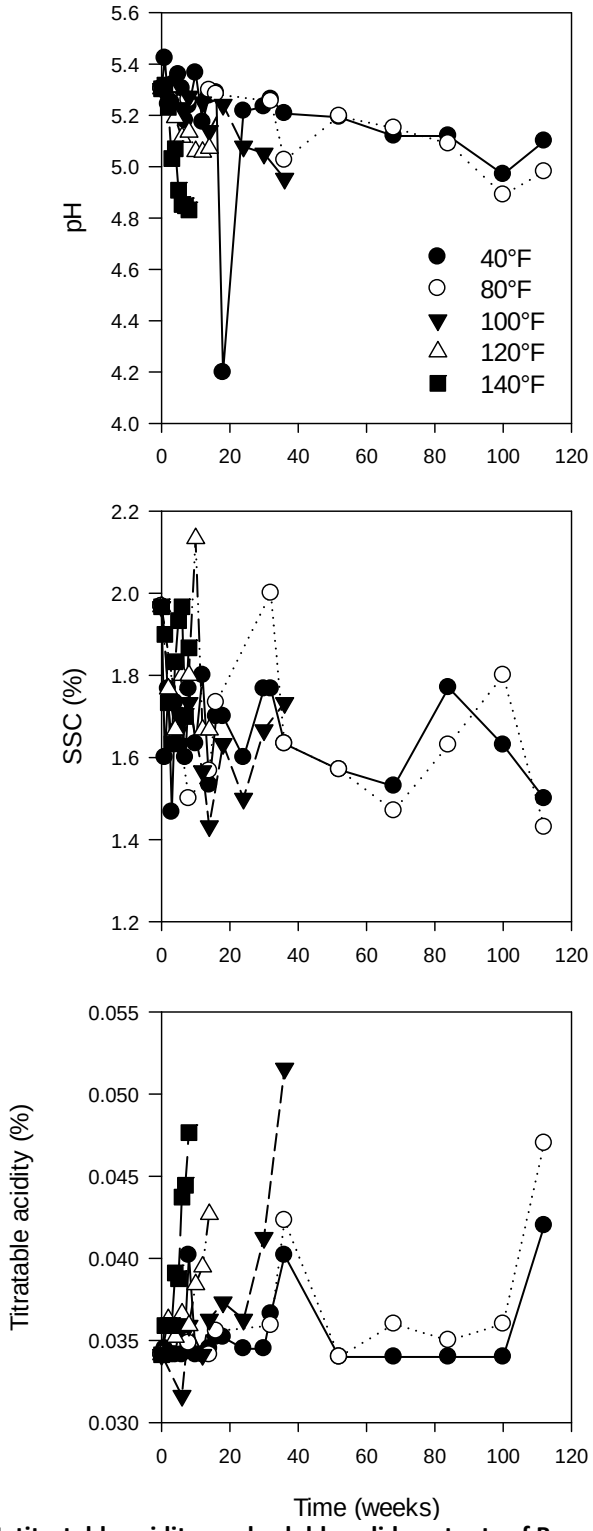


Figure 70. Changes in pH, titratable acidity, and soluble solid contents of Bacon Cheddar Sandwich during storage at 40, 80, 100, 120 and 140°F.

Soluble solid contents tended to decrease regardless of the storage temperature (Figure 70). After eight weeks of storage there was not a significant difference in the SSC of samples stored at different temperatures. After 112 weeks of storage at 40 and 80°F, the SSC of the samples was lower than that of samples stored for 8–36 weeks at temperatures higher than 100°F.

Water Activity and Moisture Content

Changes in water activity and moisture content for Bacon Cheddar Sandwich stored at different temperatures are shown in Figure 71. Water activity and moisture content fluctuated regardless of the storage time or temperature. Overall, exposure to high temperatures (120 and 140°F) resulted in similar water activity but slightly lower moisture content compared to other temperatures. However, 36 and 112-week samples stored at 100°F or at 40 and 80°F, respectively, showed high water activity and higher moisture content compared to initial values. This might have been a result of a rearrangement of water molecules and an increase in free water, which resulted in higher water activity and higher moisture content.

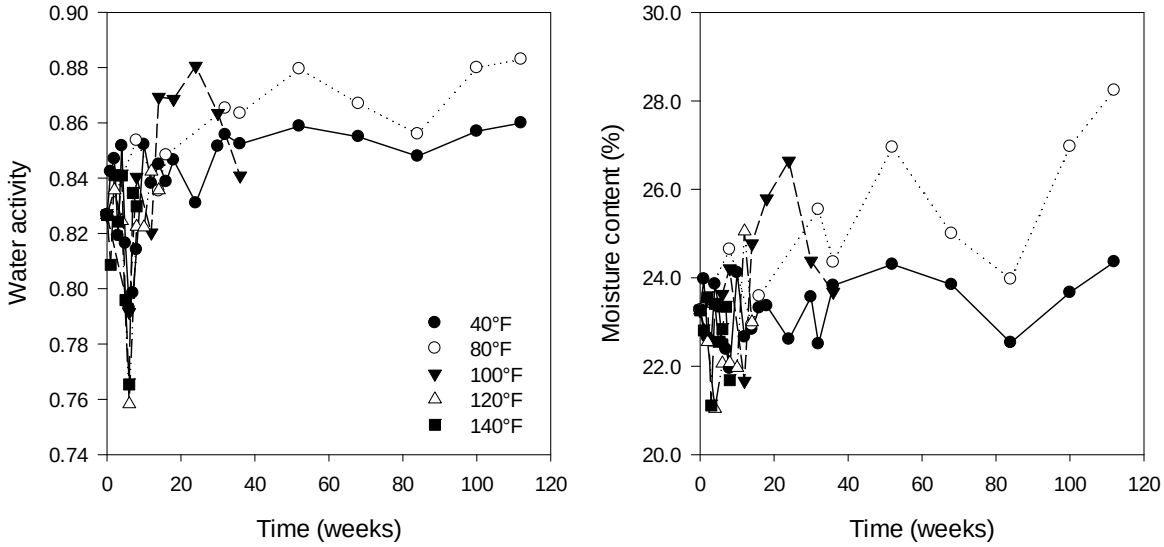


Figure 71. Changes in moisture content and water activity of Bacon Cheddar Sandwich during storage at 40, 80, 100, 120 and 140°F.

Ascorbic Acid Content

Ascorbic acid (AA) content in samples of Bacon Cheddar Sandwich decreased during storage regardless of the temperature (Figure 72). Although AA content tended to be higher in samples stored at 140°F compared to samples stored at other temperatures, this was most likely related to sample variation rather than an actual higher amount of AA. There was also some deviation in the AA content of samples stored at different temperatures for the same length of time. For example, AA content was expected to be higher in samples stored for eight weeks at 40 or 80°F (8.8 and 9.47 mg/100 g, respectively) than in those stored for the same amount of time at 100°F (11.3 mg/100 g). These differences may have resulted, once again, from variation between samples (for example, different lots or different production dates). Regardless of the

variations between samples, AA content decreased during storage. Storage duration had a great impact of AA degradation even in samples that were maintained at ambient (80°F) or in refrigerated conditions (40°F). For example, after 112 weeks AA decreased on average 93% in samples stored at 40 and 80°F. Therefore, if Bacon Cheddar Sandwiches are to be kept at ambient temperatures (80°F), there will be only 10% AA retention after two years.

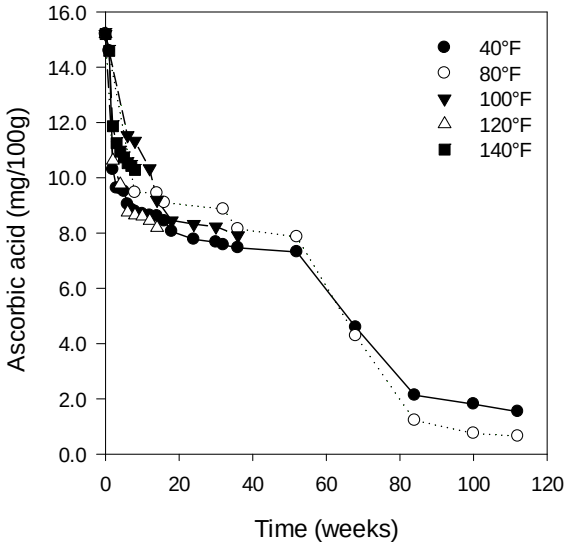


Figure 72. Changes in the ascorbic acid content of Bacon Cheddar Sandwich during a 112-week storage period at 40, 80, 100, 120, and 140°F.

Individual and Total Sugar Profiles

Figure 73 shows changes in sucrose, fructose, glucose and total sugar contents for Bacon Cheddar Sandwich during storage at 40, 80, 100, 120 and 140°F. There was a clear decrease in the concentrations of sucrose, glucose and total sugar contents for samples stored at temperatures higher than 80°F. This could have been caused by the degradation of sugars when samples were exposed to high temperatures. The samples stored at lower temperatures showed minimum changes in sugar content after a 36-week storage period, but began to show reduced sugar content thereafter. After 112 weeks, samples stored at 40 and 80°F showed approximately a 50 and 100% reduction in sucrose and glucose contents, respectively, whereas fructose content increased by about 50%.

The amount of maltodextrin decreased as the storage temperature increased, particularly in samples stored at 120 and 140°F (Figure 73). Changes in maltodextrin concentration were slight in samples stored at lower temperatures. However, after 112 weeks at 40°F the amount of maltodextrin increased most likely due to the partial hydrolysis of starch present in the samples.

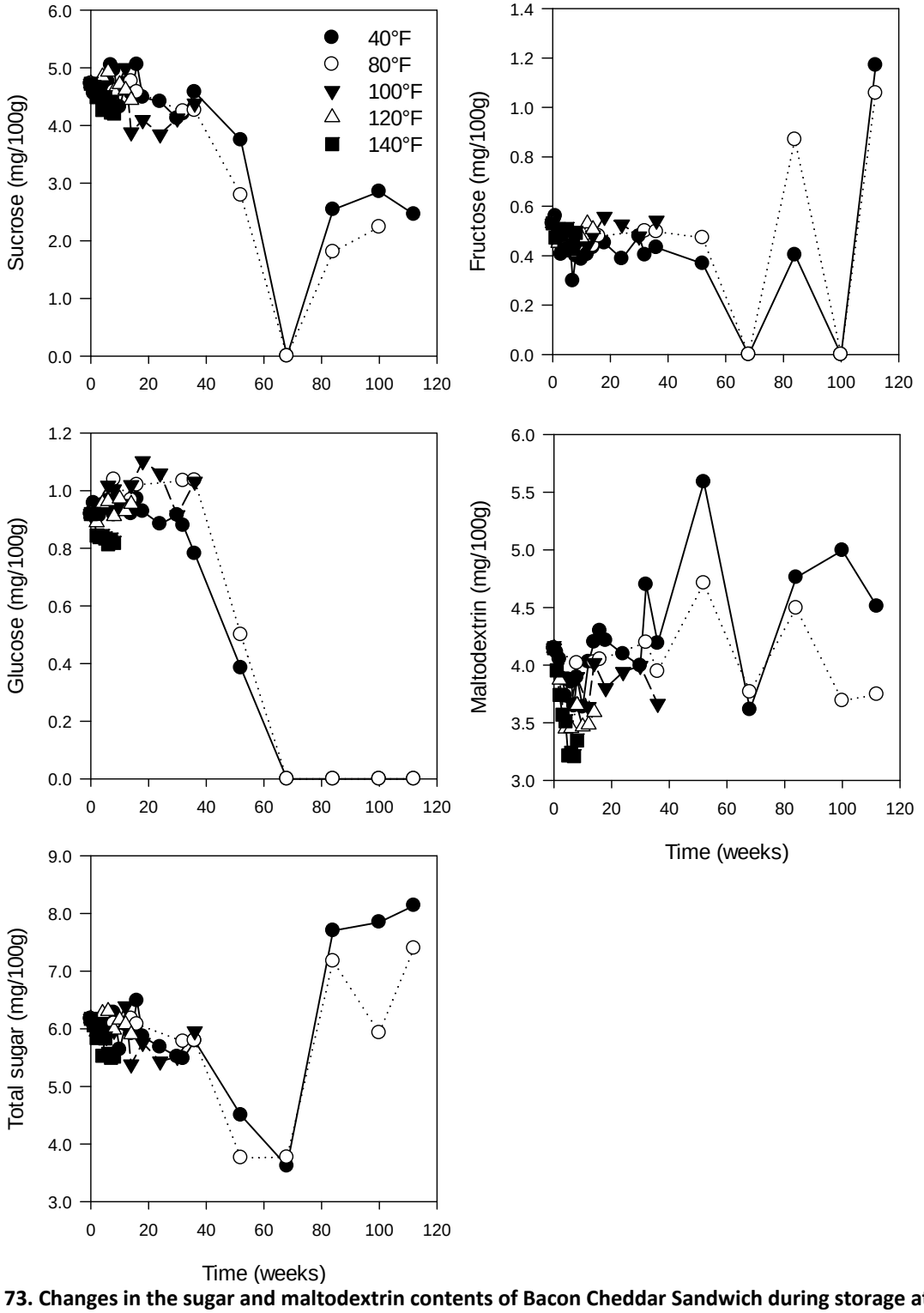


Figure 73. Changes in the sugar and maltodextrin contents of Bacon Cheddar Sandwich during storage at 40, 80, 100, 120 and 140°F.

Lipid Oxidation

Peroxide value was measured on both whole sandwich (bread and meat) and meat only, during storage at 40, 80, 100, 120 and 140°F (Figure 74). The level of lipid oxidation was reasonably low for all temperatures even after 112 weeks at 40 and 80°F or after eight weeks at 140°F. In terms of overall quality, the lipid oxidation that occurred during storage of Bacon Cheddar Sandwich was not considered critical as the levels remained low, considering a range of 7–30 meq/kg as the limit of acceptability reported in the literature for different foods (in Materials and Methods).

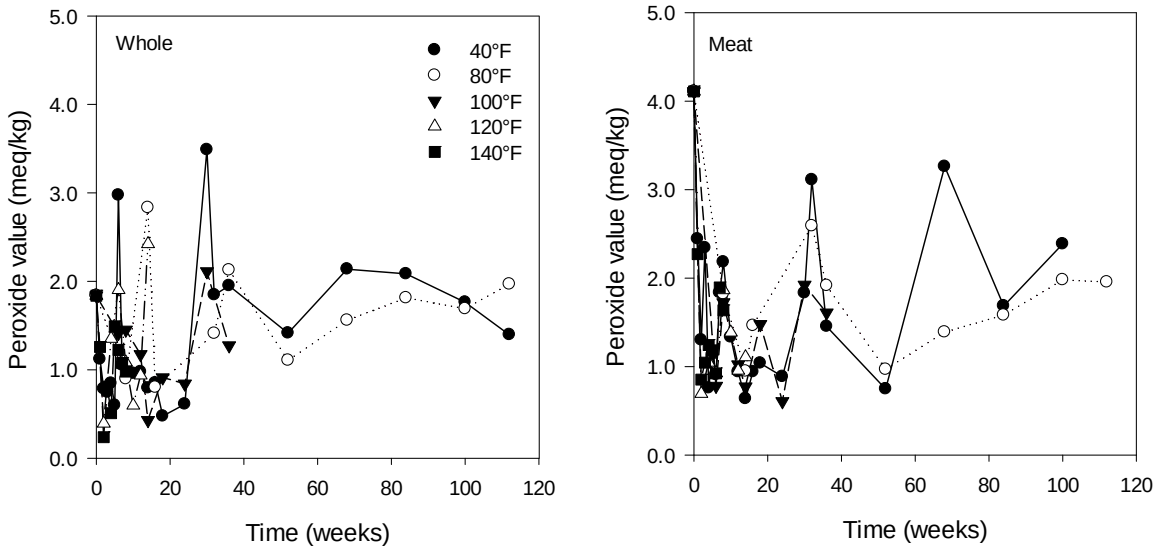


Figure 74. Changes in the peroxide value of Bacon Cheddar Sandwich (whole sandwich and meat only) during storage at 40, 80, 100, 120 and 140°F.

2.3.2.3 Summary Of The Results For Bacon Cheddar Sandwich

Below is a summary of the changes that occurred in the appearance (Table 20) and in the different physical (Table 22) and compositional (Tables 23 and 24) attributes measured in Bacon Cheddar Sandwich samples at the beginning and end of storage:

- L* value: decreased (darker color) for all temperatures.
- Chroma: decreased (duller color) for all temperatures.
- Hue: increased in samples stored at 40 and 80°F, and decreased in samples stored at 100, 120 and 140°F (deeper color).
- Texture: increased in samples stored at 40°F (harder crust), and decreased (softening) in samples stored at 80, 100, 120 and 140°F.
- pH: decreased for all temperatures.
- Acidity: increased for all temperatures.
- Soluble solids content: decreased for all temperatures.
- Moisture content: increased in samples stored at 40, 80 and 100°F, and decreased in samples stored at 120 and 140°F.

- Water activity: increased in samples stored at 40, 80, 100 and 120°F (more free water), and was approximately the same in samples stored at 140°F.
- Ascorbic acid: decreased for all temperatures.
- Sucrose: decreased for all temperatures.
- Glucose: decreased in samples stored at 40, 80 and 100°F, and increased in samples stored at 100 and 120°F.
- Fructose: increased in samples stored at 40, 80 and 100°F, and decreased in samples stored at 120 and 140°F.
- Total sugars: increased in samples stored at 40 and 80°F, and decreased in samples stored at 100, 120 and 140°F.
- Maltodextrin: increased in samples stored at 40°C, and decreased in samples stored at 80, 100, 120 and 140°F.
- Peroxide value measured in the whole sandwich: decreased in samples stored at 40, 100 and 140°F, and increased in samples stored at 80 and 120°F.
- Peroxide value measure in the meat part of the sandwich: decreased for all temperatures.

2.3.3 Wheat Snack Bread

2.3.3.1 Physical Characteristics

Appearance and Color

Brown color development took place after eight weeks at 120 and 140°F and was intensified by exposure time and temperature (Figure 75). The reaction that occurred resulting in the development of brown discoloration could have been caused by non-enzymatic browning reactions as a result of exposure of the samples to high temperatures. Difference in the color during storage might have been caused by sample variations or light exposure during photography. However, there was a tendency for the bread to darken slightly even when stored at ambient or refrigerated temperatures. Exposure for eight weeks at 140°F resulted in a marked darkening of the color and development of a toasted-like appearance of the bread, which was not seen in samples stored at lower temperatures.

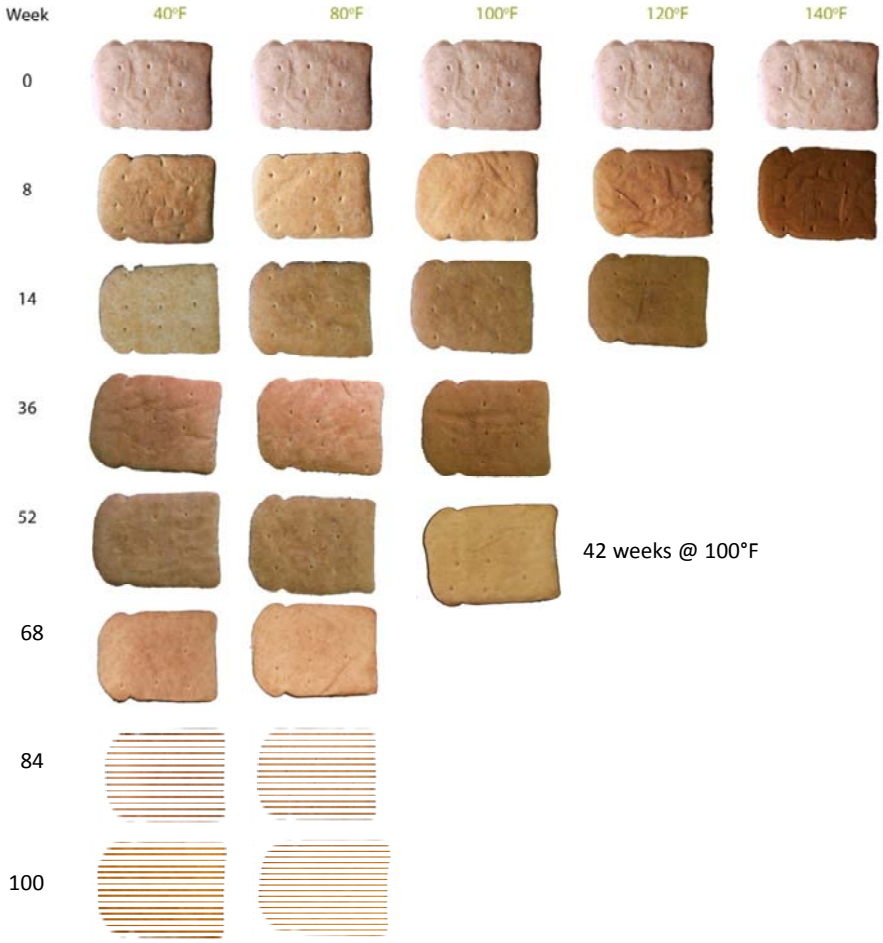


Figure 75. Changes in the appearance of Wheat Snack Bread during storage at 40, 80, 100, 120 and 140°F.

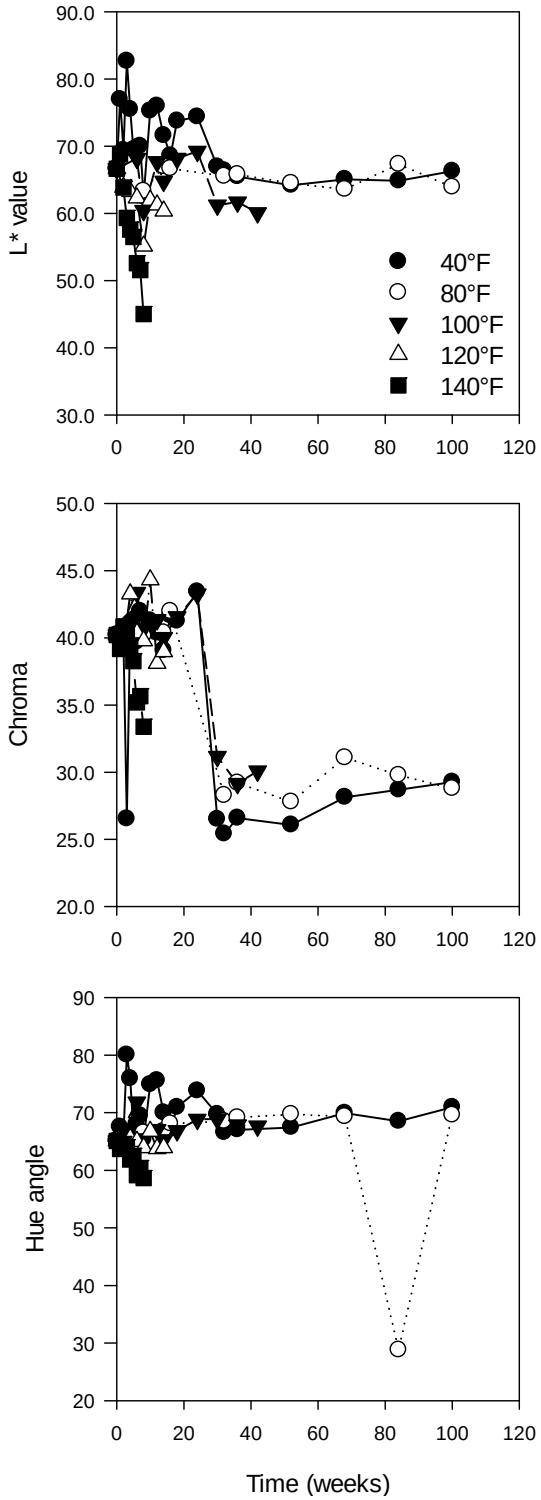


Figure 76. Changes in the color attributes (L*, chroma and hue) of Wheat Snack Bread during storage at 40, 80, 100, 120 and 140°F.

There were no major changes in L* and hue angle values for samples stored at 40 and 80°F compared to their initial values before storage (Figure 76). However, L* value significantly

changed in samples stored at 100, 120 and 140°F. Chroma values decreased significantly in samples stored at any of the temperatures used in this study, but decreases in chroma values were faster in samples stored at temperatures above 100°F. After each storage period, Wheat Snack Bread samples appeared less vivid compared to initial values. Overall, hue tended to either increase or remain close to the initial values in samples stored at 40, 80, 100 and 120°F whereas it decreased considerably (very dark brown) in samples stored at 140°F.

Texture

The most important effect of exposure to high temperature was seen on the texture of samples stored at 120 and 140°F by the fast decrease in firmness after 14 or 8 weeks of storage, respectively (Figure 77). However, the firmness of samples stored at 40, 80 and 100°F tended to increase toward the end of storage most likely due to hardening of the bread crust.

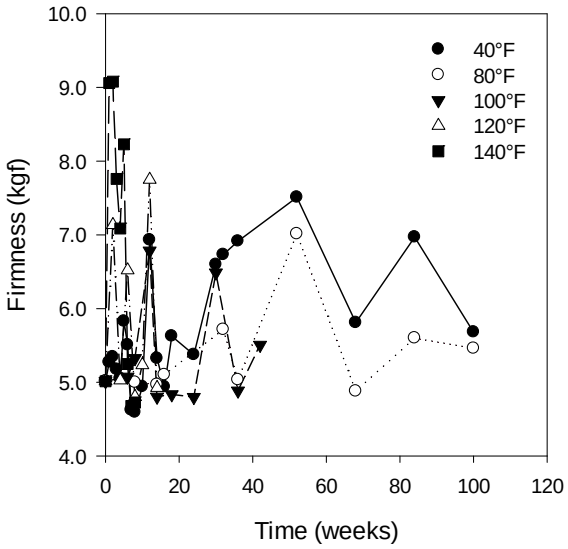


Figure 77. Changes in the texture of Wheat Snack Bread during storage at 40, 80, 100, 120 and 140°F.

2.3.3.2 Compositional Analysis

Titratable Acidity, Soluble Solids Content and pH

Changes in titratable acidity, soluble solids content and pH of Wheat Snack Bread at different temperatures (40, 80, 100, 120 and 140°F) are shown in Figure 78. The pH of bread samples decreased regardless of the temperature. Samples stored at high temperatures (120 and 140°F) showed a rapid decrease in pH, especially after eight weeks at 140°F. Overall, the higher the storage temperature, the faster the decrease in pH; samples stored at 40°F showed the least changes in pH even after 112 weeks of storage, whereas those stored for eight weeks at 40°F showed the fastest and greatest decrease.

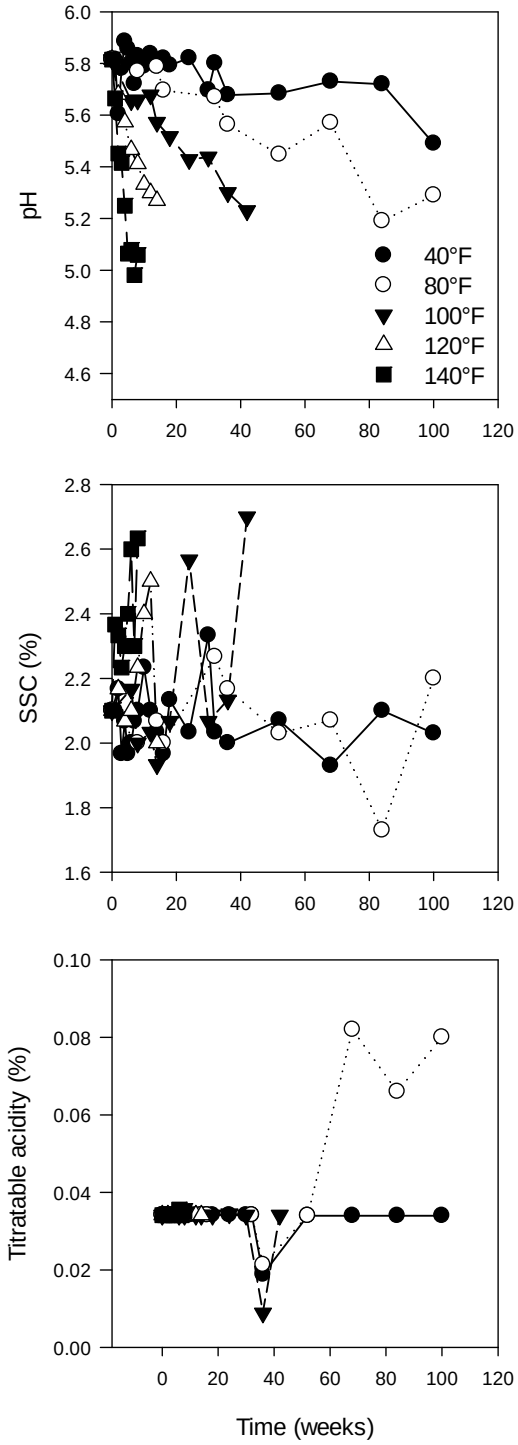


Figure 78. Changes in the titratable acidity, soluble solids content and pH of Wheat Snack Bread during storage at 40, 80, 100, 120 and 140°F.

Overall, there were no noticeable changes in the titratable acidity in the samples regardless of the storage temperature, even though the acidity of samples stored at 80°F tended to increase

toward the end of storage (Figure 78). Nevertheless, this increase might have been related to sample variations. The soluble solids content of the samples fluctuated, regardless of the temperature, but overall, at the end of each storage period, the soluble solids content tended to either increase (80, 100 and 140°F) or remain similar to initial values (40 and 120°F).

Water Activity and Moisture Content

Water activity of Wheat Snack Bread increased regardless of the storage temperature (Figure 79). A similar increase was observed for samples stored at 120 and 140°F (0.75 to 0.79) and in samples stored at 40, 80 and 100°F (0.75 to 0.82). Therefore, there was an increase in the amount of free water in the samples most likely due to the effect of time-temperature exposure.

Moisture content decreased after approximately eight weeks, regardless of storage time and temperature, increasing thereafter to attain levels comparable to those measured initially. After 100 weeks, samples stored at 40 and 80°F did not show major changes in moisture content compared to initial measurements (Figure 79).

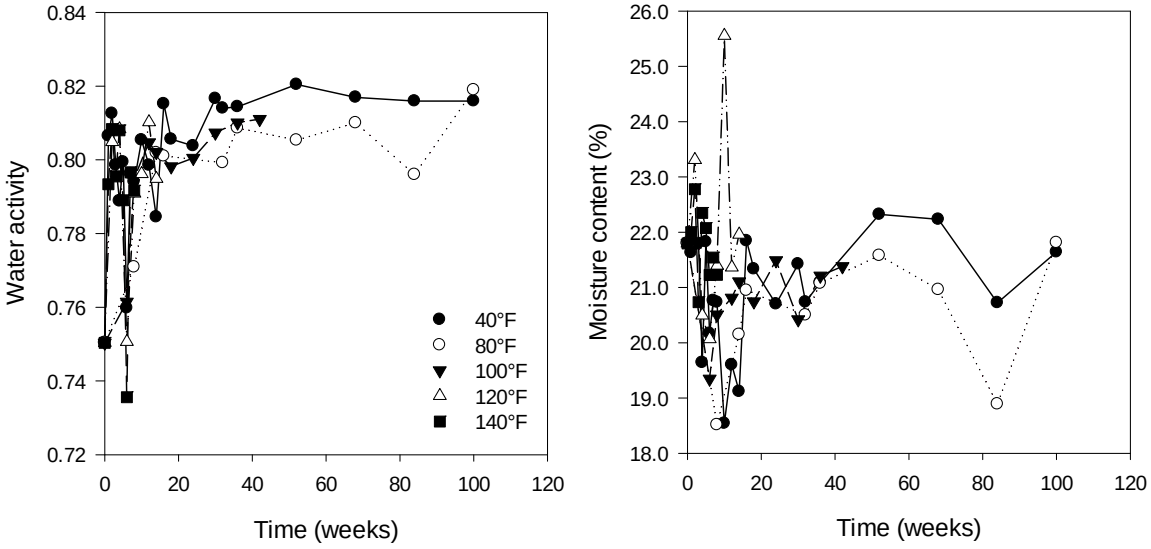


Figure 79. Changes in moisture content and water activity of Wheat Snack Bread during storage at 40, 80, 100, 120 and 140°F.

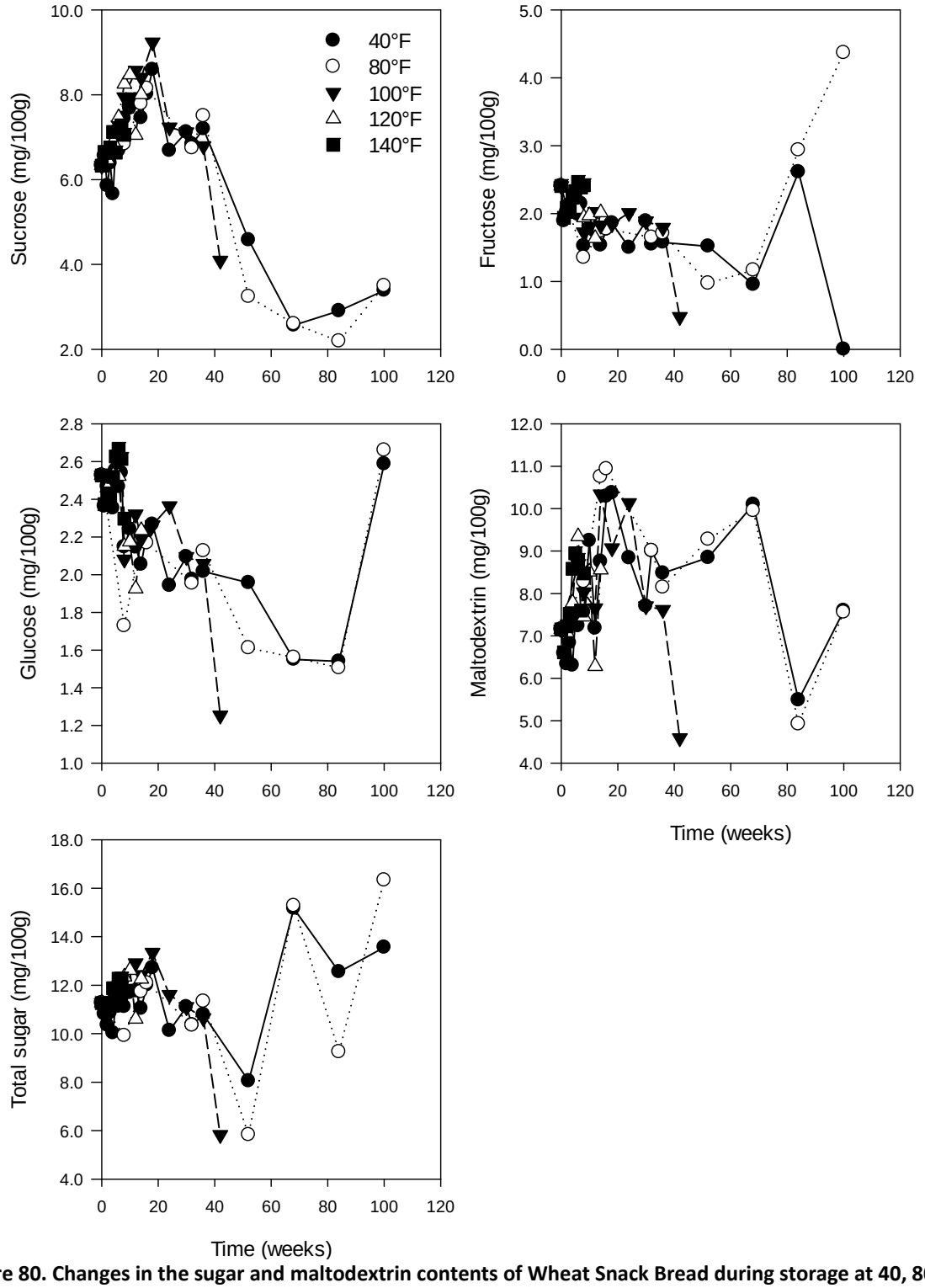


Figure 80. Changes in the sugar and maltodextrin contents of Wheat Snack Bread during storage at 40, 80, 100, 120 and 140°F.

Individual and Total Sugar Profiles

At the end of each respective storage period, sucrose decreased in samples stored at 40, 80 and 100°F, whereas there was an increase in sucrose in samples stored at 120 and 140°F (Figure 80). Conversely, glucose increased in samples stored at 40 and 80°F and decreased in samples stored at 100, 120 and 140°F. Fructose decreased in samples stored at 40, 100 and 120°F, increased in samples stored at 80°F and remained similar to initial values in samples stored at 140°F. Maltodextrin slightly increase in samples stored at all temperatures except in those stored at 100°F, where a decrease was observed.

Overall, the total sugar content increased in samples stored at all temperatures, most likely due to the increase in maltodextrin, which might have resulted from the partial hydrolyzation of starch.

Lipid Oxidation

The level of lipid oxidation was measured using peroxide value (PV) assay to monitor the primary oxidation products formed. Figure 81 represents the level of peroxide value in Wheat Snack Bread during storage at 40, 80, 100, 120 and 140°F. During storage, the degree of lipid oxidation fluctuated for all temperatures, but in general it tended to be higher in samples stored for 100 weeks at 40 and 80°F and lower for samples stored at 100, 120 and 140°F after 42, 14 and 8 weeks of storage, respectively. Lipid oxidation was most likely not responsible for quality loss of Wheat Snack Bread regardless of storage time and temperature since the samples showed a low peroxide value, and therefore low lipid oxidation, considering a range of 7–30 meq/kg as the limit of acceptability reported in the literature for different foods (in Materials and Methods).

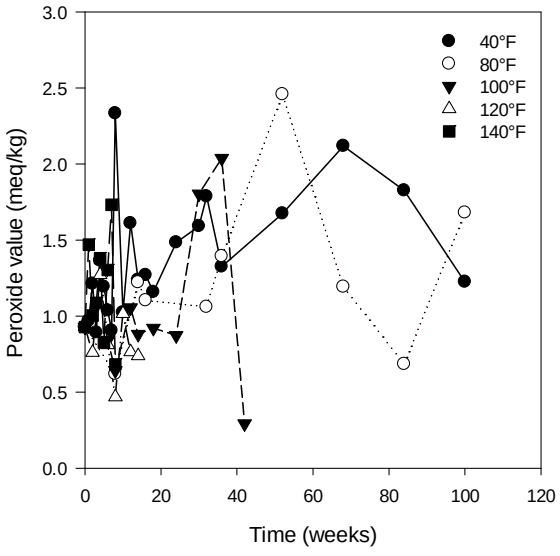


Figure 81. Changes in the peroxide value of Wheat Snack Bread during storage at 40, 80, 100, 120 and 140°F.

2.3.3.3 Summary Of The Results For Wheat Snack Bread

Below is a summary of the changes that occurred in the appearance (Table 21) and in the different physical (Table 22) and compositional attributes (Tables 23 and 24) measured in Wheat Snack Bread samples at the beginning and at end of storage:

- L* value: decreased (darker color) for all temperatures.
- Chroma: decreased (duller color) for all temperatures.
- Hue: increased in samples stored at 40, 80 and 100°F, and decreased in samples stored at 120 and 140°F (deeper color).
- Texture: increased in samples stored at 40, 80 and 100°F (harder crust), and decreased (softening) in samples stored at 120 and 140°F.
- pH: decreased for all temperatures.
- Acidity: was approximately the same in samples stored at 40, 100 and 120°F, and increased in samples stored at 80 and 140°F.
- Soluble solids content: decreased in samples stored at 40 and 120°F, and increased in samples stored at 80, 100 and 140°F.
- Moisture content: slightly decreased for all temperatures.
- Water activity: increased for all temperatures.
- Sucrose: decreased for samples stored at 40, 80 and 100°F, and increased for samples stored at 120 and 140°F.
- Glucose: increased in samples stored at 40 and 80°F, and decreased in samples stored at 100, 120 and 140°F.
- Fructose: decreased in samples stored at 40, 100 and 120°F, and increased in samples stored at 80 and 140°F.
- Total sugars: increased for samples stored at 40, 80, 120 and 140°F, and decreased in samples stored at 100°F.
- Maltodextrin: increased in samples stored at 40, 80, 120 and 140°C, and decreased in samples stored at 100°F.
- Peroxide value: increased in samples stored at 40 and 80°F, and decreased in samples stored at 100, 120 and 140°F.

2.3.4 Beef Snack, Sweet BBQ

2.3.4.1 Physical Characteristics

Appearance and Color

Samples of Beef Snack, Sweet BBQ developed a very dark brown, almost black, appearance after 8 and 14 days of storage at 120 and 140°F, respectively (Figure 82). There was also darkening of the color in samples stored at lower temperatures, but changes were subtler, particularly in samples stored at 40 and 80°F.

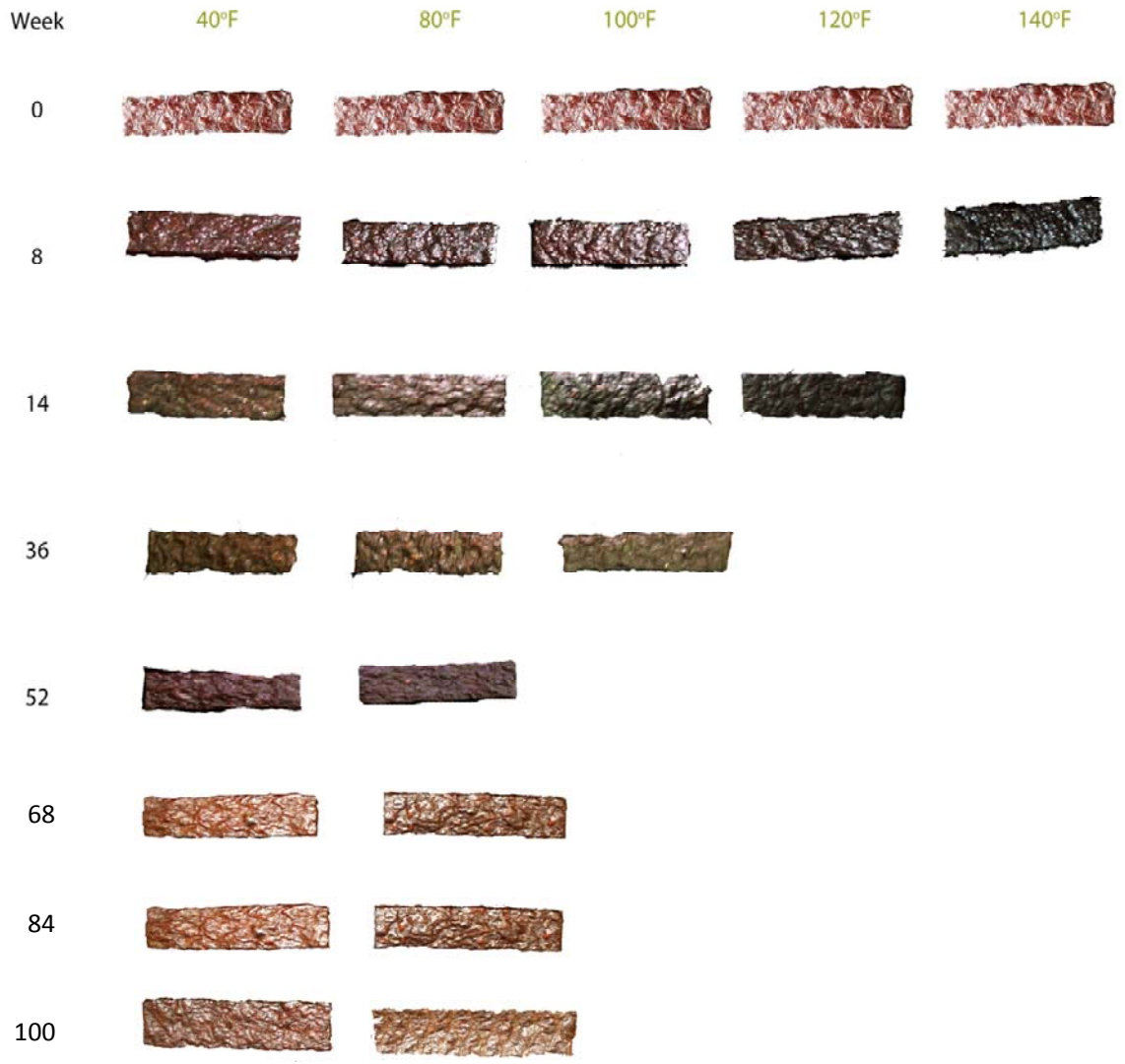


Figure 82. Changes in the appearance of Beef Snack, Sweet BBQ during storage at 40, 80, 100, 120 and 140°F.

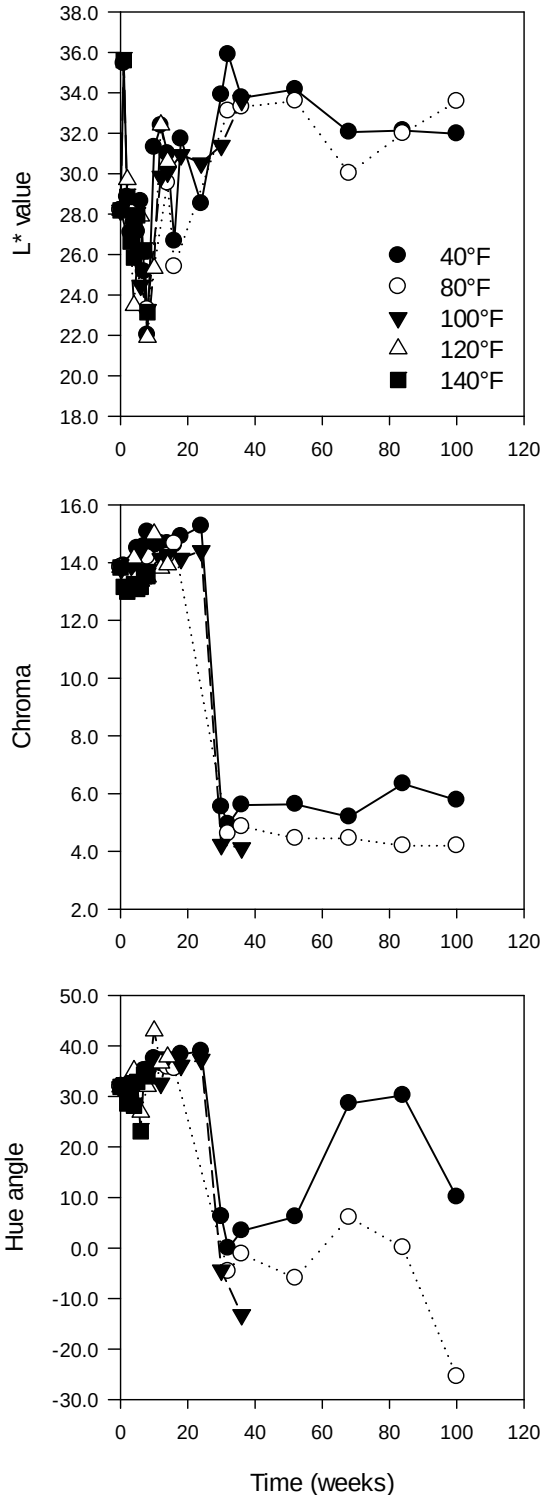


Figure 83. Changes in color attributes (L*, chroma and hue) of Beef Snack, Sweet BBQ during storage at 40, 80, 100, 120 and 140°F.

Exposure of Beef Snack, Sweet BBQ samples for eight weeks to extreme temperature conditions (140°F) resulted in decreased L* value (darker), increased hue angle (very dark brown or blackish color), and a slightly decreased chroma value (less vivid) (Figure 83). In samples stored at lower temperatures, the L* value slightly increased whereas chroma and hue decreased. Changes in color might have resulted from both color bleaching and loss of typical brown pigments (in samples stored below 120°F) or from enzymatic reactions that resulted in the development of very dark brown pigments, particularly in samples stored at 140°F.

Texture

As storage temperature increased from 40 to 140°F, the firmness of the Beef Snack, Sweet BBQ increased, resulting in samples with a very hard texture (Figure 84). The sharpest increase in firmness (harder samples) in a short period of time was observed in samples stored at 140°F after eight weeks. The main reason for the increase in firmness and therefore toughening of the samples might have been caused by loss of moisture content as well as by changes in some other components (Figures 86 and 87).

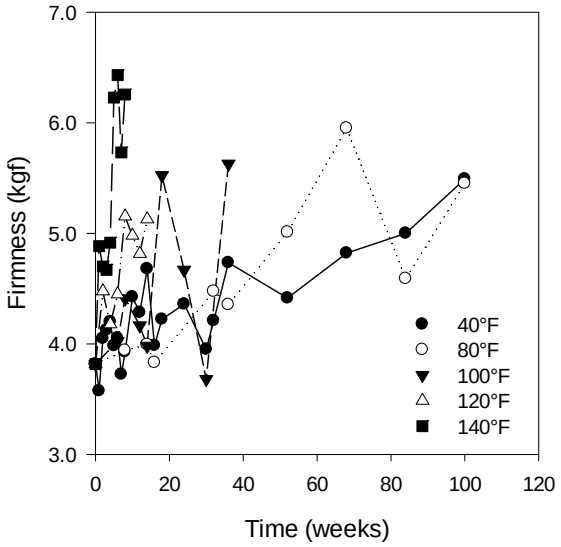


Figure 84. Changes in the texture of Beef Snack, Sweet BBQ during storage at 40, 80, 100, 120 and 140°F.

2.3.4.1 Compositional Analysis

Titratable Acidity, Soluble Solids Content and pH

As storage temperature increased, the pH of the Beef Snack, Sweet BBQ decreased, whereas the titratable acidity and soluble solids content increased (Figure 85). During storage the pH of all samples decreased regardless of the storage temperature; however, the pH of samples stored at higher temperatures decreased faster, especially in samples stored at 120 or 140°F. An increase in titratable acidity was also faster in samples stored at temperatures higher than 100°F. After eight weeks, samples stored at 140°F showed a 64% increase in soluble solids content compared to initial measurements.

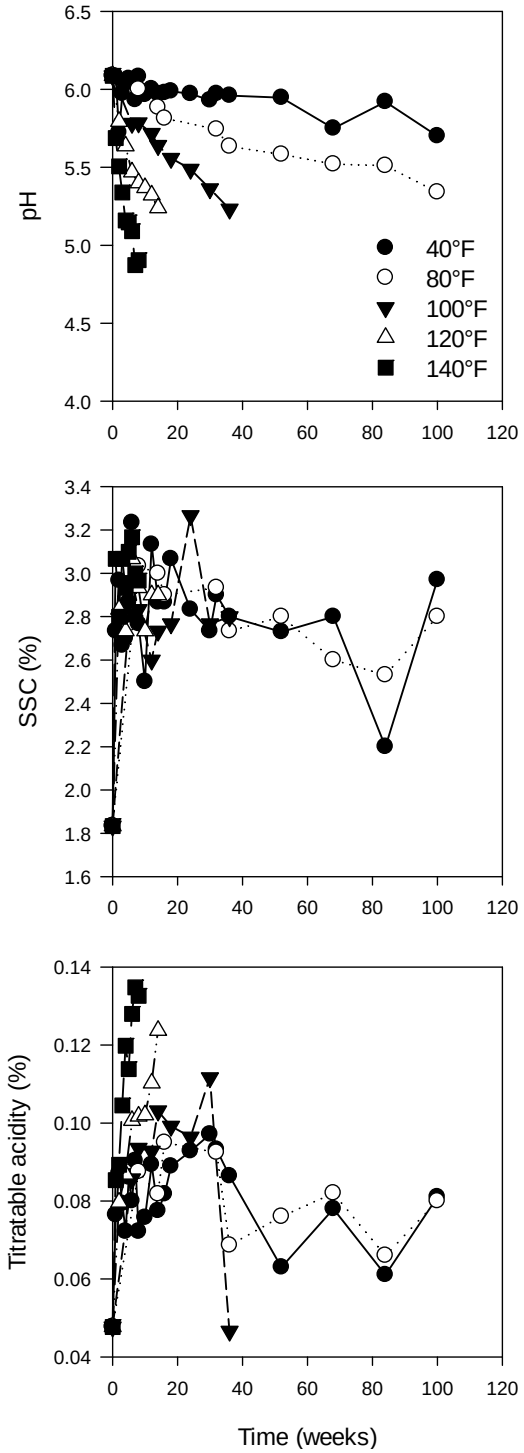


Figure 85. Changes in pH, titratable acidity and soluble solids content of Beef Snack, Sweet BBQ during storage at 40, 80, 100, 120 and 140°F.

Water Activity and Moisture Content

The results for water activity and moisture content for the Beef Snack, Sweet BBQ are shown in Figure 86. After eight weeks, samples stored at 140°F experienced the highest decrease in water activity compared to other temperatures. At the end of each respective storage period, water activity was generally higher or similar to initial values for samples stored at temperatures lower than 140°F. Moisture content decreased during storage, regardless of the storage temperature, but the decrease was sharper in samples stored for eight weeks at 100°F.

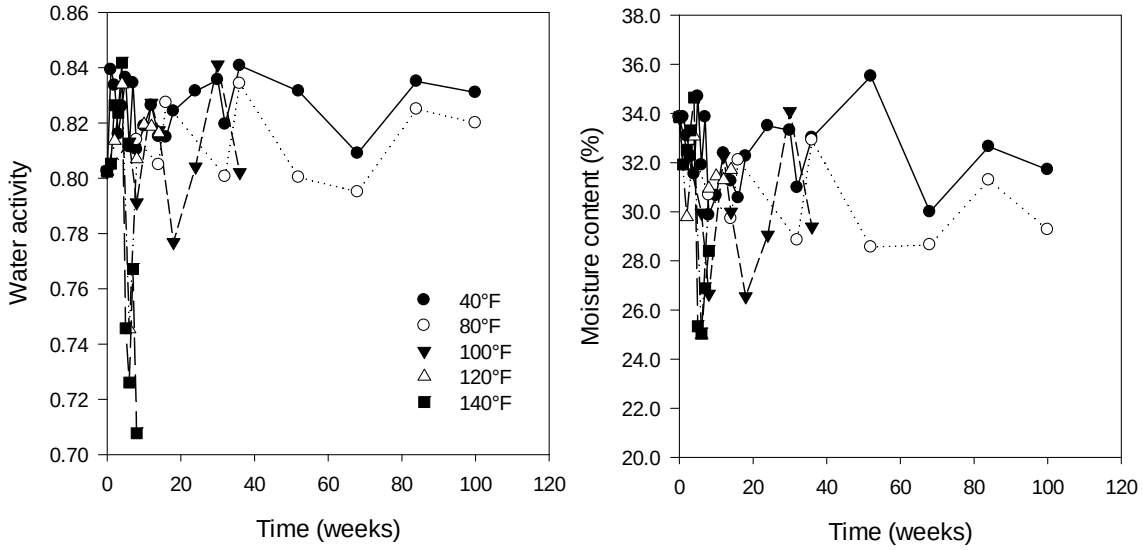


Figure 86. Changes in water activity and moisture content of Beef Snack, Sweet BBQ during storage at 40, 80, 100, 120 and 140°F.

Individual and Total Sugar Profiles

Sucrose was the main sugar measured in Beef Snack, Sweet BBQ (Figure 87). When the storage temperature increased, the amount of sucrose decreased sharply, particularly in samples stored at 100, 120 and 140°F. This could have been a result of degradation of sucrose and conversion into fructose and glucose when samples were exposed to high temperatures. Samples stored at 40 and 80°F did not show much change in the sucrose concentration, and after 110 weeks the sucrose content was higher than the values measured initially. Glucose decreased during storage, regardless of the storage temperature, and after 68 weeks there was no glucose detected in samples stored at 80°F. Conversely, fructose increased for all samples regardless of the storage temperature. The maltodextrin content of Beef Snack, Sweet BBQ samples stored at 120 and 140°F decreased significantly after eight weeks. After eight weeks, maltodextrin levels were the lowest in samples stored at 140°F compared to samples stored at other temperatures. However, after 100 weeks there was a decline of about 60% in the maltodextrin levels of samples stored at 40 and 80°F. Total sugar content profiles parallel those of sucrose and decreased in samples stored at 40 and 80°F after 8 and 14 weeks of storage, respectively. However, there was an increase in total sugar content after 100 and 36 weeks in samples stored at 40, 80 and 100°F.

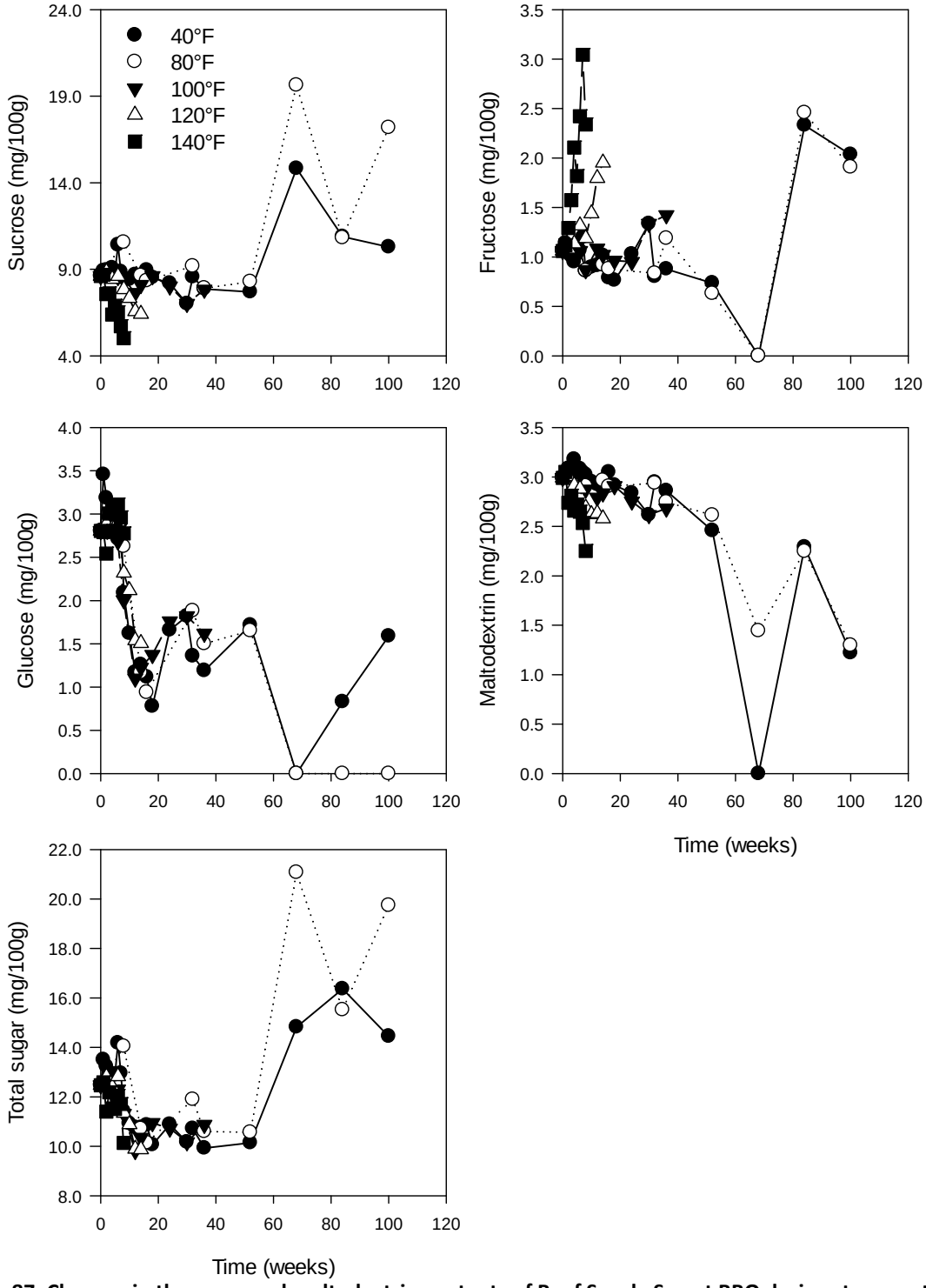


Figure 87. Changes in the sugar and maltodextrin contents of Beef Snack, Sweet BBQ during storage at 40, 80, 100, 120 and 140°F.

Lipid Oxidation

The peroxide value (PV) was measured in Beef Snack, Sweet BBQ samples during storage at 40, 80, 100, 120 and 140°F (Figure 88). Lipid oxidation levels fluctuated regardless of the storage time and temperature but tended to decrease regardless of the temperature. Although PV values were higher in this type of FSR item compared to the previous items analyzed, considering a range of 7–30 meq/kg as the limit of acceptability reported in the literature for different foods (in Materials and Methods), the PV obtained for Beef Snack, Sweet BBQ was still below 30 meq/kg.

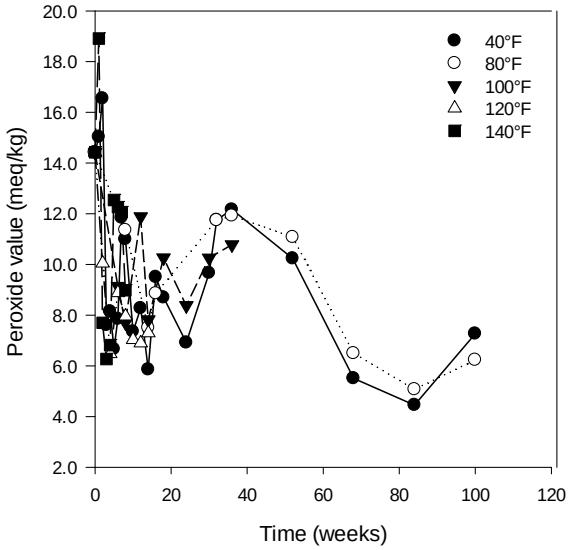


Figure 88. Changes in the peroxide value of Beef Snack, Sweet BBQ during storage at 40, 80, 100, 120 and 140°F.

2.3.4.3 Summary Of The Results For Beef Snack, Sweet BBQ

Below is a summary of the changes that occurred in the appearance (Table 20) and in the different physical (Table 22) and compositional attributes (Tables 23 and 24) measured in Beef Snack, Sweet BBQ samples at the beginning and end of storage:

- L* value: decreased (darker color) for all temperatures.
- Chroma: decreased (duller color) for all temperatures.
- Hue: increased in samples stored at 40, 80 and 100°F, and decreased in samples stored at 120 and 140°F (deeper color).
- Texture: increased for all temperatures.
- pH: decreased for all temperatures.
- Acidity: increased for all temperatures.
- Soluble solids content: increased for all temperatures.
- Moisture content: decreased for all temperatures.

- Water activity: increased in samples stored at 40, 80, 100 and 120°F, and decreased in samples stored at 140°F.
- Sucrose: increased in samples stored at 40 and 80°F and decreased in samples stored at 100, 120 and 140°F.
- Glucose: decreased for all temperatures.
- Fructose: increased for all temperatures.
- Total sugars: increased in samples stored at 40 and 80°F, and decreased in samples stored at 100, 120 and 140°F.
- Maltodextrin: decreased for all temperatures.
- Peroxide value: decreased for all temperatures.

2.3.5 Applesauce, CHO Enhanced (Zapplesauce)

2.3.5.1 Physical Characteristics

Appearance and Color

As the temperature increased, the characteristic yellowish appearance of applesauce changed; the color darkened, becoming yellowish-brown and in some cases, light brown (Figure 89). The brown color development occurred after eight weeks of storage at 120°F, and after that same period of time samples stored at 140°F were completely brown as if they were overcooked. Color changes were subtler in samples exposed to lower temperatures, as the samples maintained a typical yellowish color even after 112 weeks of storage. Color changes in samples stored at 40°F were very slight. The brownish appearance of Applesauce resulted most likely from non-enzymatic browning caused by exposure of the food to high temperatures.

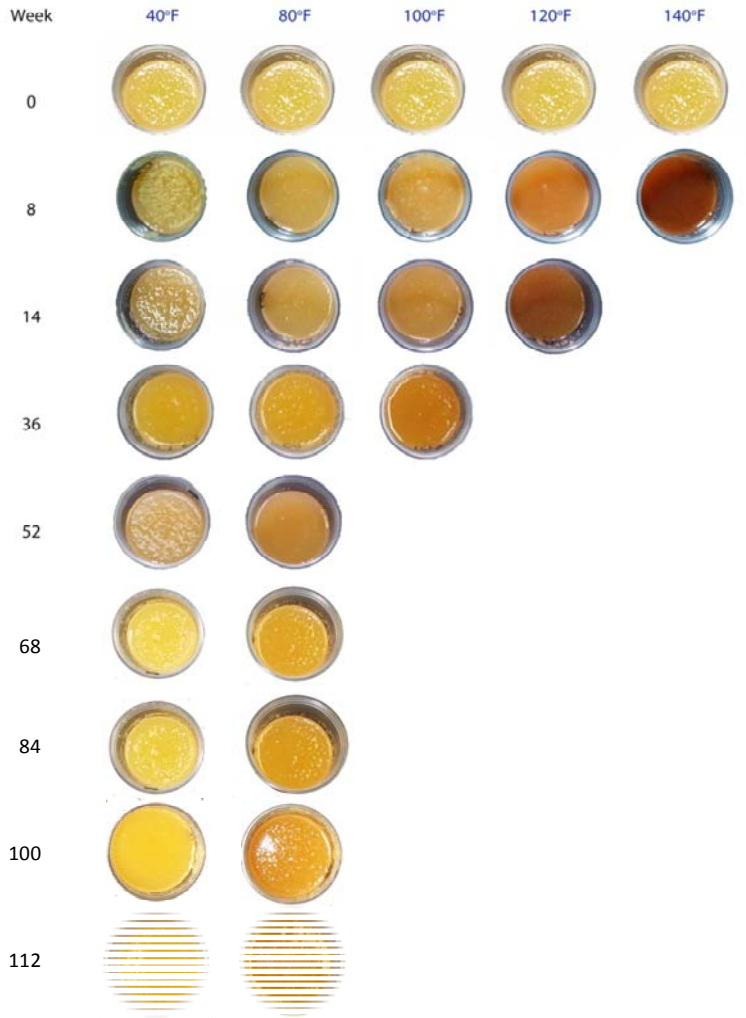


Figure 89. Changes in the appearance of Applesauce during storage at 40, 80, 100, 120 and 140°F.

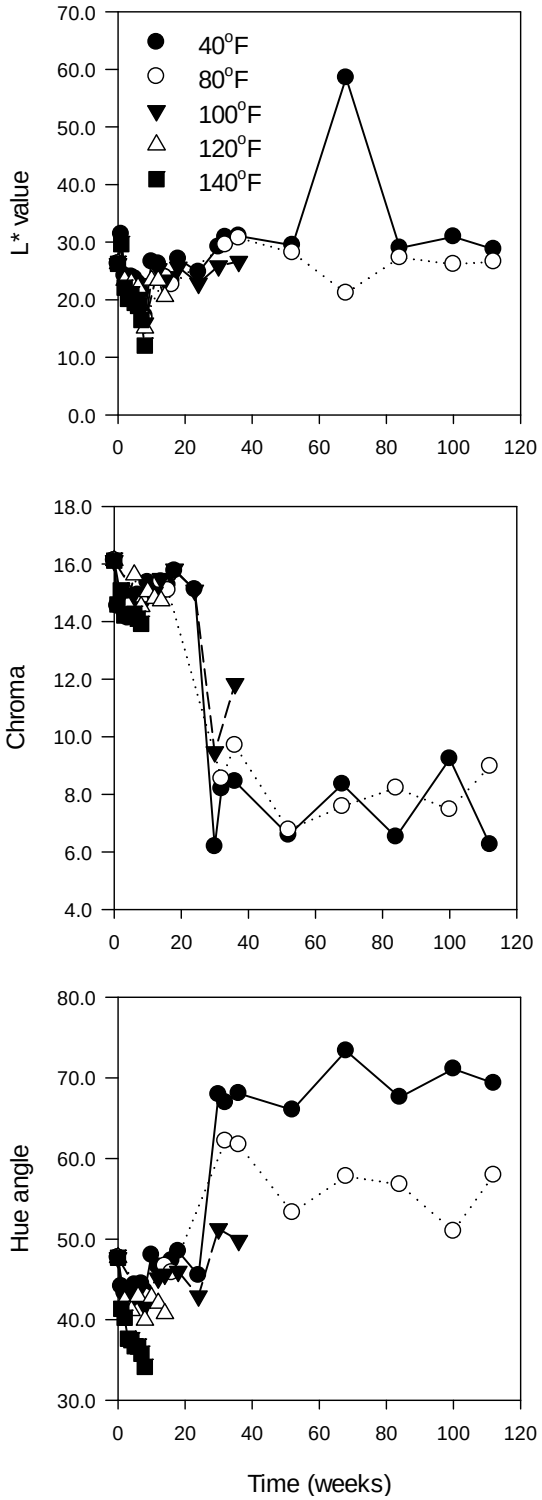


Figure 90. Changes in color attributes (L*, chroma and hue) of Applesauce during storage at 40, 80, 100, 120 and 140°F.

Figure 90 shows the changes in L* value, hue angle and chroma values in Applesauce samples during storage at different temperatures. After 8 and 14 weeks L* values decreased markedly (darker samples) in samples stored at 120 and 140°F, respectively. In samples stored at 40, 80 and 100°F, the L* value slightly increased (lighter samples). Chroma values decreased regardless of the storage temperature, meaning that the Applesauce color became less vivid and duller toward the end of storage. Hue angle values decreased in samples stored at 120 and 140°F, representing a darkening of the characteristic yellow color of applesauce; however hue angle values tended to increase in samples stored at lower temperatures. The increase in hue angle might have been caused by degradation of carotenoid pigments sometimes present in apple products.

Texture

Changes in the texture of Applesauce stored at different temperatures are shown in Figure 91. The major effect of temperature was seen on the texture of Applesauce samples stored at 120 and 140°F. Exposure to extreme temperatures caused a decrease in the firmness of the samples from 0.07 to 0.05 kgf at the end of 8 and 14 weeks of storage, respectively. This decrease in firmness was translated by a thinner or watery texture (loss of consistency of the puree) particularly in samples exposed to temperatures higher than 80°F. The texture of samples stored at 40°F for 112 weeks was similar to that measured initially (before storage).

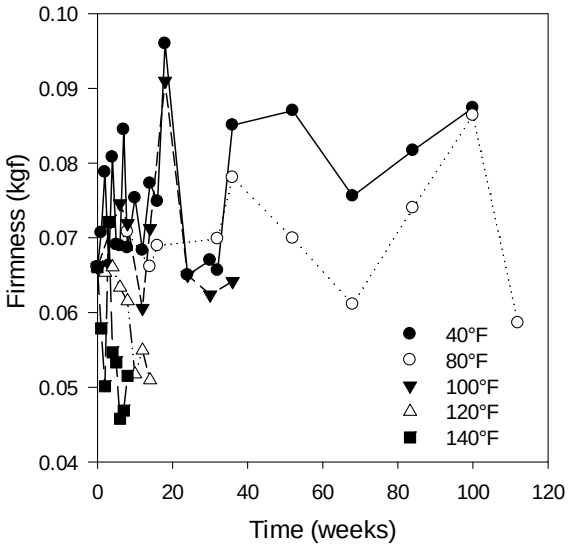


Figure 91. Changes in the texture of Applesauce during storage at 40, 80, 100, 120 and 140°F.

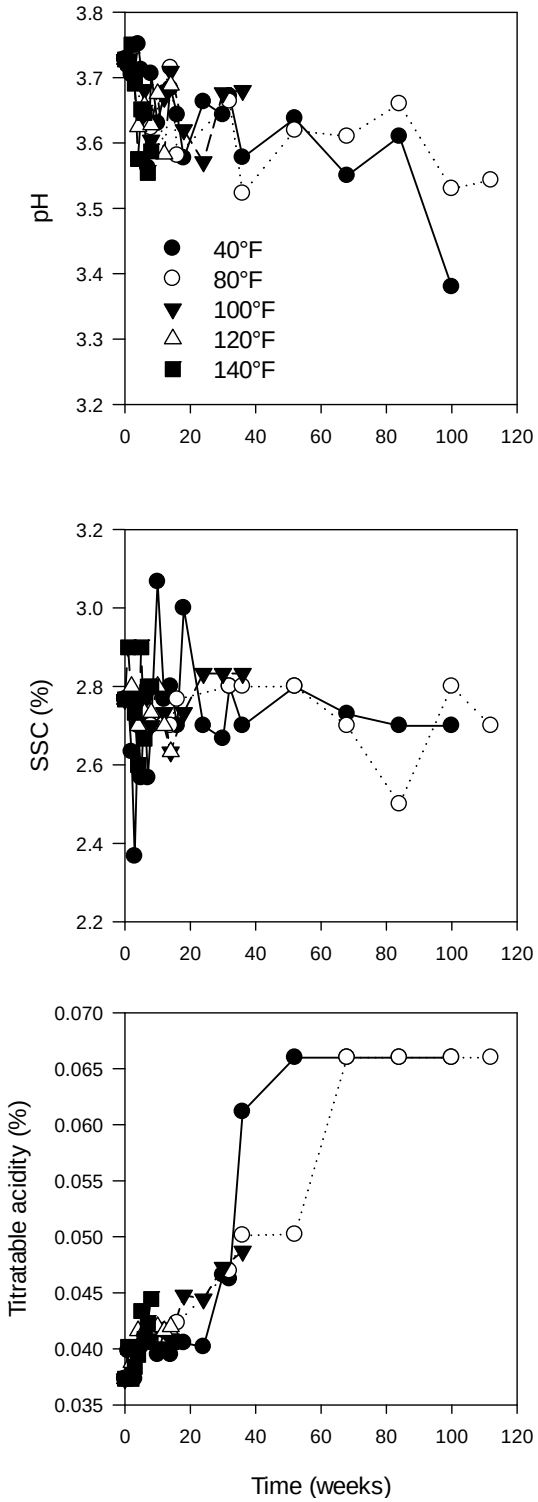


Figure 92. Changes in pH, titratable acidity and soluble solids contents of Applesauce during storage at 40, 80, 100, 120 and 140°F.

2.3.5.2 Compositional Analysis

Titratable Acidity, Soluble Solids Content and pH

The titratable acidity, soluble solids content and pH of Applesauce stored at different temperatures are shown in Figure 92. The pH showed a decreasing trend regardless of the storage temperature; while expectedly the titratable acidity showed an increasing trend during storage regardless of the temperature. Soluble solids content fluctuated inconsistently between temperatures, but changes were very slight; SSC of samples stored at 100 and 140°F increased by the end of the storage period while SSC decreased in samples stored at 40, 80 and 120°F.

Water Activity and Moisture Content

Water activity increased during storage regardless of temperature; however, samples stored at 140°F showed the fastest decrease in water activity compared to samples stored at other temperatures (Figure 93).

The moisture content of Applesauce decreased slightly for samples stored at 100°F or lower temperatures, but exposure to higher temperatures resulted in an increased moisture content (Figure 93). The possible reason for that could have been that bound water molecules became free and contributed to the increase in the total moisture content and also in water activity.

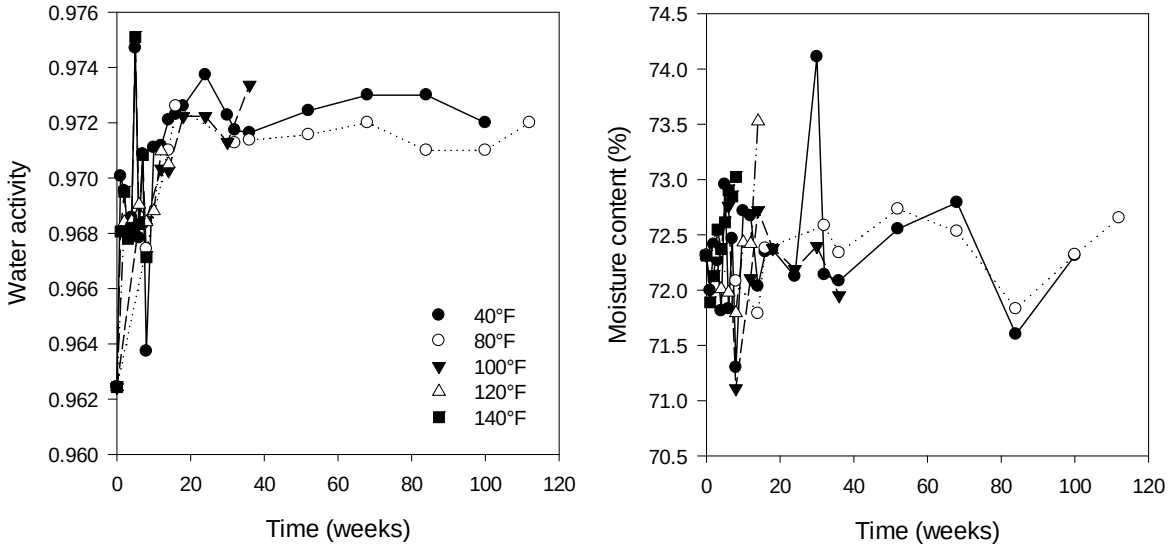


Figure 93. Changes in water activity and moisture content of Applesauce during storage at 40, 80, 100, 120 and 140°F.

Ascorbic Acid Content

The ascorbic acid (vitamin C) is a key compound as it not only prevents oxidation and browning reactions in food, but also contributes to vitamin C in the diet. In the case of Applesauce, it is added to increase the vitamin C content of the food. In this study, there were smaller changes (approximately 21%) in the amount of the ascorbic acid of samples stored at refrigerated

conditions (40°F) compared to those stored at higher temperatures (Figure 94). However, as the temperature increased, the degradation of total ascorbic acid during storage was striking. For example, after 14 weeks, the ascorbic acid content of Applesauce decreased by approximately 79% in samples stored at 120°F and by 93% in samples stored for eight weeks at 140°F.

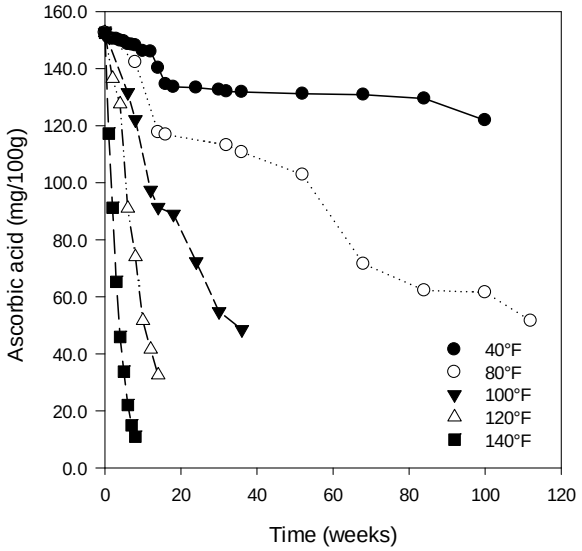


Figure 94. Ascorbic acid changes in Applesauce during storage at 40, 80, 100, 120 and 140°F.

Individual and Total Sugar Profiles

Sucrose levels decreased significantly, regardless of the storage temperature, due to the hydrolysis of this sugar into glucose and fructose (Figure 95). Glucose and fructose decreased in samples stored at 40 and 80°F but increased in samples stored at higher temperatures, possibly due to the accelerated hydrolytic metabolism. Applesauce is an FSR item enhanced in maltodextrin for increased performance; therefore initial levels are higher compared to commercial applesauce products. In this study, maltodextrin decreased over prolonged storage even at refrigerated or ambient conditions (40 and 80°F), remained practically constant after 36 weeks at 100°F and slightly increased in samples stored at 120 and 140°F. It is possible that the increase in maltodextrin in samples stored at higher temperatures might have been caused by the degradation of more complex carbohydrates such as pectin or starch, which are common compounds in apple products. Overall, the total sugar content decreased in samples stored at 40 and 80°F due to a reduction in sucrose, fructose and maltodextrin levels; remained constant in samples stored at 100°F and increased in samples stored at 120 and 140°F, due to the increase in simple sugars and maltodextrin.

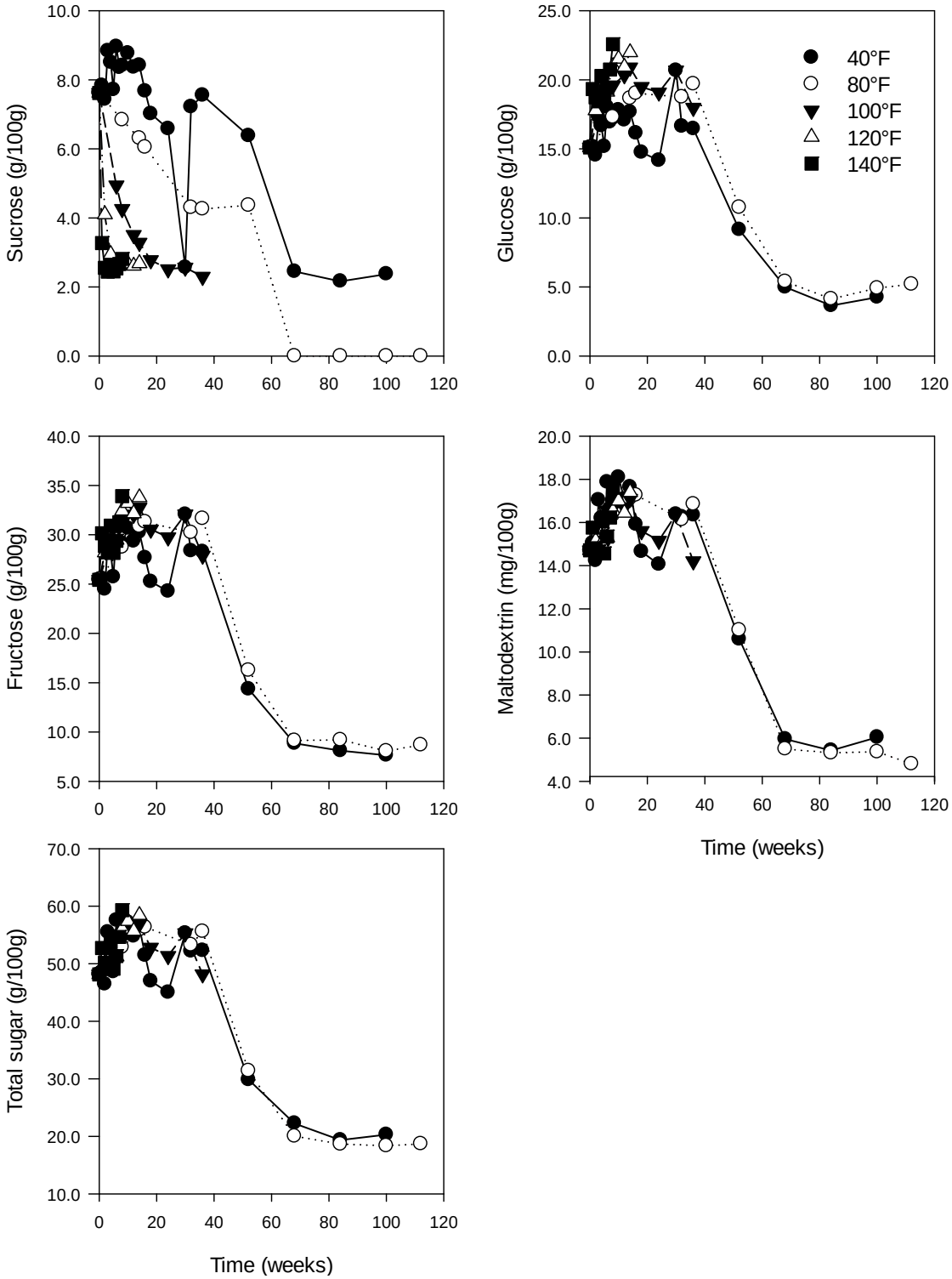


Figure 95. Changes in the sugar and maltodextrin contents of Applesauce during storage at 40, 80, 100, 120 and 140°F.

2.3.5.3 Summary Of The Results For Applesauce

Below is a summary of the changes that occurred in the appearance (Table 20) and in the different physical (Table 22) and compositional (Tables 23 and 24) attributes measured in Applesauce samples at the beginning and end of storage:

- L* value: increased for samples stored at 40, 80 and 100°F, and decreased for samples stored at 120 and 140°F. The increase in L* value might have been caused by sample variation.
- Chroma: decreased (duller color) for all temperatures.
- Hue: increased in samples stored at 40, 80 and 100°F, and decreased in samples stored at 120 and 140°F (deeper color).
- Texture: was approximately the same for samples stored at 40°F, and decreased (less consistent, more liquid texture) in samples stored at 80, 100, 120 and 140°F.
- pH: decreased for all temperatures.
- Acidity: increased in samples stored at 40, 80 and 100°F, and was approximately the same in samples stored at 120 and 140°F.
- Soluble solids content: decreased in samples stored at 40, 80 and 120°F, and increased in samples stored at 100 and 140°F.
- Moisture content: decreased in samples stored at 40, 80 and 100°F, and increased in samples stored at 120 and 140°F.
- Water activity: increased for all temperatures.
- Ascorbic acid: decreased for all temperatures.
- Sucrose: increased in samples stored at 40 and 80°F, and decreased in samples stored at 100, 120 and 140°F.
- Glucose: decreased for all temperatures.
- Fructose: increased for all temperatures.
- Total sugars: increased in samples stored at 40 and 80°F, and decreased in samples stored at 100, 120 and 140°F.
- Maltodextrin: decreased for all temperatures.

2.3.6 Italian-Style Sandwich

2.3.6.1 Physical Characteristics

Appearance and Color

As temperature increased, the color of Italian-Style Sandwich samples changed from a yellowish-white to dark brownish (Figure 96). Development of a dark brown color was very fast in samples stored at 140°F. After eight weeks the sandwiches looked very dark, as if they were toasted. At 120°F, the brown color development was less striking, but after 14 weeks the samples appeared much darker compared to the initial samples before storage. Color changes at lower temperatures were subtler, and by the end of storage, the color had only changed from a yellowish-white to a light brown.

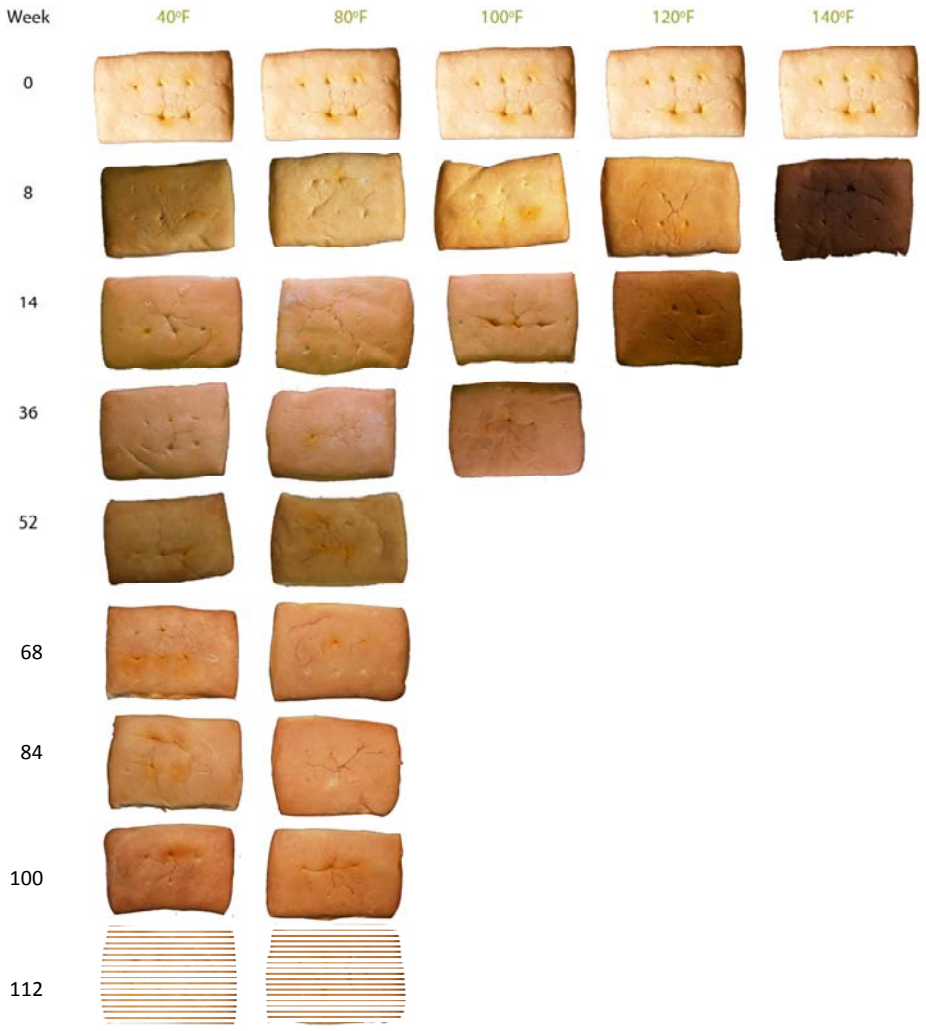


Figure 96. Changes in the appearance of Italian-Style Sandwich during storage at 40, 80, 100, 120 and 140°F.

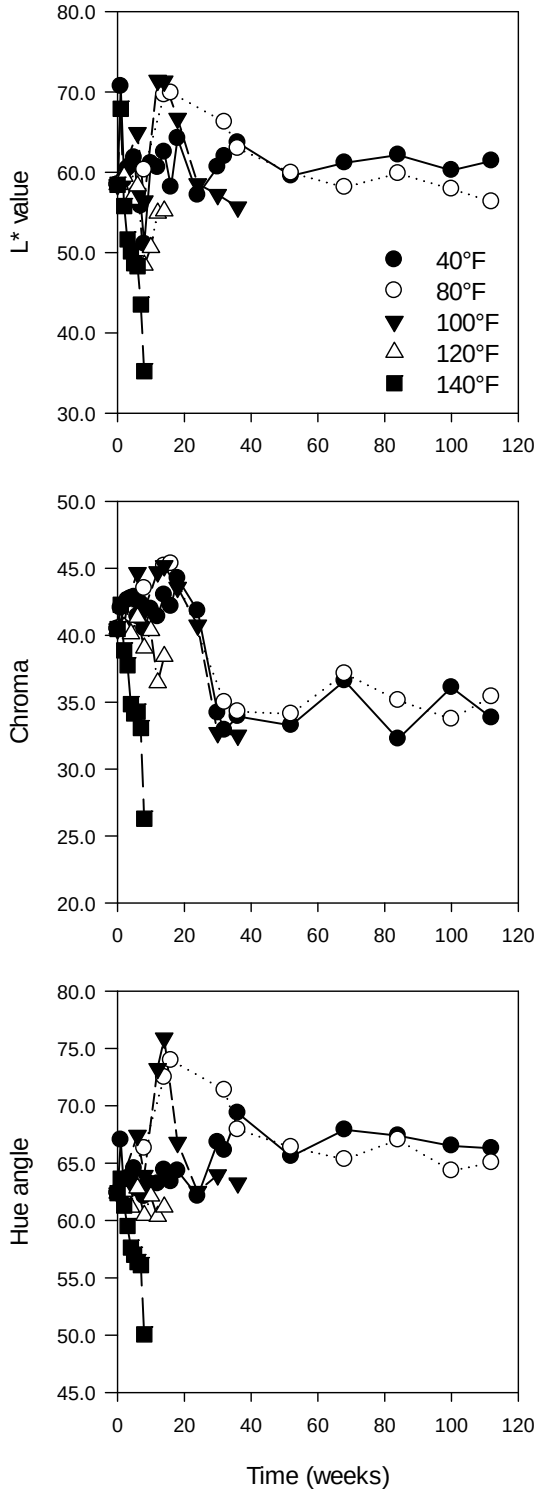


Figure 97. Changes in color attributes (L*, chroma and hue) of Italian-Style Sandwich during storage at 40, 80, 100, 120 and 140°F.

L* values decreased in samples stored at temperatures higher than 40°F, meaning that the sandwiches became darker, which confirms visual observations (Figure 97). In samples stored for 112 weeks at 40°F there was a slight increase in the L* values, but those were very close to the values measured initially. Chroma values decreased in all samples regardless of the storage temperature, meaning that by the end of each respective storage period samples appeared less vivid. Hue values decreased in samples stored at 120 and 140°F, meaning that the color of the sandwiches became dark brown. However, the hue tended to increase in samples stored at lower temperatures; but the increase in hue was slight, and by the end of storage there was not a marked difference between the initial hue values and those measured before storage.

Texture

Italian-Style Sandwich samples stored at refrigerated condition (40°F) were firmer even after 112 weeks than samples stored at higher temperatures (Figure 98). That could have been the result of dehydration of the sandwiches or an increase in firmness produced by cooler temperatures, even though the firmness of the samples was measured after conditioning all the samples at room temperature. As the temperature increased, the firmness decreased, due to softening of the samples exposed to elevated temperatures; however, when compared to initial values, the decrease in firmness was very slight.

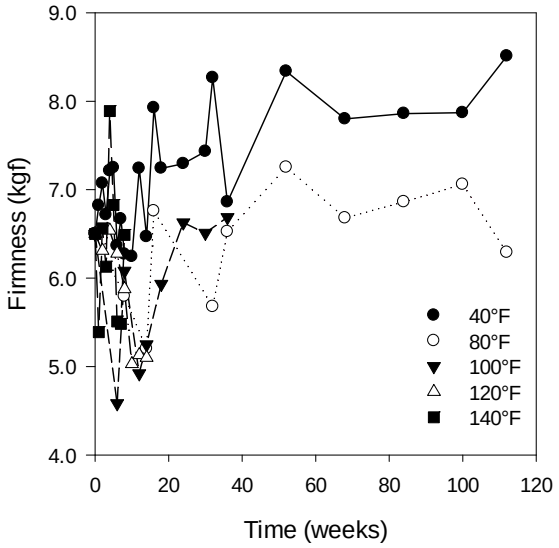


Figure 98. Changes in the firmness of Italian-Style Sandwich during a 112-week storage period at 40, 80, 100, 120 and 140°F.

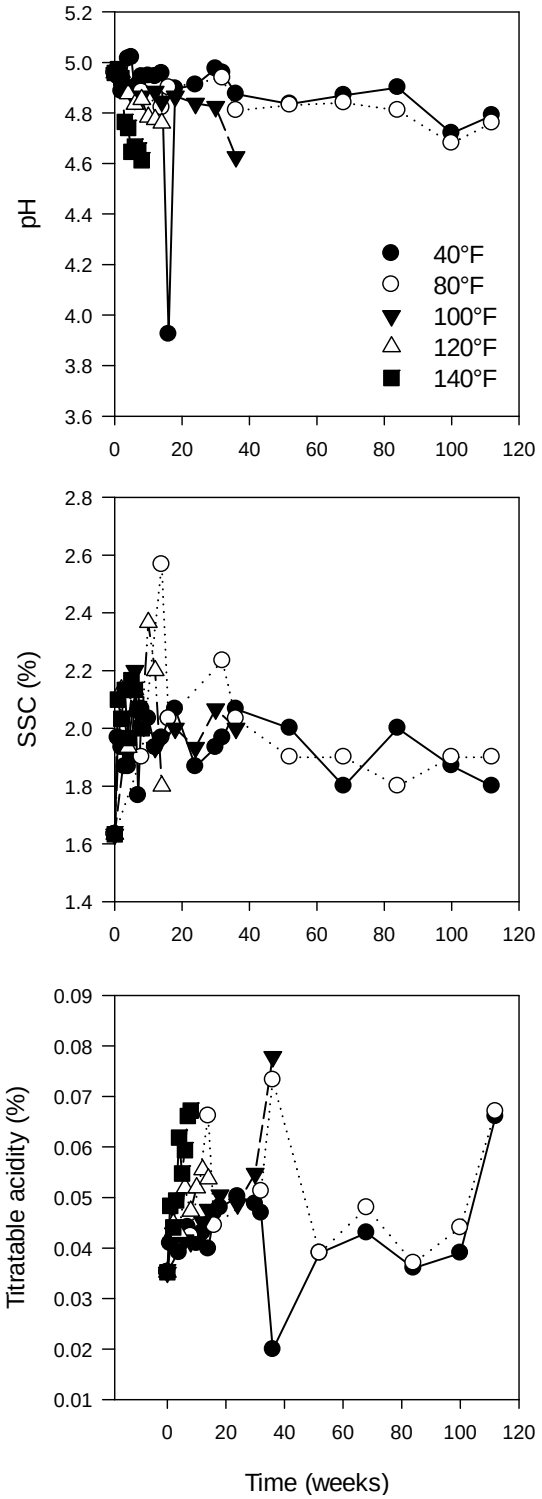


Figure 99. Changes in pH, titratable acidity and soluble solids content of Italian-Style Sandwich during a 112-week storage period at 40, 80, 100, 120 and 140°F.

3.3.6.2 Compositional Analysis

Titratable Acidity, Soluble Solids Content and pH

The pH of Italian-Style Sandwiches decreased during storage regardless of the temperature, whereas, as expected, the titratable acidity increased (Figure 99). Thus, by the end of each respective storage period the samples were more acidic than they were initially. Conversely, the soluble solids content increased regardless of the storage temperature, most likely because there were some complex carbohydrates that, due to time-temperature exposure, possibly broke down into simple carbohydrates (such as fructose and glucose), which are more soluble and contributed to an increase in the soluble solids content.

Water Activity and Moisture Content

Figure 100 shows the changes in water activity and moisture content for Italian-Style Sandwich stored at different temperatures. Water activity increased during storage regardless of temperature, most likely due to an increase in free-water. Moisture content showed an inconsistent trend and increased in samples stored at 80, 100 and 120°F, most likely due to an increase in free-water (increase in water activity), but slightly decreased in samples stored at 40 and 140°F. Although the decrease in moisture content was very minor, samples exposed at such opposite temperatures (refrigerated and extremely hot) might have been subjected to surface dryness either caused by hot or refrigerated temperatures.

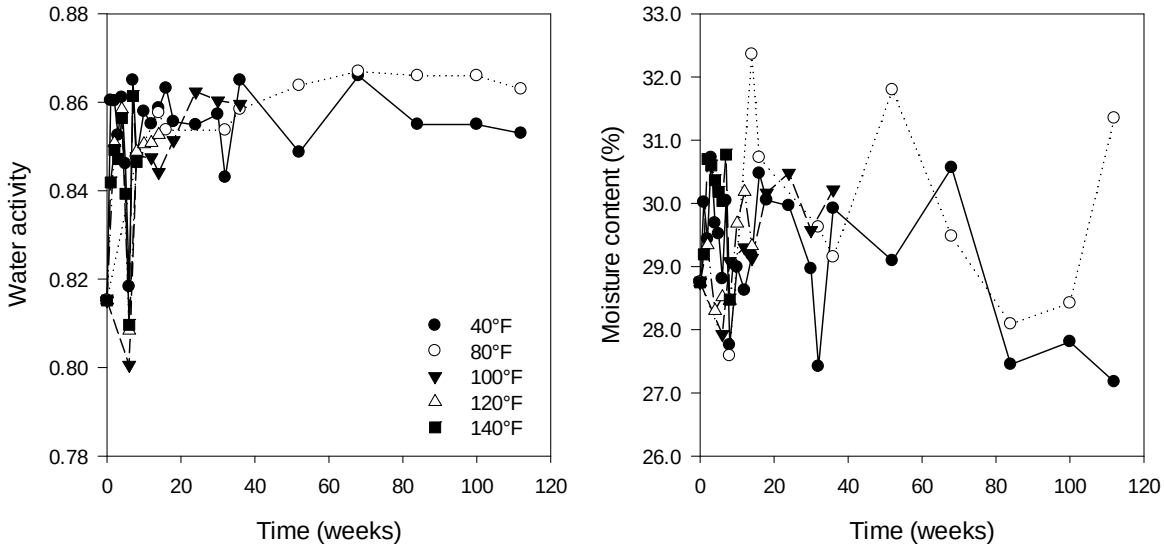


Figure 100. Changes in moisture content and water activity of Italian-Style Sandwich during a 112-week storage period at 40, 80, 100, 120 and 140°F.

Ascorbic Acid Content

Ascorbic acid (AA) content of Italian-Style Sandwich samples decreased during storage regardless of the temperature (Figure 101). After eight weeks, the AA content of samples stored at 140°F decreased by 37%, while in samples stored at 40 or 80°F, the decrease was

slightly lower (23%). However, as the length of storage increased, the AA degradation also increased. For example, in samples stored for 36 days at 120°F there was a decrease of about 46% in the initial AA content. At 40 and 80°F, the AA content was reduced by approximately 99 and 95%, respectively, after 112 weeks of storage. Similar to the results obtained for AA degradation during storage of Bacon Cheddar Sandwiches, if Italian-Style Sandwiches are to be kept at ambient temperatures (80°F), there will be only 5% AA retention after two years. Furthermore, the use of refrigeration temperature (40°F) does not seem to have an advantageous effect on AA retention for this type of food, since, after 112 weeks, the AA retention was only approximately 0.4%.

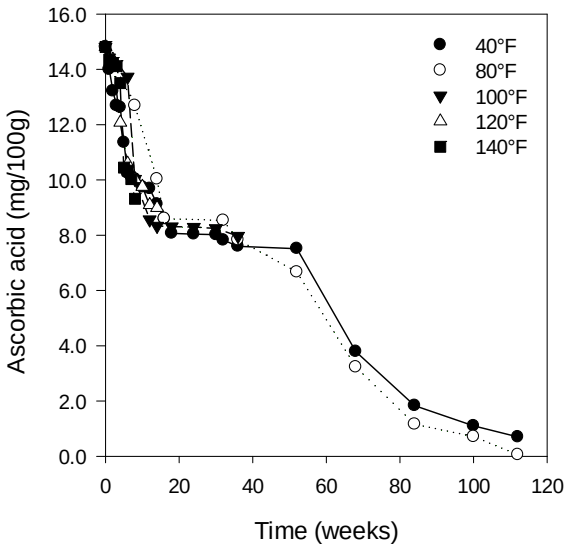


Figure 101. Changes in ascorbic acid content of Italian-Style Sandwich during a 112-week storage period at 40, 80, 100, 120 and 140°F.

Individual and Total Sugar Profiles

The sucrose content decreased in samples stored at 40, 80 and 140°F and slightly increased in samples stored at 100 and 120°F (Figure 102). Conversely, glucose increased in samples stored at 40 and 80°F and decreased in samples stored at higher temperatures. Fructose and maltodextrin both increased in samples stored at 140°F and decreased in all other samples stored at lower temperatures. Overall, total sugars decreased in samples stored at 140°F and increased in samples stored at lower temperatures. This could have been the result of the degradation of sugars when exposed to high temperatures.

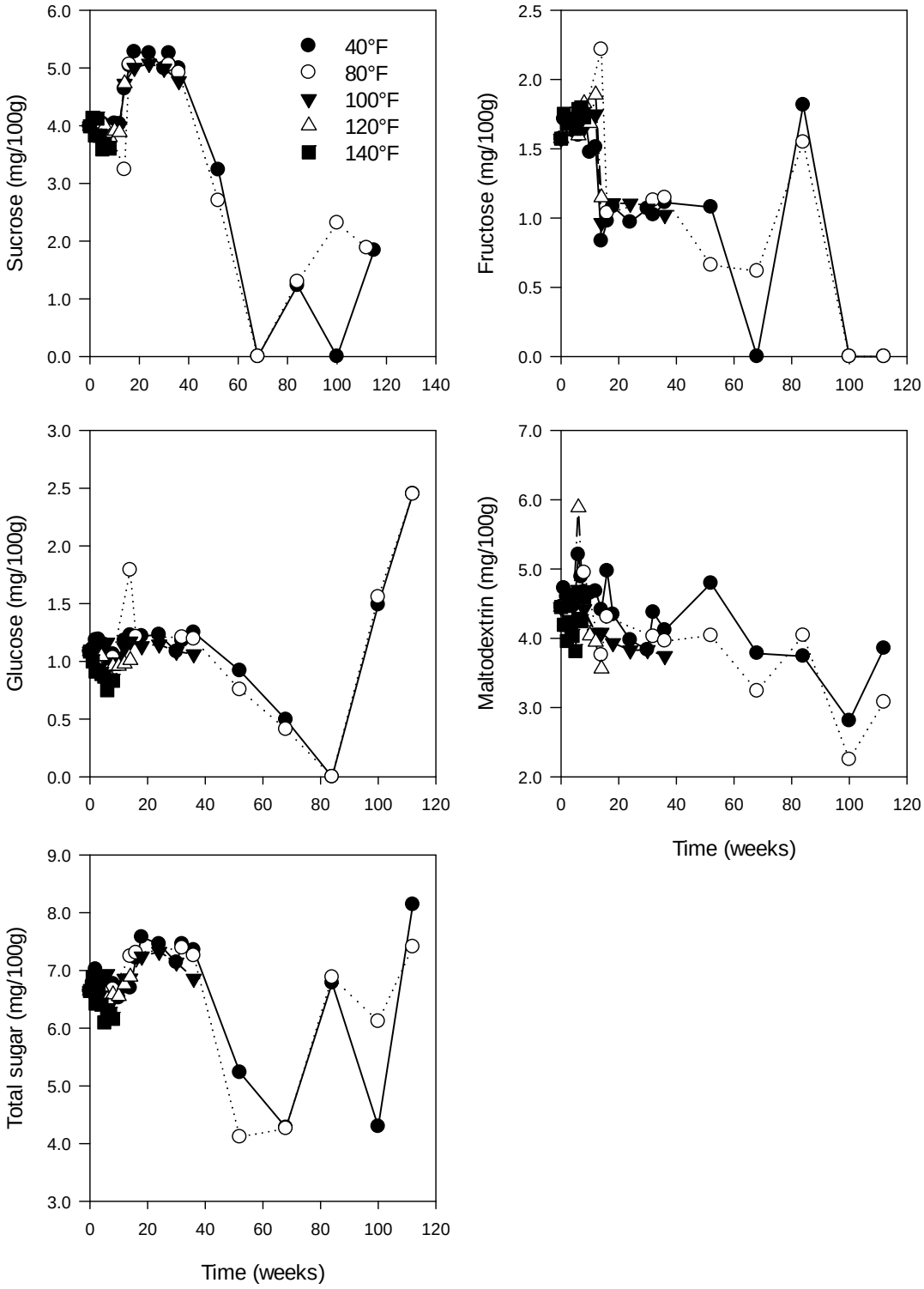


Figure 102. Changes in the sugar and maltodextrin contents of Italian-Style Sandwich during storage at 40, 80, 100, 120 and 140°F.

Lipid Oxidation

The degree of lipid oxidation was measured using the peroxide value (PV) assay to monitor the primary oxidation products formed. There were two types of sampling methods applied to this product: the whole sandwich or the meat part of the sandwich, which were used to measure the level of peroxide value during storage at 40, 80, 100, 120 and 140°F (Figure 103). The results showed that the PV increased in the meat part of the sandwich regardless of the temperature; however, the highest increase was seen after eight weeks in samples stored at 40°F or after 112 weeks in samples stored at 40 and 80°F. Therefore, exposure time also seems to have a significant effect on the increase in the PV of the samples even if stored at refrigerated or ambient temperatures. The PV measured in the whole sandwich was not as consistent as that measured in the meat only; it decreased in samples stored at 80, 100 and 140°F and increased in samples stored at 40 and 120°F. Nevertheless, for Italian-Style Sandwich the lipid oxidation was not found to be critical, regardless of storage temperature and duration, considering a range of 7–30 meq/kg as the limit of acceptability reported in the literature for different foods (in Materials and Methods).

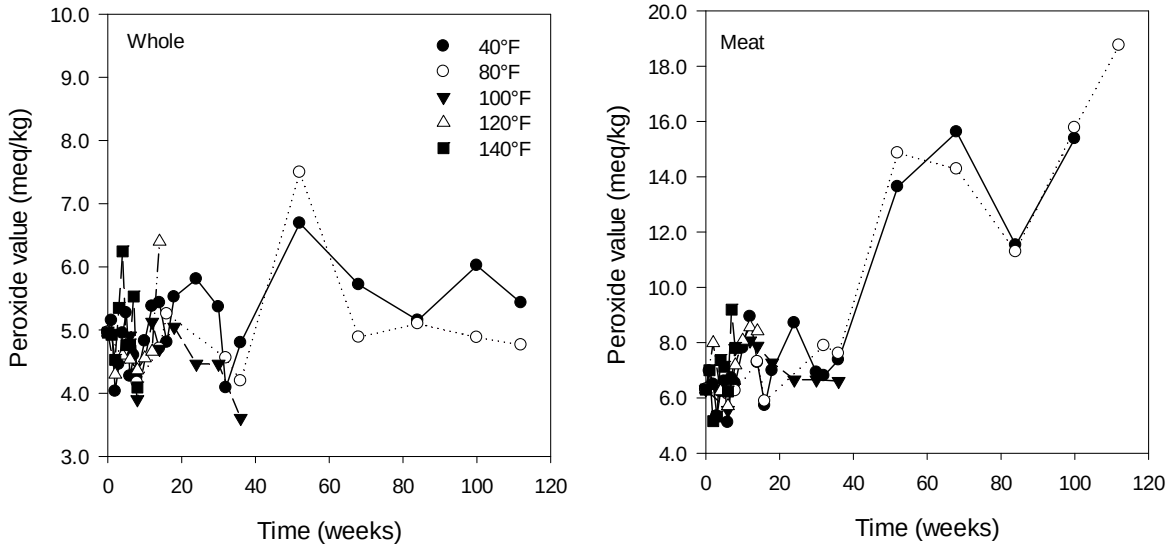


Figure 103. Changes in the peroxide value in the whole Italian-Style Sandwich and meat only during storage at 40, 80, 100, 120 and 140°F.

2.3.6.3 Summary Of The Results For Italian-Style Sandwich

Below is a summary of the changes that occurred in the appearance (Table 21) and in the different physical (Table 22) and compositional (Tables 23 and 24) attributes measured in Italian-Style Sandwich samples at the beginning and end of storage:

- L* value: increased for samples stored at 40°F, and decreased for samples stored at 80, 100, 120 and 140°F.
- Chroma: decreased (duller color) for all temperatures.
- Hue: increased in samples stored at 40, 80 and 100°F, and decreased in samples stored at 120 and 140°F (deeper color).
- Texture: increased in samples stored at 40°F, and decreased in samples stored at 80, 100, 120 and 140°F.
- pH: decreased for all temperatures.
- Acidity: increased for all temperatures.
- Soluble solids content: increased for all temperatures.
- Moisture content: increased in samples stored at 40, 80, 100 and 120°F, and decreased in samples stored at 140°F.
- Water activity: increased for all temperatures.
- Ascorbic acid: decreased for all temperatures.
- Sucrose: decreased in samples stored at 40, 80 and 140°F, and increased in samples stored at 100 and 120°F.
- Glucose: increased in samples stored at 40 and 80°F, and decreased in samples stored at 100, 120 and 140°F.
- Fructose: decreased in samples stored at 40, 80, 100 and 120°F, and increased in samples stored at 140°F.
- Total sugars: increased in samples stored at 40, 80 100 and 120°F, and decreased in samples stored at 140°F.
- Maltodextrin: decreased in samples stored at 40, 80, 100 and 120°F, and increased in samples stored at 140°F.
- Peroxide value measure in the whole sandwich: increased in samples stored at 40 and 120°F, and decreased in samples stored at 80, 100 and 140°F.
- Peroxide value measured in the meat part of the sandwich: increased for all temperatures.

2.3.7 Tortillas

2.3.7.1 Physical Characteristics

Appearance and Color

The visual color of the Tortillas samples changed from a light-yellowish color with some brown spots to a darker-brown color (Figure 104). The brown color development was faster and more intense in samples stored at 120 and 140°F than in samples stored at lower temperatures. After eight weeks, samples stored at 140°F developed a dark brown coloration as if the tortillas had been toasted. The color of samples stored at 40 and 80°F also changed but never developed a toasted-like appearance like that of samples stored at higher temperatures.

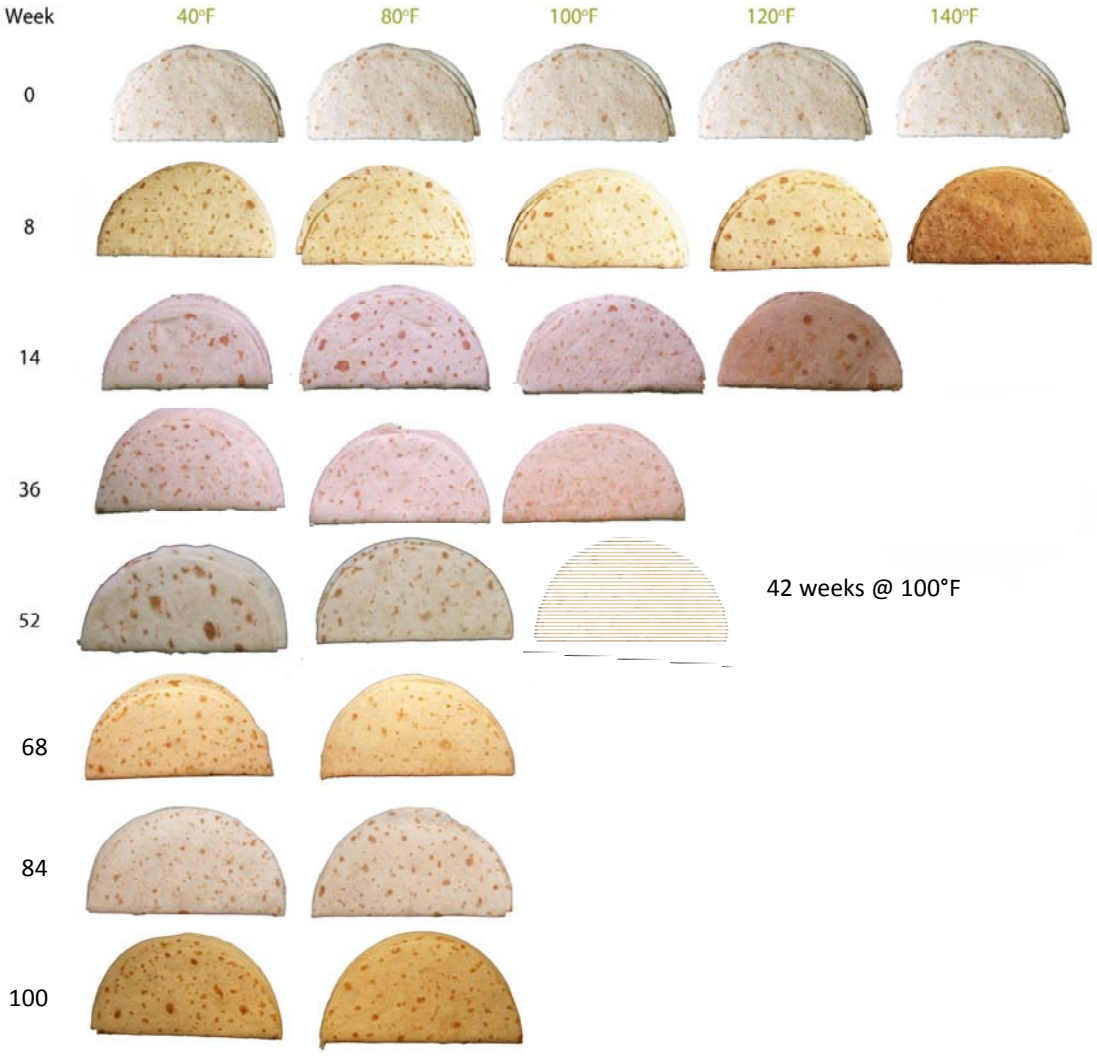


Figure 104. Changes in the appearance of Tortillas during storage at 40, 80, 100, 120 and 140°F.

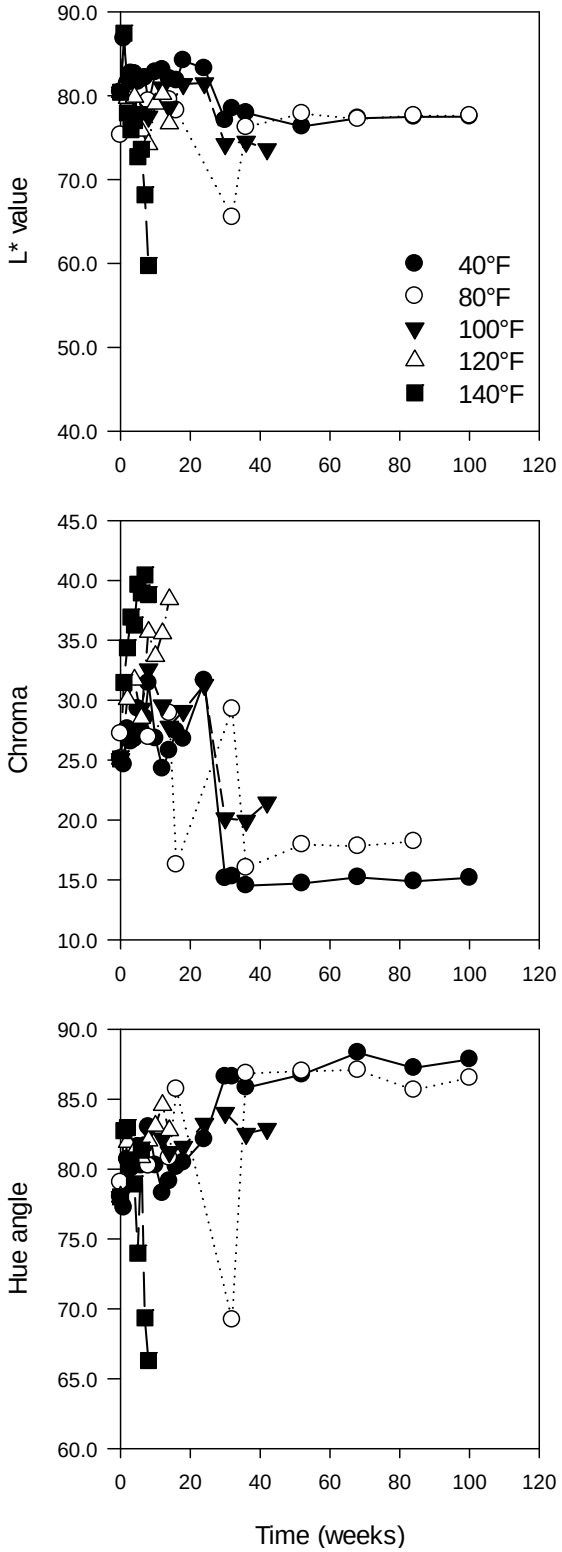


Figure 105. Changes in color attributes (L*, chroma and hue) of Tortillas during storage at 40, 80, 100, 120 and 140°F.

The L* value of Tortillas decreased regardless of the temperature (Figure 105). Extreme temperature conditions (120 and 140°F) considerably decreased the L* values when compared with ambient (80°F) and refrigerated conditions (40°F). Chroma values increased in samples stored at 120 and 140°F, most likely as a result of darkening of the color. However, the chroma decreased in samples stored at 40, 80 and 100°F, probably due to superficial dryness and development of a duller color (lower chroma) (Figure 105). The hue angle value significantly decreased in samples stored at 140°F because the color turned darker after eight weeks, yet the hue angle values slightly increased in samples stored at lower temperatures (Figure 105).

Texture

After eight weeks, Tortilla samples store at refrigerated condition (40°F) showed higher firmness values than those stored at higher temperatures (Figure 106). Exposure to extreme temperature conditions (100, 120 and 140°F) contributed to a considerable decrease in the firmness of the samples. The firmness of samples stored at 80°F slightly decreased, whereas there was a slight increase in firmness of the samples stored for 100 weeks at 40°F. Such increase in firmness might have resulted from loss of moisture and desiccation of the tortillas.

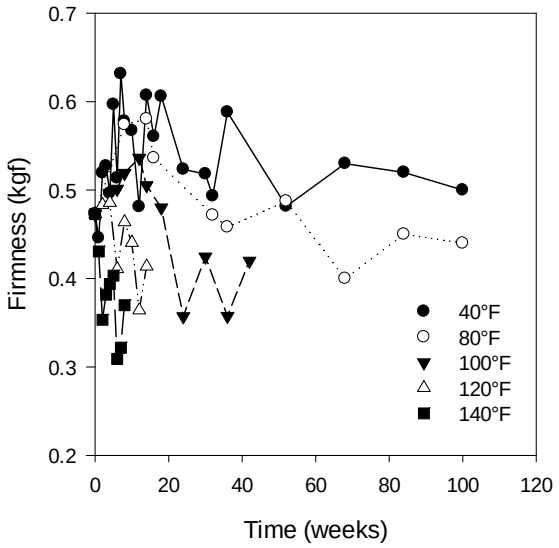


Figure 106. Changes in the texture of Tortillas during storage at 40, 80, 100, 120 and 140°F.

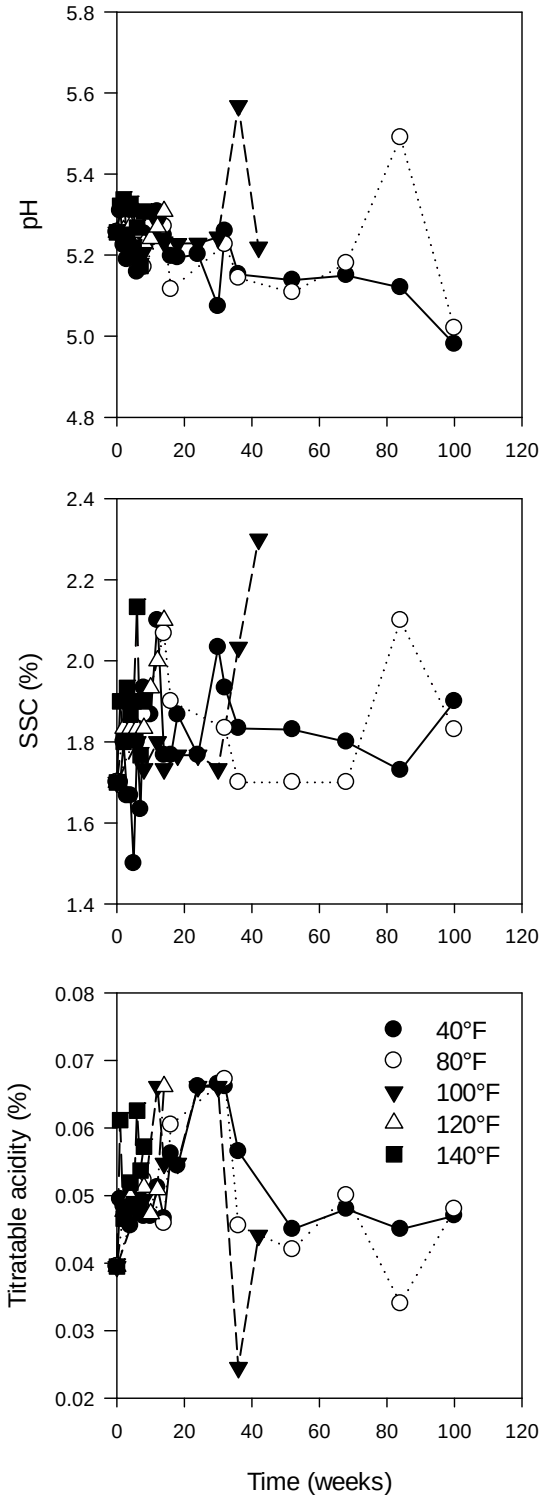


Figure 107. Changes in titratable acidity, soluble solids content and pH of Tortillas during storage at 40, 80, 100, 120 and 140°F.

2.3.7.2 Compositional Analysis

Titratable Acidity, Soluble Solids Content and pH

The titratable acidity, soluble solids content and pH of Tortillas stored at different temperatures are shown in Figure 107. In samples stored at 120 and 140°F, pH values tended to increase with time, whereas in samples stored at lower temperatures pH decreased. There was a marked increase in the titratable acidity of samples stored at 120 and 140°F, a slight increase in samples stored at 40 and 80°F and practically no change in the acidity of samples stored for 42 weeks at 100°F (Figure 107). The soluble solids content increased regardless of the storage temperature, but the highest increase was measured in samples stored for 42 weeks at 100°F.

Water Activity and Moisture Content

Changes in water activity and moisture content for Tortillas stored at different temperatures are shown in Figure 108. The values for water activity and moisture content fluctuated regardless of storage time or temperature. However, by the end of each respective storage period, water activity increased, whereas moisture content decreased, regardless of the storage temperature. Therefore, tortilla samples tended to dry during storage regardless of the temperature.

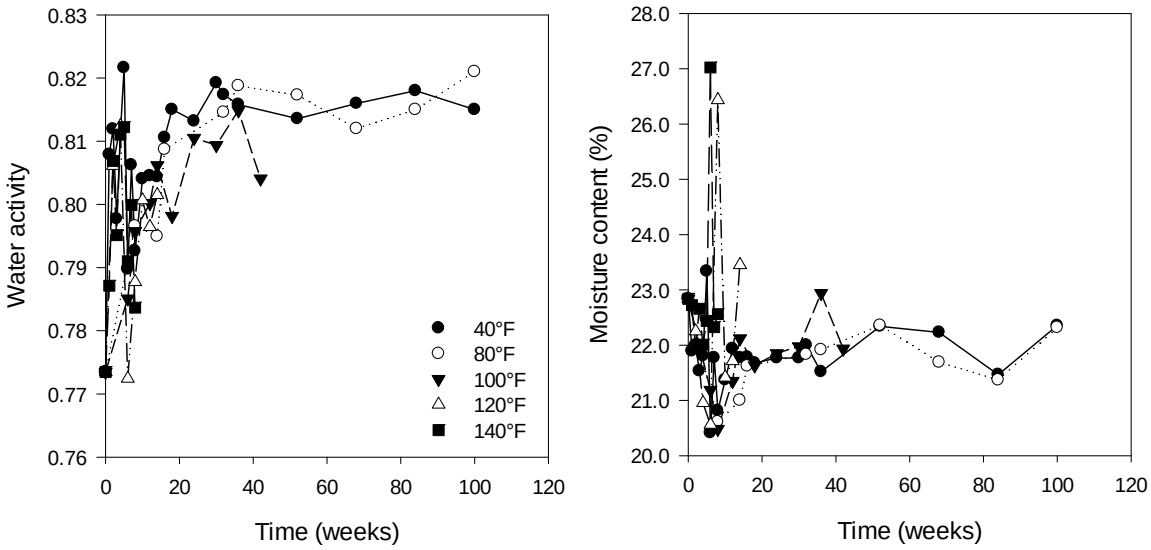


Figure 108. Changes in water activity and moisture content of Tortillas during storage at 40, 80, 100, 120 and 140°F.

Individual and Total Sugar Profiles

The results for the sugar profiles in Tortillas samples are shown in Figure 109. There were no initial detectable levels of glucose in samples of Tortillas, and its levels did not increase regardless of the storage temperature or storage duration. Sucrose and maltodextrin contents decreased during storage regardless of the temperature, whereas fructose levels increased in samples stored at 140°F and decreased in samples stored at lower temperatures. There were

no great changes in the total sugar contents of Tortillas, but overall there was a slight increase in samples stored at 40 and 80°F and a slight decrease in samples stored at higher temperatures. Sugar levels tended to decrease initially but then increased by the end of storage, particularly sucrose and fructose, whereas maltodextrin levels decreased toward the end of storage. The increase in sucrose and fructose might have resulted from hydrolysis of maltodextrin into simple sugars such as sucrose and fructose.

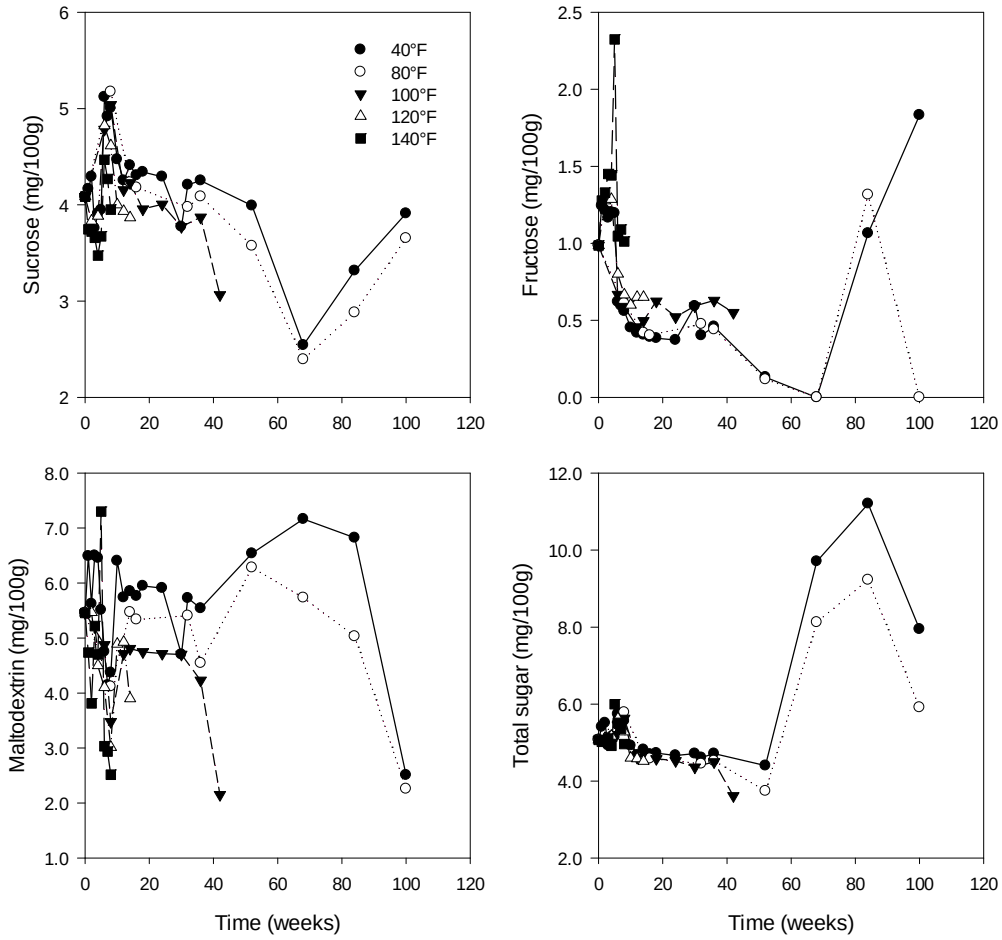


Figure 109. Changes in the sugar and maltodextrin contents of Tortillas during storage at 40, 80, 100, 120 and 140°F.

Lipid Oxidation

The magnitude of lipid oxidation was measured using peroxide value (PV) assay to monitor the primary oxidation products formed in storage at 40, 80, 100, 120 and 140°F. The degree of lipid oxidation fluctuated regardless of the storage time or temperature (Figure 110). The results showed that, after storage, the level of lipid oxidation in Tortillas samples were low for all temperatures. Therefore the lipid oxidation was not found to be critical for Tortillas, considering a range of 7–30 meq/kg as the limit of acceptability reported in the literature for different foods (in Materials and Methods). However, the levels of PV tended to increase during

storage regardless of the temperature. In samples stored at 40 and 80°F, the PV initially decreased but after 52 weeks increased.

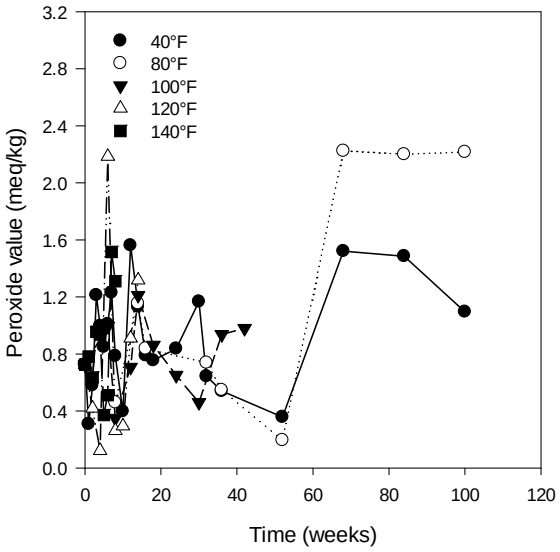


Figure 110. Changes in the peroxide value of Tortillas during storage at 40, 80, 100, 120 and 140°F.

2.3.7.3 Summary Of The Results For Tortillas

Below is a summary of the changes that occurred in the appearance (Table 21) and in the different physical (Table 22) and compositional (Tables 23 and 24) attributes measured in Tortillas samples at the beginning and end of storage:

- L* value: decreased for all temperatures.
- Chroma: decreased in samples stored at 40, 80 and 100°F, and increased in samples stored at 120 and 140°F.
- Hue: increased in samples stored at 40, 80, 100 and 120°F, and decreased in samples stored at 140°F (deeper color).
- Texture: increased in samples stored at 40°F, and decreased in samples stored at 80, 100, 120 and 140°F.
- pH: decreased for all temperatures.
- Acidity: increased in samples stored at 40, 80, 120 and 140°F, and changed slightly from the initial values in samples stored at 100°F.
- Soluble solids content: increased in samples stored at 40, 80, 100 and 140°F, and decreased in samples stored at 120°F.
- Moisture content: decreased for all temperatures.
- Water activity: increased for all temperatures.
- Sucrose: decreased for all temperatures.
- Glucose: no glucose was detected.

- Fructose: increased in samples stored at 40 and 140°F, and decreased in samples stored at 80, 100 and 120°F.
- Total sugars: increased in samples stored at 40 and 80°F, and decreased in samples stored at 100, 120 and 140°F.
- Maltodextrin: decreased for all temperatures.
- Peroxide value: increased in samples stored at 40, 80 and 120°F, and decreased in samples stored at 100 and 140°F.

2.3.8 Honey BBQ Beef Sandwich

2.3.8.1 Physical Characteristics

Appearance and Color

In general, as the temperature and storage time increased, sandwich samples became darker, with the color changing from a light yellowish-brown to a darker brown (Figure 111). A dark toasted-like brown color developed in samples stored for eight weeks at 140°F and after 14 weeks at 120°F. The color of samples stored at lower temperatures also changed from a light to a more brownish color, but the color remained lighter than the color of samples stored at higher temperatures.

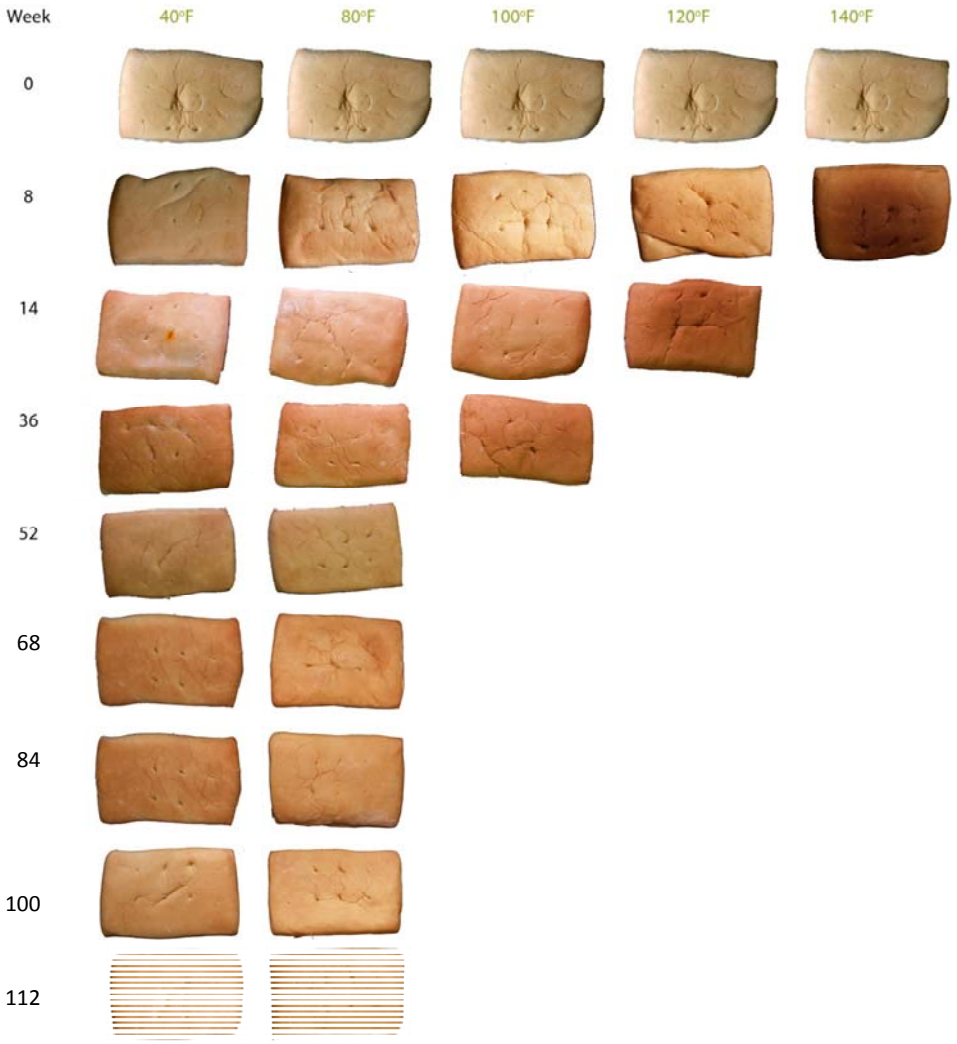


Figure 111. Changes in the appearance of Honey BBQ Beef Sandwich during storage at 40, 80, 100, 120 and 140°F.

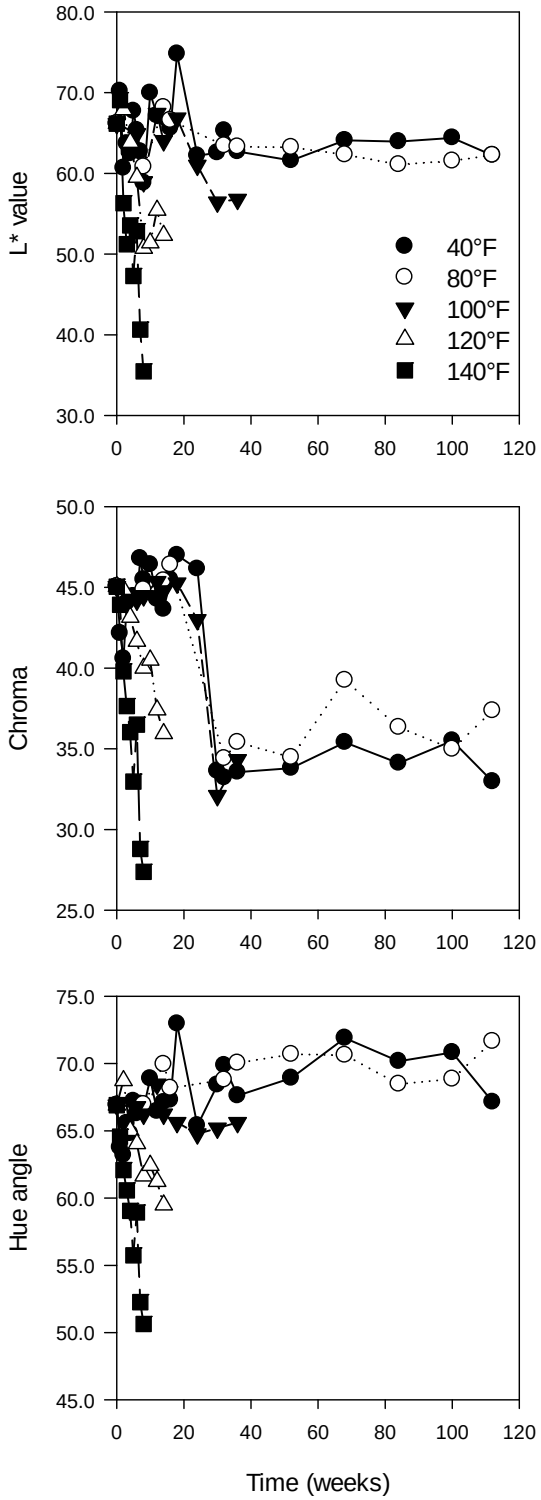


Figure 112. Changes in color attributes (L*, chroma and hue) of Honey BBQ Beef Sandwich during storage at 40, 80, 100, 120 and 140°F.

L* values decreased (darkening) during storage regardless of the storage temperature (Figure 112). However, decreases in L* values were more accentuated in samples stored at 100, 120 and 140°F. For example, the L* value of samples stored at 140°F decreased by about 47% after eight weeks when the sample color became very dark brown. Similarly, chroma values decreased during storage regardless of the temperature, meaning that by the end of each storage period the color of the sandwiches appeared less vivid. Hue angle values decreased in samples stored at 120 and 140°F (more dark brown color) but increased in samples stored at lower temperatures.

Texture

After eight weeks of storage, Honey BBQ Beef Sandwich samples stored at high temperatures (120 and 140°F) showed a considerable decrease in firmness values when compared with samples stored at other temperatures (Figure 113). At the end of each storage period, samples stored at 120 and 140°F were less firm than at the beginning of storage, whereas samples stored at lower temperatures were slightly firmer. A possible explanation for the differences in texture is that samples stored at high temperatures lost their moisture faster than those stored at lower temperatures and became softer. Even though samples stored at lower temperatures also lost moisture during storage, the process was slower and therefore, instead of softening, there was instead a desiccation of the tissues.

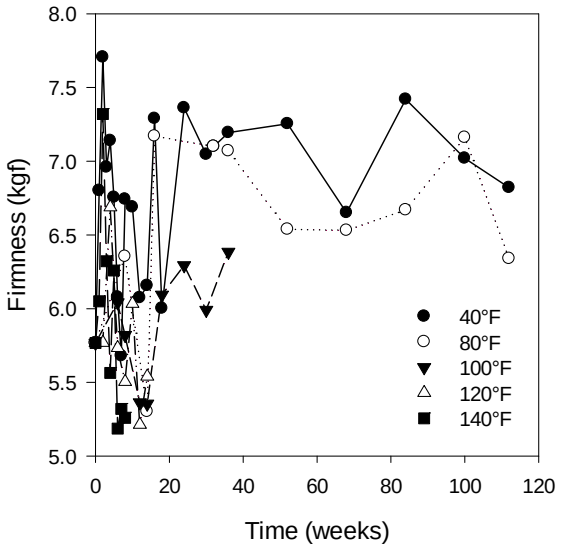


Figure 113. Changes in the texture of Honey BBQ Beef Sandwich during storage at 40, 80, 100, 120 and 140°F.

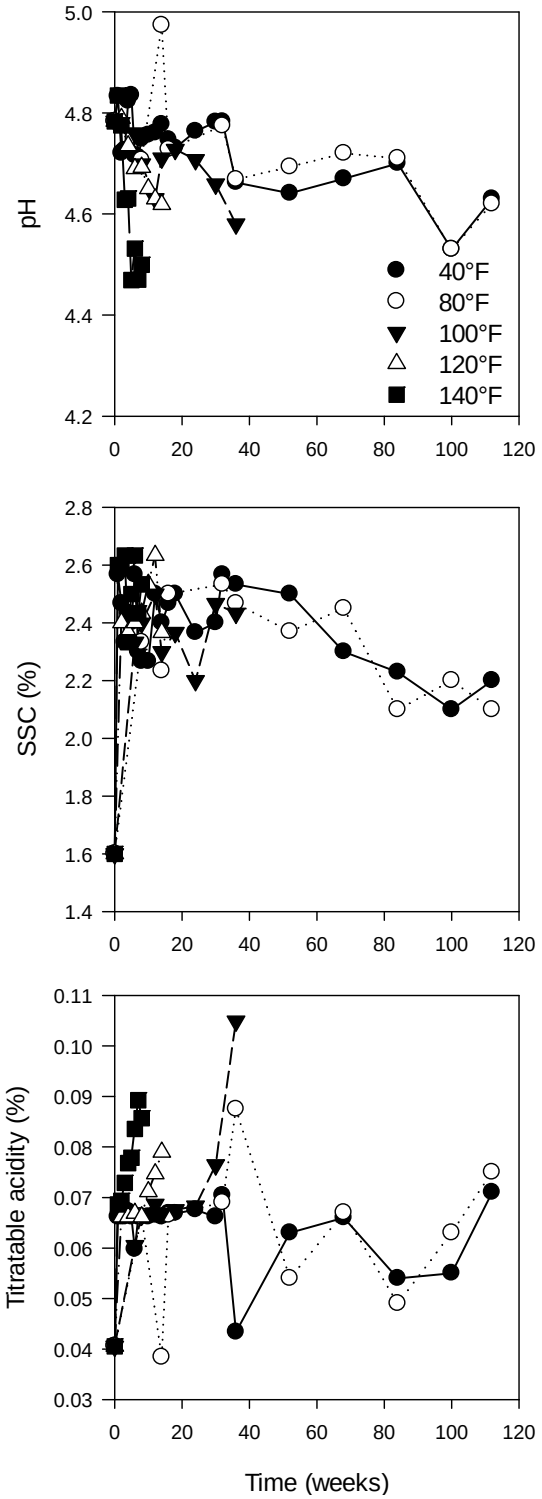


Figure 114. Changes in pH, titratable acidity and soluble solids content of Honey BBQ Beef Sandwich during storage at 40, 80, 100, 120 and 140°F.

2.3.8.2 Compositional Analysis

Titratable Acidity, Soluble Solids Content and pH

The pH of Honey BBQ Beef Sandwich decreased during storage regardless of the temperature (Figure 114). However, a faster and higher decrease was observed for samples stored for eight weeks at 140°F, whereas samples stored at 40°F showed the least decrease. Titratable acidity increased during storage regardless of the temperature. However, samples stored for eight weeks at 140°F showed an increase in acidity of about 110%, whereas acidity increased by about 78% in samples stored for 112 weeks at 40 or 80°F. The soluble solids content increased regardless of the temperature, most likely due to the increase in some of the simple sugars, such as fructose and glucose. However, the increase was greater in samples stored at 140°F than those stored at lower temperatures.

Water Activity and Moisture Content

Changes in water activity and moisture content for the Honey BBQ Beef Sandwich stored at different temperatures (40, 80, 100, 120 and 140°F) are shown in Figure 115. Water activity slightly increased during storage regardless of the temperature; however, at the end of each respective storage period, there was no difference in the water activity between samples stored at 40, 80 or 100°F (0.86), and there was also no difference in the water activity between samples stored at 120 and 140°F (0.85). Moisture content decreased regardless of the storage temperature (Figure 115), but the decrease was faster in samples stored at high temperatures. For example, after eight weeks there was a decrease of about 8% in the moisture content of the samples stored at 140°F, whereas it took about 112 weeks for samples stored at 40°F to lose about the same amount of water.

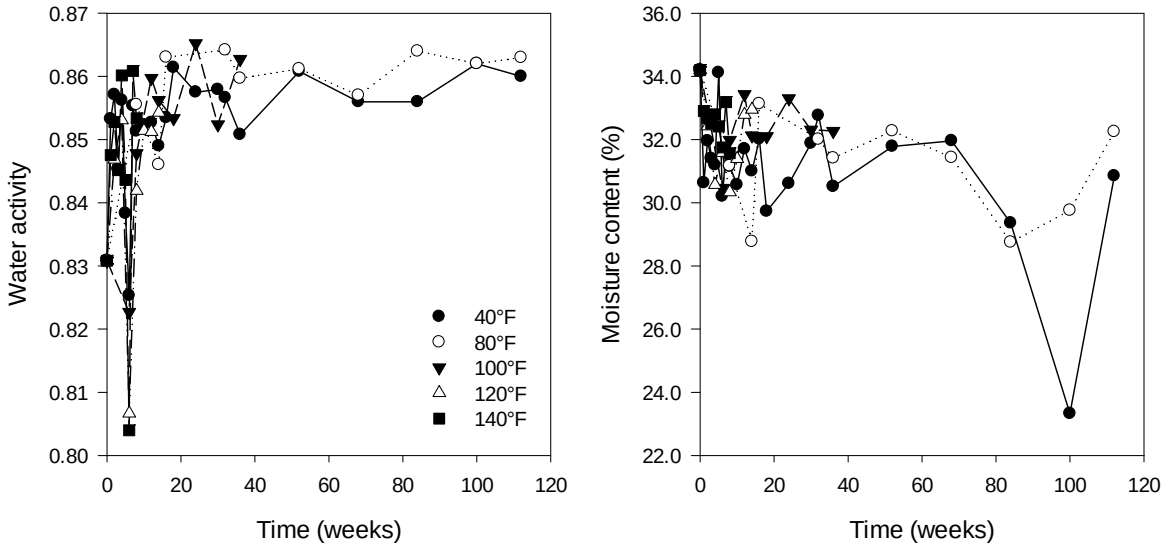


Figure 115. Changes in moisture content and water activity of Honey BBQ Beef Sandwich during storage at 40, 80, 100, 120 and 140°F.

Ascorbic Acid Content

Similar to the results obtained for the two other types of sandwiches (Italian-Style and Bacon Cheddar), the ascorbic acid (AA) content of Honey BBQ Beef Sandwich decreased during storage regardless of the temperature (Figure 116). After eight weeks, the AA content of samples stored at 140°F decreased by 24%. As the length of storage increased, the AA degradation also increased. For example, in samples stored for 36 days at 120°F there was a decrease of about 42% in the initial AA content. After 112 weeks of storage at 40 and 80°F, the AA content was reduced by approximately 95 and 93%, respectively. Similar to the results obtained for AA degradation during storage of the two other types sandwiches, if Honey BBQ Beef Sandwiches are to be kept at ambient temperatures (80°F), there will be only 7% AA retention after two years.

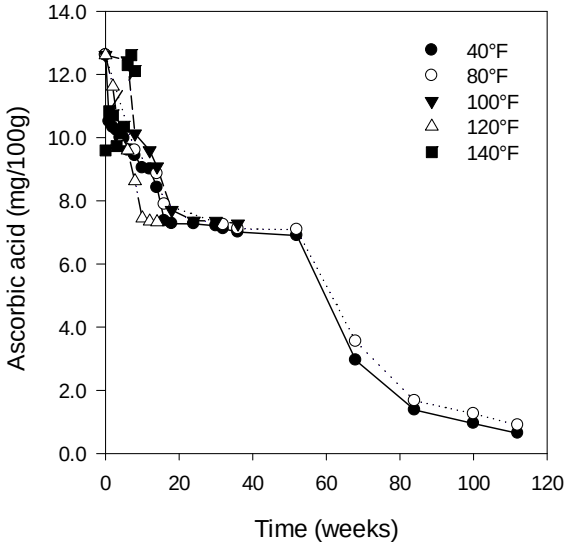


Figure 116. Changes in ascorbic acid content of Honey BBQ Beef Sandwich during storage at 40, 80, 100, 120 and 140°F.

Individual and Total Sugar Profiles

Changes in sucrose, fructose, glucose, total sugars and maltodextrin contents for Honey BBQ Beef Sandwich during storage at 40, 80, 100, 120 and 140°F are shown in Figure 117. The sucrose content decreased regardless of the storage temperature; however, the decrease in sucrose was faster in samples stored at 140°F. Changes in fructose and glucose did not show a consistent trend with temperature increase. Therefore, the fructose content decreased in samples stored at 100 and 120°F but increased in those stored at 40, 80 and 140°F. The glucose content increased in samples stored at 40, 80 and 100°F but decreased in those stored at 120 and 140°F. In general, the total sugar content tended to decrease except for samples stored at 80°F. The decrease in total sugar content was most likely due to a decrease in sucrose content. The maltodextrin content also decreased during storage regardless of the temperature, but the decrease was less accentuated than that observed for sucrose content. For example, it is

possible that the increase in fructose and glucose observed for samples stored for 112 weeks at 40 and 80°F might have resulted from the breakdown of maltodextrin into simple sugars.

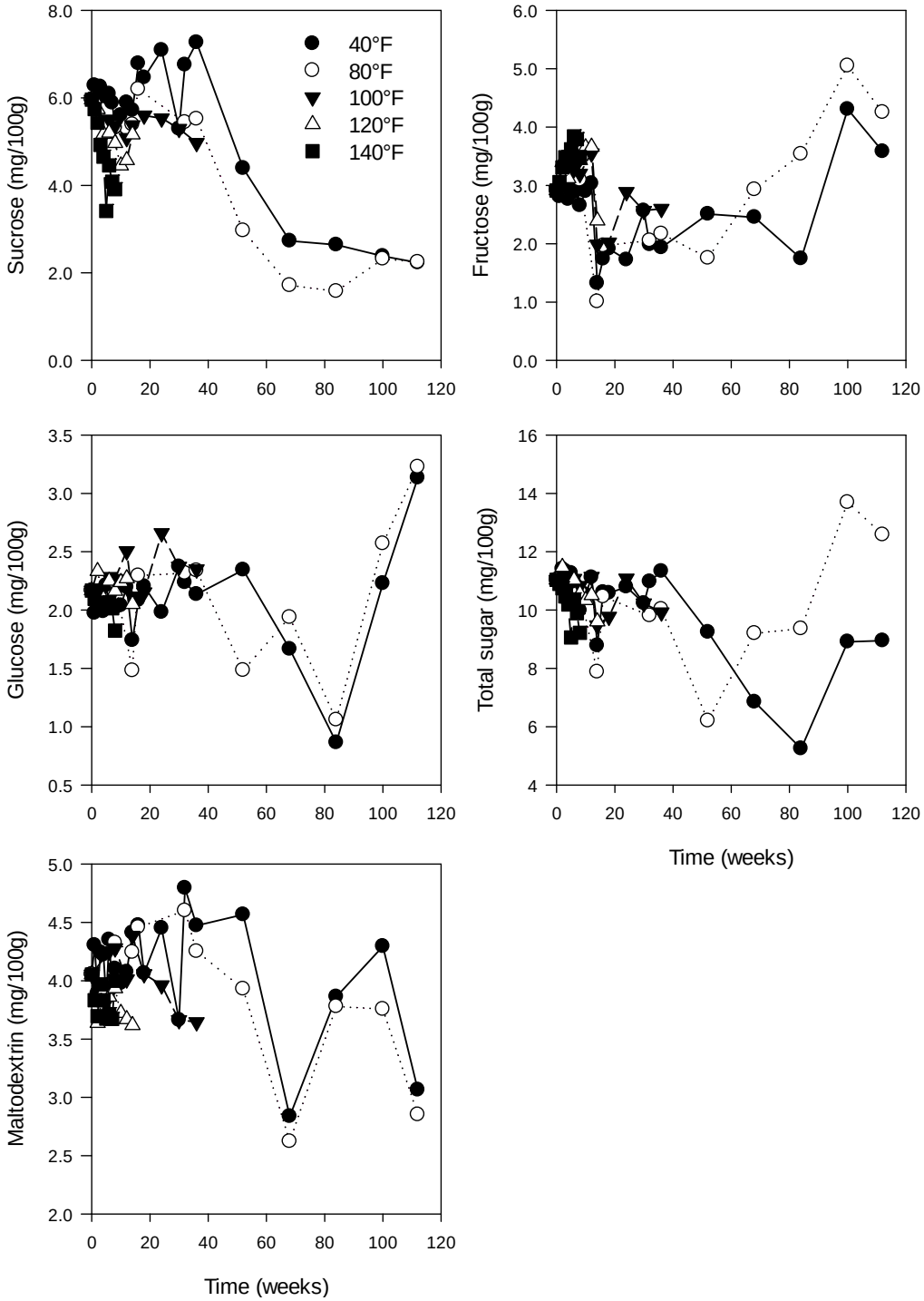


Figure 117. Changes in the sugar and maltodextrin contents of Honey BBQ Beef Sandwich during storage at 40, 80, 100, 120 and 140°F.

Lipid Oxidation

Peroxide value (PV) assay was used to measure the level of lipid oxidation for the primary oxidation products formed. Because of the complexity of the food matrix and the meat distribution in this type of sandwich, there were two types of sampling methods used. Therefore, lipid oxidation was measured in the whole sandwich comprising bread and meat, or measured in only the meat part of sandwich (Figure 118). In general, lipid oxidation values were higher in the meat part than in the entire sandwich. Nevertheless, lipid oxidation increased in both the whole sandwich and meat part regardless of the storage temperature. However, when samples were stored for 112 weeks at 40 or 80°F there was a significant increase in the PV value of the meat. Thus, refrigerated temperatures did not prevent the oxidation of fats when samples were stored for long periods of time.

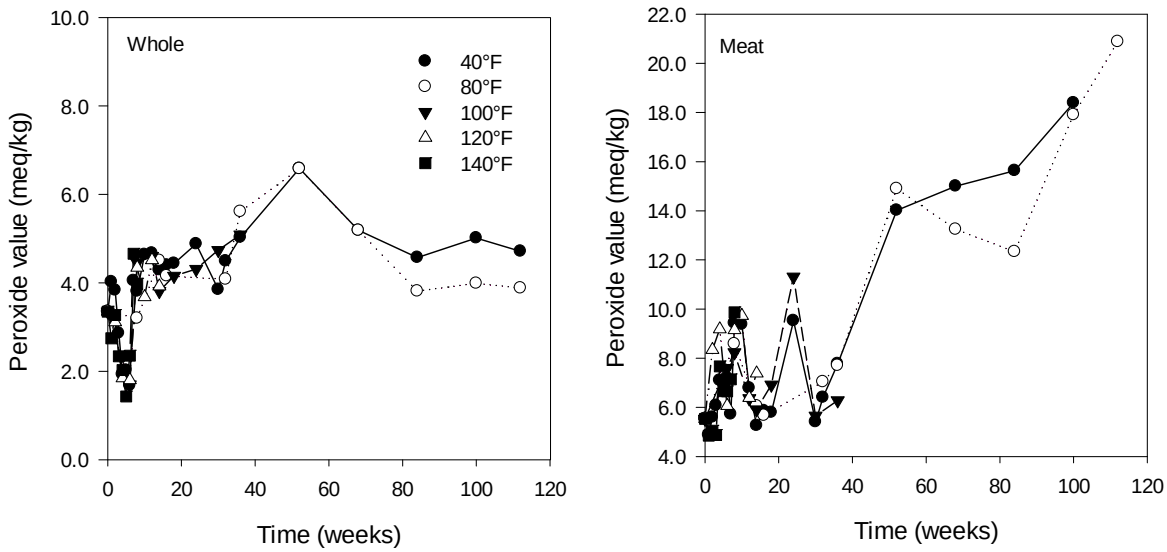


Figure 118. Changes in the peroxide value of whole sandwich and meat part only of Honey BBQ Beef Sandwich during storage at 40, 80, 100, 120 and 140°F.

2.3.8.3 Summary Of The Results For Honey BBQ Beef Sandwich

Below is a summary of the changes that occurred in the appearance (Table 20) and in the different physical (Table 22) and compositional (Tables 23 and 24) attributes measured in Honey BBQ Beef Sandwich samples at the beginning and end of storage:

- L* value: decreased for all temperatures.
- Chroma: decreased for all temperatures.
- Hue: increased in samples stored at 40 and 80°F, and decreased in samples stored at 100, 120 and 140°F (deeper color).
- Texture: increased in samples stored at 40, 80 and 100°F, and decreased in samples stored at 120 and 140°F.

- pH: decreased for all temperatures.
- Acidity: increased for all temperatures.
- Soluble solids content: increased for all temperatures.
- Moisture content: decreased for all temperatures.
- Water activity: increased for all temperatures.
- Ascorbic acid: decreased for all temperatures.
- Sucrose: decreased for all temperatures.
- Glucose: increased in samples stored at 40, 80 and 100°F, and decreased in samples stored at 120 and 140°F.
- Fructose: increased in samples stored at 40, 80 and 140°F, and decreased in samples stored at 100 and 120°F.
- Total sugars: decreased in samples stored at 40, 100, 120 and 140°F, and increased in samples stored at 80°F.
- Maltodextrin: decreased for all temperatures.
- Peroxide value measured in the whole sandwich: increased for all temperatures.
- Peroxide value measured in the meat part of the sandwich: increased for all temperatures.

2.3.9 Dessert Bar Chocolate Banana Nut

2.3.9.1 Physical Characteristics

Appearance and Color

Dessert Bar Chocolate Banana Nut stored under high temperature conditions (120 and 140°F) showed a dramatic darkening of the color becoming very dark brown after 8 or 14 days of storage, respectively (Figure 119). The color of samples stored at 100°F also darkened during storage, and after 42 weeks the visual color of the dessert bar was identical to that of samples stored for 14 weeks at 120°F. The color of samples stored at lower temperatures (40 and 80°F) first became darker, but then the color lightened by the end of the storage period. This could have been attributed to a defect in photography, but results from objective color measurements (L*a*b*) confirm that there was an increase in L* value for samples stored at 40 and 80°F (Figure 120).

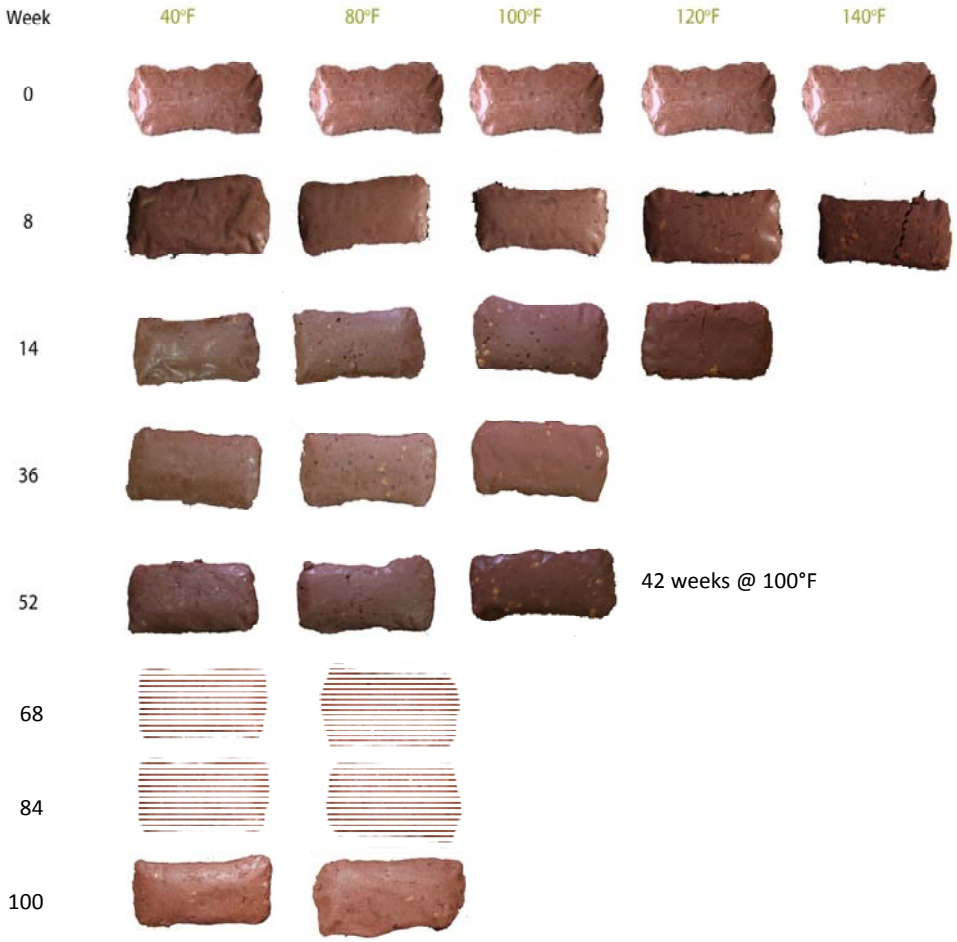


Figure 119. Changes in the appearance of Dessert Bar Chocolate Banana Nut during storage at 40, 80, 100, 120 and 140°F.

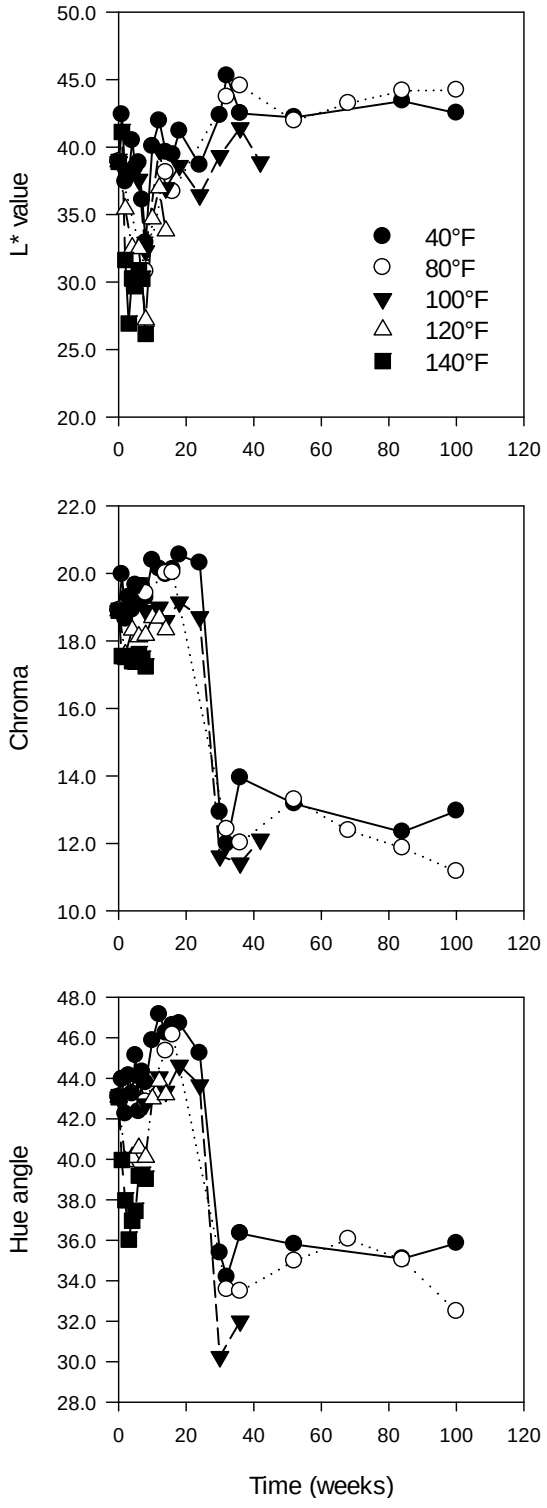


Figure 120. Changes in color attributes (L*, chroma and hue) of Dessert Bar, Chocolate Banana Nut during storage at 40, 80, 100, 120 and 140°F.

L* values decreased (darker samples) during storage for samples stored at 120 and 140°F (Figure 120). For samples stored at 100°F, L* values decreased up to 24 weeks of storage and then increased; however, after 42 weeks, L* values were similar to those measured initially. The L* value of samples stored at 40 and 80°F fluctuated during storage, but overall, after 100 weeks, L* values were higher (lighter samples) than they were initially. A decrease in L* values corresponded to darkening of the samples, particularly in those stored at high temperatures, whereas an increase in L* values corresponded to an increase in lightness, which may have resulted from prolonged storage and bleaching of the color. Chroma and hue values decreased during storage regardless of the temperature, meaning that the color of the samples became less vivid and darker.

Texture

Exposure of Dessert Bar, Chocolate Banana Nut to extreme temperature conditions (120 and 140°F) significantly decreased their firmness after eight weeks of storage, compared to its exposure to other temperatures (Figure 121). This change in texture most likely resulted from a softening of the food or degradation (easily breaking into small pieces) when exposed to extremely high temperatures. Although the texture of samples stored at 40, 80 and 100°F also tended to decrease during storage, the decrease was much smaller when compared to that observed for samples exposed to higher temperatures. Therefore, after 100 weeks, the texture of samples stored at 40°F decreased by approximately 21%, whereas the texture of samples stored for only eight weeks at 140°F decreased by approximately 57%.

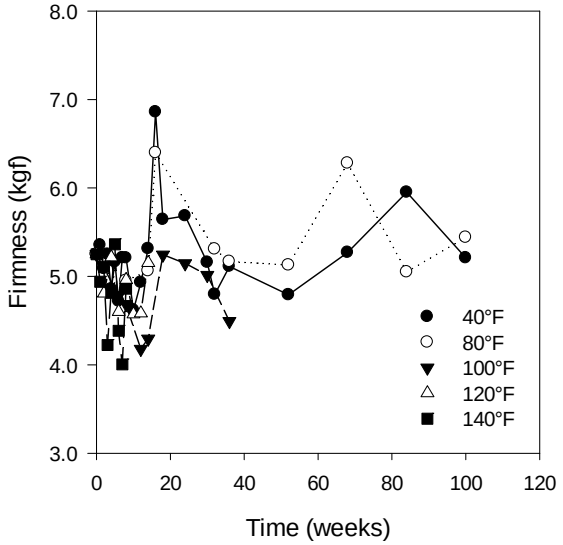


Figure 121. Changes in the texture of Dessert Bar, Chocolate Banana Nut during storage at 40, 80, 100, 120 and 140°F

2.3.9.2 Compositional Analysis

Titratable Acidity, Soluble Solids Content and pH

The effect of different temperatures (40, 80, 100, 120 and 140°F) on titratable acidity, total soluble solids content, and pH for Dessert Bar, Chocolate Banana Nut is shown in Figure 122. The pH decreased during storage regardless of the temperature; however, the pH of samples stored at high temperatures was lower and decreased more rapidly than the pH of samples stored at low temperatures, particularly in samples stored at 120 and 140°F.

The titratable acidity increased in samples stored at 120 and 140°F but by the end of storage remained practically the same in samples stored at lower temperatures. Titratable acidity attained the highest value in samples stored for 8 weeks at 140°F and after 14 weeks in samples stored 120°F. Thus, the acidity of the samples was higher than it was initially. The smaller changes observed in the pH of samples stored between 40 and 100°F compared to higher changes in the pH of samples stored at higher temperatures contributed to no changes in acidity or increased acidity, respectively.

The soluble solids content (SSC) increased significantly during storage regardless of the temperature (Figure 122). However, the increase was faster and more dramatic in samples stored at 140°F compared to that observed in samples stored at lower temperatures. For example, after eight weeks at 140°F, the SSC content of the samples increased by approximately 117%, whereas after 100 weeks at 40°F the SSC increased by approximately 91%. The increase in SSC might have resulted from changes in the food matrix and with some of the components becoming part of the soluble material.

Water Activity and Moisture Content

Changes in water activity and moisture content for Dessert Bar, Chocolate Banana Nut stored at different temperatures are shown in Figure 123. Although the dessert bar had initial low moisture content and water activity, it tended to decrease during storage regardless of the temperature. Decreases in water activity were more dramatic in samples stored at 120 and 140°F compared to those stored at lower temperatures. The decrease in moisture may have contributed to the changes in the texture of the samples during storage (Figure 121) and also to changes in the color of the samples, which became less vivid during storage (Figure 120).

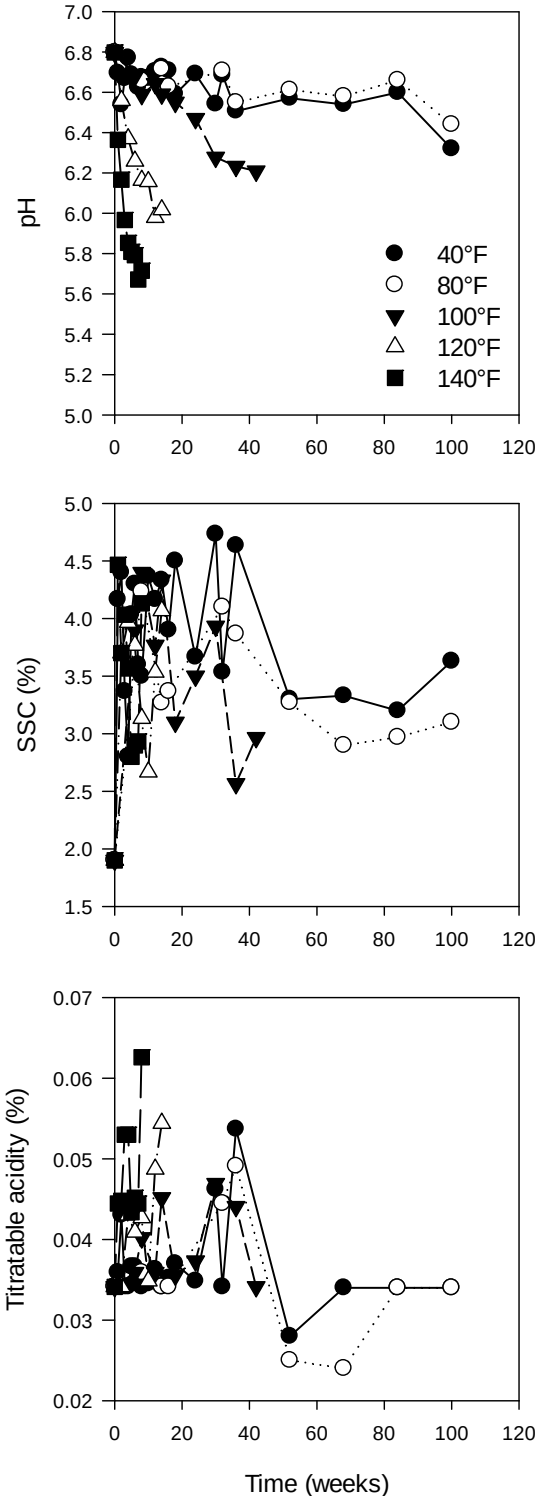


Figure 122. Change in pH, titratable acidity and soluble solids content in Dessert Bar, Chocolate Banana Nut during storage at 40, 80, 100, 120 and 140°F

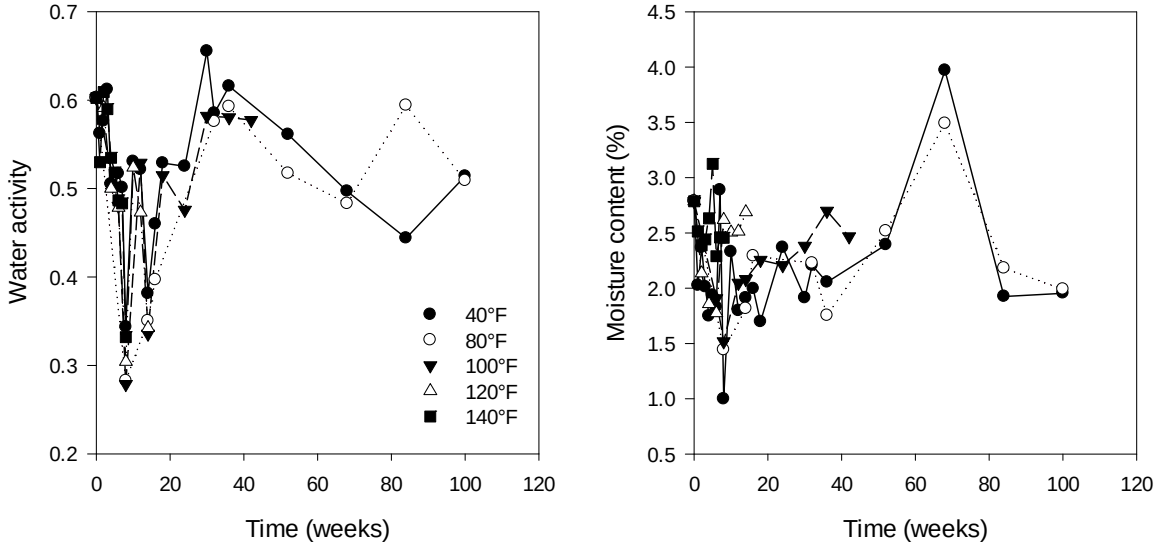


Figure 123. Changes in moisture content and water activity of Dessert Bar, Chocolate Banana Nut during storage at 40, 80, 100, 120 and 140°F

Individual and Total Sugar Profiles

The Dessert Bar, Chocolate Banana Nut initial total sugar content was primarily composed of sucrose (92.3%), glucose (5.4%) and fructose (2.3%). Exposure to high temperatures (120 and 140°F) resulted in a sudden decrease in the concentration of sucrose, glucose and fructose, particularly in samples stored at 120 and 140°F (Figure 124). The sucrose content increased in samples stored at 40°F and decreased in samples stored at higher temperatures; the glucose content increased in samples stored at 40, 80 and 100°F, but decreased in samples stored at 120 and 140°F; fructose increased in samples stored at 40 and 80°F and decreased in samples stored a 100, 120 and 140°F.

Overall, the total sugars increased in samples stored at 40°F due to the increase in sucrose, glucose and fructose, and decreased in samples stored at higher temperatures due to a decrease in sucrose. In samples stored at temperatures higher than 40°F there was most likely an increase in sucrose hydrolysis and conversion to monosaccharides such as fructose and glucose. At 40°F the increase in sucrose, glucose and fructose might have resulted from a gradual degradation of other carbohydrate components of the sample and conversion to simpler sugars such as glucose.

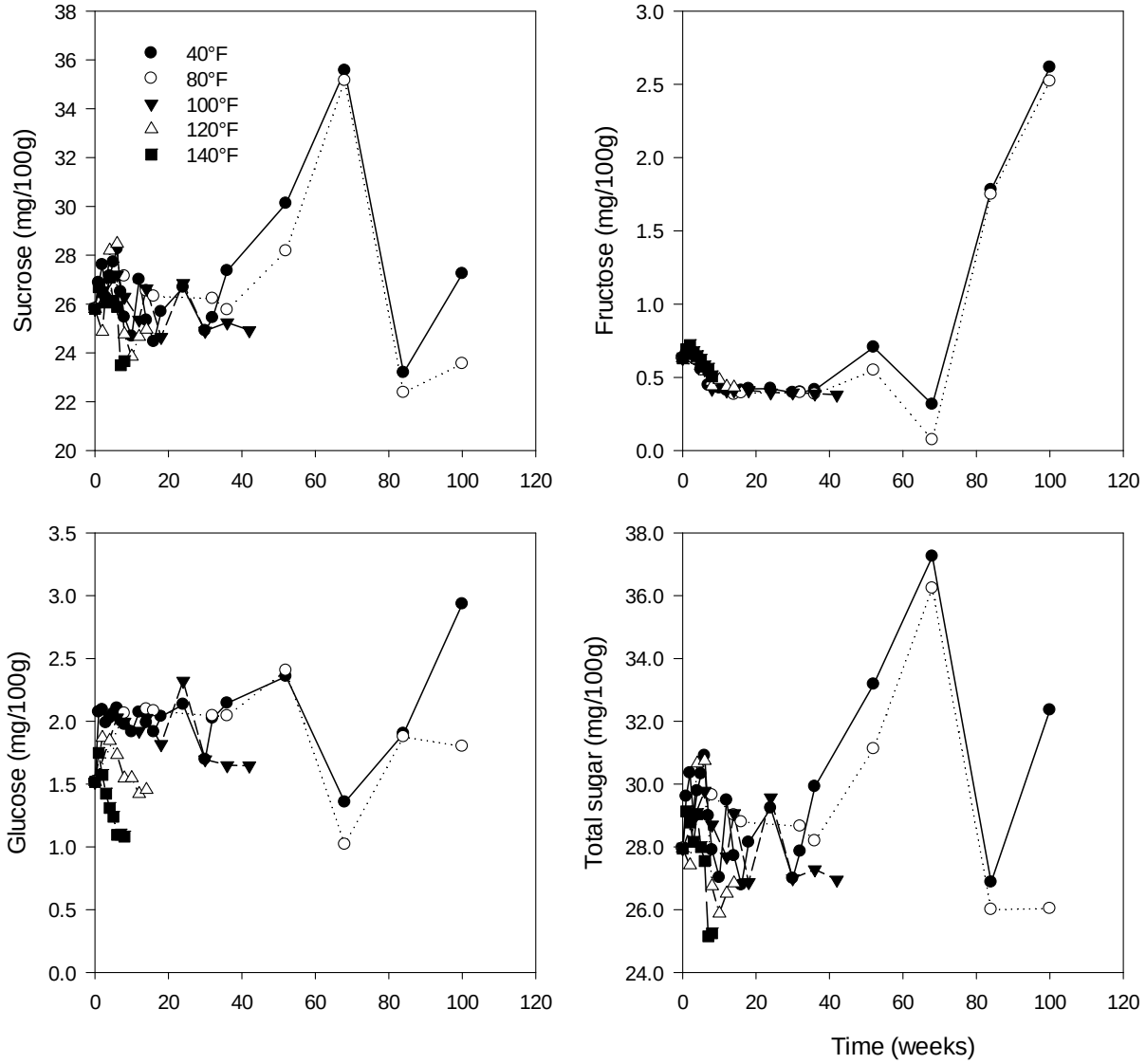


Figure 124. Changes in the sugar profiles of Dessert Bar, Chocolate Banana Nut during a 112-week storage period at 40, 80, 100, 120 and 140°F

Lipid Oxidation

The amount of lipid oxidation in the Dessert Bar, Chocolate Banana Nut was measured using peroxide value (PV) assay to monitor the primary oxidation products formed during storage at 40, 80, 100, 120 and 140°F. The degree of lipid oxidation fluctuated regardless of the storage time and temperature (Figure 125). In samples stored at 40, 120 and 140°F, the PV increased during storage, whereas in samples stored at 80 and 100°F, the PV tended to decrease. It is possible that at 120 and 140°F the lipid/fat content of the samples tended to oxidize faster over a short period of time (within 8 to 14 weeks) as a result of overheating. At 40°F, the increase in PV was possibly due to the extended storage period (100 weeks) rather than a temperature

effect. However, the values obtained for PV were below those normally considered objectionable for a variety of food products (see Material and Methods section).

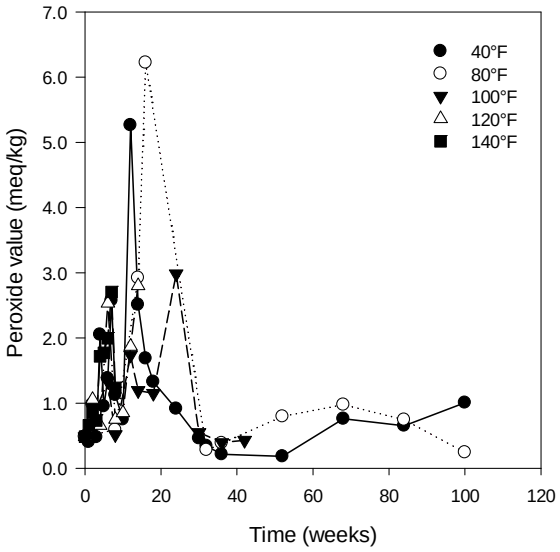


Figure 125. Changes in the peroxide value of Dessert Bar, Chocolate Banana Nut storage at 40, 80, 100, 120 and 140°F

2.3.9.3 Summary Of The Results For Dessert Bar, Chocolate Banana Nut

Below is a summary of the changes that occurred in the appearance (Table 21) and in the different physical (Table 22) and compositional (Tables 23 and 24) attributes measured in Dessert Bar, Chocolate Banana Nut samples at the beginning and end of storage:

- L* value: increased in samples stored at 40 and 80°F, was approximately the same in samples stored at 100°F and decreased in samples stored at 120 and 140°F.
- Chroma: decreased for all temperatures.
- Hue: decreased for all temperatures.
- Texture: decreased for all temperatures.
- pH: decreased for all temperatures.
- Acidity: did not change in samples stored at 40, 80 and 100°F, and increased in samples stored at 120 and 140°F.
- Soluble solids content: increased for all temperatures.
- Moisture content: decreased for all temperatures.
- Water activity: decreased for all temperatures.
- Sucrose: increased in samples stored at 40°F, and decreased in samples stored at 80, 100, 120 and 140°F.
- Glucose: increased in samples stored at 40, 80 and 100°F, and decreased in samples stored at 120 and 140°F.

- Fructose: increased in samples stored at 40 and 80°F, and decreased in samples stored at 80, 100 and 120°F.
- Total sugars: increased in samples stored at 40°F, and decreased in samples stored at 80, 100, 120 and 140°F.
- Maltodextrin: no maltodextrin detected.
- Peroxide value: increased in samples stored at 40, 120 and 140°F, and decreased in samples stored at 80 and 100°F.

Table 20. Initial and final appearance (after storage at 40, 80, 100, 120 and 140°F) of Applesauce, Bacon Cheddar and Beef BBQ Sandwiches and Beef Snack BBQ

FSR Item	Temperature (°F)	Appearance		FSR Item	Temperature (°F)	Appearance	
		Initial	Final[a]			Initial	Final[a]
Applesauce	40			Beef BBQ sandwich	40		
	80				80		
	100				100		
	120				120		
	140				140		
Bacon-cheddar sandwich	40			Beef snack BBQ	40		
	80				80		
	100				100		
	120				120		
	140				140		

([a]) Final: 112 weeks at 40 or 80°F; 36 weeks at 100°F; 14 weeks at 120°F; 8 weeks at 140°F.

Table 21. Initial and final appearance (after storage at 40, 80, 100, 120 and 140°F) of Wheat Bread, Dessert Bar, French Toast, Italian-Style Sandwich and Tortillas

FSR Item	Temperature (°F)	Appearance		FSR Item	Temperature (°F)	Appearance	
		Initial	Final[a]			Initial	Final[a]
Bread	40			Italian sandwich	40		
	80				80		
	100				100		
	120				120		
	140				140		
Dessert bar	40			Tortillas	40		
	80				80		
	100				100		
	120				120		
	140				140		
French toast	40						
	80						
	100						
	120						
	140						

([a]) Final: Wheat Bread, Dessert Bar and Tortillas—112 weeks at 40 or 80°F; 42 weeks at 100°F; 14 weeks at 120°F; 8 weeks at 140°F. French Toast and Italian-Style Sandwich—112 weeks at 40 or 80°F; 36 weeks at 100°F; 14 weeks at 120°F; 8 weeks at 140°F.

Table 22. Initial and final color and texture (after storage at 40, 80, 100, 120 and 140°F) of selected FSR items

FSR Item	Temperature (°F)	L* value		Chroma		Hue		Texture (kgf)	
		Initial	Final[a]	Initial	Final[a]	Initial	Final[a]	Initial	Final[a]
Applesauce	40	26.2	28.8	16.1	6.3	47.7	69.3	0.07	0.07
	80	26.2	26.6	16.1	9.0	47.7	57.9	0.07	0.06
	100	26.2	26.6	16.1	11.8	47.7	49.8	0.07	0.06
	120	26.2	20.6	16.1	14.7	47.7	40.7	0.07	0.05
	140	26.2	12.0	16.1	13.9	47.7	34.2	0.07	0.05
Bacon-cheddar sandwich	40	73.2	68.8	49.2	34.8	75.0	76.3	11.94	14.51
	80	73.2	65.5	49.2	38.7	75.0	76.0	11.94	9.23
	100	73.2	59.6	49.2	36.0	75.0	68.9	11.94	8.64
	120	73.2	60.0	49.2	41.9	75.0	64.2	11.94	6.85
	140	73.2	41.7	49.2	32.7	75.0	55.4	11.94	7.14
Beef BBQ sandwich	40	66.1	62.2	45.0	33.0	66.9	67.1	5.77	6.82
	80	66.1	62.2	45.0	37.4	66.9	71.7	5.77	6.34
	100	66.1	56.8	45.0	34.3	66.9	65.6	5.77	6.38
	120	66.1	52.3	45.0	35.9	66.9	59.5	5.77	5.54
	140	66.1	35.5	45.0	27.4	66.9	50.6	5.77	5.36
Beef snack BBQ	40	28.2	32.0	13.8	5.8	31.9	10.1	3.82	5.49
	80	28.2	33.6	13.8	4.2	31.9	-25.5	3.82	5.45
	100	28.2	33.6	13.8	4.1	31.9	-13.2	3.82	5.63
	120	28.2	30.6	13.8	13.9	31.9	37.8	3.82	5.13
	140	28.2	23.1	13.8	13.5	31.9	34.0	3.82	6.26
Bread	40	66.6	66.3	40.2	29.3	65.1	70.9	5.01	5.68
	80	66.6	63.9	40.2	28.8	65.1	69.6	5.01	5.46
	100	66.6	60.1	40.2	30.1	65.1	67.7	5.01	5.51
	120	66.6	60.3	40.2	39.0	65.1	63.9	5.01	4.92
	140	66.6	45.0	40.2	33.4	65.1	58.7	5.01	4.73
Dessert bar	40	38.9	42.5	18.9	13.0	43.1	35.9	3.24	2.57
	80	38.9	44.2	18.9	11.2	43.1	32.5	3.24	2.45
	100	38.9	38.9	18.9	12.1	43.1	32.0	3.24	2.59
	120	38.9	33.8	18.9	18.3	43.1	43.2	3.24	1.49
	140	38.9	26.2	18.9	17.3	43.1	39.0	3.24	1.41
French toast	40	54.3	60.8	36.6	33.1	62.0	75.9	5.25	5.21
	80	54.3	55.9	36.6	37.1	62.0	70.9	5.25	5.44
	100	54.3	52.0	36.6	27.9	62.0	62.9	5.25	4.49
	120	54.3	50.2	36.6	32.6	62.0	58.5	5.25	5.15
	140	54.3	32.7	36.6	25.1	62.0	49.5	5.25	4.86
Italian sandwich	40	58.4	61.4	40.5	33.8	62.4	66.3	6.50	8.51
	80	58.4	56.3	40.5	35.4	62.4	65.1	6.50	6.29
	100	58.4	55.7	40.5	32.5	62.4	63.3	6.50	6.69
	120	58.4	55.2	40.5	38.4	62.4	61.2	6.50	5.10
	140	58.4	35.2	40.5	26.3	62.4	50.1	6.50	6.49
Tortillas	40	80.4	77.5	25.1	15.2	78.0	87.8	0.47	0.50
	80	80.4	77.6	27.2	18.2	79.0	86.5	0.47	0.44
	100	80.4	73.6	25.1	21.5	78.0	82.9	0.47	0.42
	120	80.4	76.7	25.1	38.4	78.0	82.8	0.47	0.41
	140	80.4	59.7	25.1	38.8	78.0	66.3	0.47	0.37

[a] Final: Applesauce; Bacon Cheddar, Beef BBQ and Italian-Style Sandwiches; Beef Snack; French Toast—112 weeks at 40 or 80°F; 36 weeks at 100°F; 14 weeks at 120°F; 8 weeks at 140°F. Wheat Bread, Dessert Bar and Tortillas—112 weeks at 40 or 80°F; 42 weeks at 100°F; 14 weeks at 120°F; 8 weeks at 140°F.

Table 23. Initial and final chemical composition (after storage at 40, 80, 100, 120 and 140°F) of selected FSR items

FSR Item	Temperature (°F)	MC (%)		a_w		pH		Acidity (%)		SSC (%)		AA (mg/100g)		PV (meq/kg) (Whole)		PV (meq/kg) (Meat)	
		Initial	Final[a]	Initial	Final[a]	Initial	Final[a]	Initial	Final[a]	Initial	Final[a]	Initial	Final[a]	Initial	Final[a]	Initial	Final[a]
Applesauce	40	72.31	71.82	0.96	0.98	3.73	3.50	0.04	0.07	2.77	2.70	152.55	121.25	*	*	*	*
	80	72.31	72.65	0.96	0.97	3.73	3.54	0.04	0.05	2.77	2.70	152.55	51.53	*	*	*	*
	100	72.31	71.95	0.96	0.97	3.73	3.68	0.04	0.05	2.77	2.83	152.55	48.54	*	*	*	*
	120	72.31	75.53	0.96	0.97	3.73	3.69	0.04	0.04	2.77	2.63	152.55	32.54	*	*	*	*
	140	72.31	73.02	0.96	0.97	3.73	3.59	0.04	0.04	2.77	2.80	152.55	10.96	*	*	*	*
Bacon-cheddar sandwich	40	23.26	24.36	0.83	0.86	5.30	5.10	0.03	0.04	1.97	1.50	15.20	0.65	1.84	1.40	4.11	2.30
	80	23.26	28.24	0.83	0.88	5.30	4.98	0.03	0.05	1.97	1.43	15.20	1.54	1.84	1.97	4.11	1.95
	100	23.26	23.68	0.83	0.84	5.30	4.95	0.03	0.05	1.97	1.73	15.20	7.91	1.84	1.27	4.11	1.61
	120	23.26	23.00	0.83	0.84	5.30	5.07	0.03	0.04	1.97	1.67	15.20	8.19	1.84	2.42	4.11	1.11
	140	23.26	21.68	0.83	0.83	5.30	4.83	0.03	0.05	1.97	1.87	15.20	10.29	1.84	0.98	4.11	1.64
Beef BBQ sandwich	40	34.20	30.85	0.83	0.86	4.78	4.63	0.04	0.07	1.60	2.20	12.61	0.64	3.35	4.71	5.53	16.33
	80	34.20	32.25	0.83	0.86	4.78	4.62	0.04	0.08	1.60	2.10	12.61	0.90	3.35	3.88	5.53	20.88
	100	34.20	32.27	0.83	0.86	4.78	4.58	0.04	0.11	1.60	2.40	12.61	7.28	3.35	5.09	5.53	6.28
	120	34.20	32.95	0.83	0.85	4.78	4.62	0.04	0.08	1.60	2.40	12.61	7.32	3.35	3.92	5.53	7.38
	140	34.20	31.57	0.83	0.85	4.78	4.50	0.04	0.09	1.60	2.50	12.61	9.60	3.35	3.98	5.53	9.86
Beef snack BBQ	40	33.84	31.71	0.80	0.83	6.09	5.70	0.05	0.08	0.83	2.97	*	*	14.42	7.27	*	*
	80	33.84	29.27	0.80	0.82	6.09	5.34	0.05	0.08	0.83	2.80	*	*	14.42	6.23	*	*
	100	33.84	29.39	0.80	0.80	6.09	5.23	0.05	0.05	0.83	2.80	*	*	14.42	10.78	*	*
	120	33.84	31.70	0.80	0.82	6.09	5.24	0.05	0.12	0.83	2.90	*	*	14.42	7.29	*	*
	140	33.84	28.41	0.80	0.71	6.09	4.90	0.05	0.13	0.83	2.97	*	*	14.42	8.98	*	*
Bread	40	21.80	21.64	0.75	0.82	5.82	5.49	0.03	0.03	2.10	2.03	*	*	0.93	1.23	*	*
	80	21.80	21.81	0.75	0.82	5.82	5.29	0.03	0.08	2.10	2.20	*	*	0.93	1.68	*	*
	100	21.80	21.38	0.75	0.81	5.82	5.23	0.03	0.03	2.10	2.70	*	*	0.93	0.29	*	*
	120	21.80	21.96	0.75	0.79	5.82	5.27	0.03	0.03	2.10	2.00	*	*	0.93	0.74	*	*
	140	21.80	21.23	0.75	0.79	5.82	5.06	0.03	0.04	2.10	2.63	*	*	0.93	0.68	*	*
Dessert bar	40	2.79	1.95	0.60	0.51	6.80	6.32	0.03	0.03	1.90	3.63	*	*	0.49	1.01	*	*
	80	2.79	1.99	0.60	0.51	6.80	6.44	0.03	0.03	1.90	3.10	*	*	0.49	0.24	*	*
	100	2.79	2.47	0.60	0.58	6.80	6.21	0.03	0.03	1.90	2.97	*	*	0.49	0.43	*	*
	120	2.79	2.69	0.60	0.34	6.80	6.02	0.03	0.05	1.90	4.07	*	*	0.49	2.80	*	*
	140	2.79	2.46	0.60	0.33	6.80	5.72	0.03	0.06	1.90	4.13	*	*	0.49	1.23	*	*
French toast	40	27.75	28.21	0.77	0.86	5.38	4.95	0.03	0.03	2.17	2.70	*	*	1.74	0.65	*	*
	80	27.75	28.66	0.77	0.85	5.38	4.86	0.03	0.03	2.17	2.93	*	*	1.74	1.23	*	*
	100	27.75	26.91	0.77	0.84	5.38	5.12	0.03	0.03	2.17	2.57	*	*	1.74	0.65	*	*
	120	27.75	27.23	0.77	0.83	5.38	4.95	0.03	0.03	2.17	3.27	*	*	1.74	0.60	*	*
	140	27.75	17.31	0.77	0.82	5.38	4.67	0.03	0.03	2.17	3.07	*	*	1.74	1.36	*	*
Italian sandwich	40	28.75	27.18	0.82	0.85	4.96	4.79	0.04	0.07	1.63	1.80	14.81	0.06	4.96	5.43	6.30	13.79
	80	28.75	31.35	0.82	0.86	4.96	4.76	0.04	0.07	1.63	1.90	14.81	0.70	4.96	4.76	6.30	18.75
	100	28.75	30.22	0.82	0.86	4.96	4.63	0.04	0.08	1.63	2.00	14.81	7.97	4.96	3.60	6.30	6.60
	120	28.75	29.32	0.82	0.85	4.96	4.76	0.04	0.05	1.63	1.80	14.81	8.99	4.96	6.40	6.30	8.41
	140	28.75	28.48	0.82	0.85	4.96	4.61	0.04	0.07	1.63	2.00	14.81	9.31	4.96	4.09	6.30	7.81
Tortillas	40	22.84	22.35	0.77	0.82	5.26	4.98	0.04	0.05	1.70	1.90	*	*	0.73	1.10	*	*
	80	22.84	22.32	0.77	0.82	5.26	5.02	0.04	0.05	1.70	1.83	*	*	0.73	2.22	*	*
	100	22.84	21.93	0.77	0.80	5.26	5.22	0.04	0.04	1.70	2.30	*	*	0.73	0.18	*	*
	120	22.84	23.45	0.77	0.80	5.26	5.31	0.04	0.07	1.70	1.63	*	*	0.73	1.32	*	*
	140	22.84	22.56	0.77	0.78	5.26	5.31	0.04	0.06	1.70	1.90	*	*	0.73	0.31	*	*

(*) Not measured; ([a]) Final: Applesauce; Bacon Cheddar, Beef BBQ and Italian-Style Sandwiches; Beef Snack; French Toast—112 weeks at 40 or 80°F; 36 weeks at 100°F; 14 weeks at 120°F; 8 weeks at 140°F. Wheat Bread, Dessert Bar and Tortillas—112 weeks at 40 or 80°F; 42 weeks at 100°F; 14 weeks at 120°F; 8 weeks at 140°F. MC = Moisture Content; a_w = Water Activity; SSC = Soluble Solids Content; AA = Ascorbic Acid (vitamin C); PV = Peroxide Value.

Table 24. Initial and final chemical composition (after storage at 40, 80, 100, 120 and 140°F) of selected FSR items

FSR Item	Temperature (°F)	Sucrose (g/100g)		Glucose (g/100g)		Fructose (g/100g)		Total sugars (g/100g)		Maltodextrine (g/100g)	
		Initial	Final*	Initial	Final*	Initial	Final*	Initial	Final*	Initial	Final*
Applesauce	40	8.61	10.29	2.80	1.59	1.06	2.03	12.47	14.45	2.99	1.22
	80	8.61	17.18	2.80	0.00	1.06	1.91	12.47	19.75	2.99	1.30
	100	8.61	7.83	2.80	1.62	1.06	1.42	12.47	10.87	2.99	2.68
	120	8.61	6.41	2.80	1.51	1.06	1.95	12.47	9.87	2.99	2.58
	140	8.61	5.02	2.80	2.78	1.06	2.34	12.47	10.13	2.99	2.25
Bacon-cheddar sandwich	40	4.72	2.46	0.92	0.00	0.53	1.17	6.17	8.14	4.15	4.51
	80	4.72	2.59	0.92	0.00	0.53	1.06	6.17	7.39	4.15	3.75
	100	4.72	4.38	0.92	1.03	0.53	0.54	6.17	5.96	4.15	3.67
	120	4.72	4.44	0.92	0.95	0.53	0.51	6.17	5.90	4.15	3.59
	140	4.72	4.21	0.92	0.82	0.53	0.49	6.17	5.52	4.15	3.35
Beef BBQ sandwich	40	5.96	2.23	2.17	3.13	2.91	3.58	11.03	9.78	4.05	3.06
	80	5.96	2.25	2.17	3.23	2.91	4.25	11.03	12.58	4.05	2.85
	100	5.96	4.97	2.17	2.35	2.91	2.60	11.03	9.92	4.05	3.64
	120	5.96	5.16	2.17	2.05	2.91	2.39	11.03	9.60	4.05	3.62
	140	5.96	3.91	2.17	1.82	2.91	3.49	11.03	9.22	4.05	4.00
Beef snack BBQ	40	8.61	10.29	2.80	1.59	1.06	2.03	12.47	14.45	2.99	1.22
	80	8.61	17.18	2.80	0.00	1.06	1.91	12.47	19.75	2.99	1.30
	100	8.61	7.83	2.80	1.62	1.06	1.42	12.47	10.87	2.99	2.68
	120	8.61	6.41	2.80	1.51	1.06	1.95	12.47	9.87	2.99	2.58
	140	8.61	5.02	2.80	2.78	1.06	2.34	12.47	10.13	2.99	2.25
Bread	40	6.33	3.38	2.53	2.59	2.41	0.00	11.26	13.56	7.15	7.59
	80	6.33	3.50	2.53	2.66	2.41	4.37	11.26	16.33	7.15	7.55
	100	6.33	4.09	2.53	1.25	2.41	0.48	11.26	5.83	7.15	4.59
	120	6.33	8.01	2.53	2.23	2.41	2.01	11.26	12.26	7.15	8.56
	140	6.33	7.06	2.53	2.30	2.41	2.42	11.26	11.77	7.15	8.47
Dessert bar	40	25.80	27.24	1.52	2.93	0.63	2.61	27.94	32.35	ND	ND
	80	25.80	23.55	1.52	1.88	0.63	2.52	27.94	26.03	ND	ND
	100	25.80	24.93	1.52	1.65	0.63	0.38	27.94	26.95	ND	ND
	120	25.80	24.95	1.52	1.45	0.63	0.43	27.94	26.84	ND	ND
	140	25.80	23.66	1.52	1.08	0.63	0.51	27.94	25.25	ND	ND
French toast	40	8.51	8.59	5.62	5.77	4.81	5.58	18.93	23.32	3.38	3.38
	80	8.51	0.00	5.62	5.71	4.81	6.41	18.93	15.92	3.38	3.35
	100	8.51	6.72	5.62	7.27	4.81	6.16	18.93	20.16	3.38	2.72
	120	8.51	6.93	5.62	6.47	4.81	5.77	18.93	19.16	3.38	2.81
	140	8.51	4.83	5.62	7.40	4.81	7.29	18.93	19.52	3.38	2.95
Italian sandwich	40	3.99	1.84	1.08	2.45	1.57	0.00	6.64	8.14	4.45	3.85
	80	3.99	1.88	1.08	2.45	1.57	0.00	6.64	7.41	4.45	3.08
	100	3.99	4.77	1.08	1.06	1.57	1.02	6.64	6.86	4.45	3.74
	120	3.99	4.73	1.08	1.01	1.57	1.15	6.64	6.89	4.45	3.56
	140	3.99	3.60	1.08	0.83	1.57	1.73	6.64	6.16	4.45	4.59
Tortillas	40	4.08	3.91	0.00	0.00	0.99	1.83	5.07	7.94	5.46	2.51
	80	4.08	3.65	0.00	0.00	0.99	0.00	5.07	5.91	5.46	2.26
	100	4.08	3.06	0.00	0.00	0.99	0.55	5.07	3.61	5.46	2.15
	120	4.08	3.87	0.00	0.00	0.99	0.65	5.07	4.52	5.46	3.90
	140	4.08	3.95	0.00	0.00	0.99	1.01	5.07	4.96	5.46	2.52

(ND) Not detected; ([a]) Final: Applesauce; Bacon Cheddar, Beef BBQ and Italian-Style Sandwiches; Beef Snack; French Toast—112 weeks at 40 or 80°F; 36 weeks at 100°F; 14 weeks at 120°F; 8 weeks at 140°F. Wheat Bread, Dessert Bar and Tortillas—112 weeks at 40 or 80°F; 42 weeks at 100°F; 14 weeks at 120°F; 8 weeks at 140°

2.4 General Conclusions

For all nine of FSR items evaluated (Filled French Toast Pocket; Bacon Cheddar Pocket Sandwich; Wheat Snack Bread; Beef Snack, Sweet BBQ; Applesauce, CHO Enhanced; Italian-Style Sandwich; Tortillas; Honey BBQ Beef Sandwich; Dessert Bar, Chocolate Banana Nut), there were some similar trends in the physical and compositional degradation during storage at refrigerated and non-refrigerated temperatures, particularly when items were exposed to extreme temperatures, namely at 100, 120 and 140°F. Samples stored at lower temperatures (40 and 80°F) showed in some case lesser changes in their physical and compositional attributes, particularly when stored under refrigerated conditions (40°F). Overall:

- All FSR items showed marked changes in their initial color, particularly items stored at temperatures higher than 80°F which developed a dark brown coloration. The brownish appearance was attributed to non-enzymatic browning reactions (Maillard reactions; amino acid + reducing sugar-glucose) that might have occurred during exposure to high temperatures.

- Changes in texture were dependent on the temperature and on the FSR item evaluated. In general softening tended to occur is samples stored at temperatures higher than 80°F, except the beef snack that toughened, regardless of the temperature.

- Changes in texture were most likely related to decrease in moisture content which was observed for all beef snack, beef Honey BBQ sandwich, bread and tortilla and in most samples stored at temperatures higher than 80°F.

- Water activity increased in all FSR items, regardless of the storage temperature except for dessert bar for which water activity decreased. Increased in water activity results in more free water available for chemical reactions to occur such as hydrolysis/oxidation of some compounds, namely sugars and ascorbic acid.

- FSR samples tended to be more acid (lower pH/higher acidity) as storage progressed and overall there was an increase in soluble solids content due most likely to the breakdown of complex sugars (sucrose, maltodextrin) into simple sugars (fructose and glucose).

- Although there was not a trend in the sugar profiles for the different FSR items, total sugar content tended to decrease in samples stored at temperatures higher than 80°F mainly due to the decrease in sucrose (the main sugar in most items). Decrease in sucrose content resulted in an increase in fructose and glucose. Maltodextrin also tended to decrease (breaks down into glucose) during storage, regardless of the temperature.

- The lipid oxidation values in FSR items were relatively low and not critical considering the limits of acceptability between 7-18 meq/kg. The low peroxide values obtained even for samples that were exposed at high temperatures indicate that the FSR foods used in this study were highly stable against oxidation. This was due to its high content in saturated fatty acids, which ensured its stability against oxidative rancidity and most likely due to the low permeability of the packages to oxygen, which prevented the entrance of air and therefore fat oxidation. Although when lipid oxidation on the meat was analyzed separately from the bread (in sandwiches containing meat), the PV values tended to be higher in the meat but yet not critical.

3 Physical And Compositional Attributes Of FSR Items During Storage At Fluctuating Temperatures

3.1 Introduction

Based on the data collected regarding the effect of constant temperatures on the quality and shelf life of nine selected FSR items (see Section 2), five FSR shelf-life limiting items were identified to be used in this part of the project. The objective of this work was to expose the identified FSR from each menu to laboratory-simulated "real life" time-temperature conditions of typical environmental conditions encountered during supply chain activities and measure the changes in the physical and chemical attributes when these items were exposed to non-constant temperatures. The physicochemical data collected was then used to validate the sensory analysis data and further improve the accuracy and robustness of the FSR shelf-life models developed in Phase I.

3.2 Materials And Methods

3.2.1 FSR Items

From the three currently available FSR menus, five individual menu items were selected (Table 25). From Menu 1 the following items were selected: Filled French Toast Pocket (1), Bacon Cheddar Pocket Sandwich (2), and Applesauce CHO Enhanced (3); from Menu 2: Italian-Style Sandwich (4); and from Menu 3: Honey BBQ Beef Sandwich (5). These five items were chosen for the validation study based on the following considerations:

Shelf Life

Based on sensory data collected in Phase I, the shelf life (weeks of storage before the mean overall quality drops below a score of 4.0) of Applesauce, Bacon Cheddar Pocket Sandwich and Italian-Style Sandwich expired after 30, 6 and 2 weeks of storage at 100°F, 120°F and 140°, respectively. The shelf life of Honey BBQ Beef Sandwich expired after 24, 6, and 3 weeks of storage at 100°F, 120°F and 140°F, respectively. Finally, the shelf life of Filled French Toast expired after 30, 8 and 4 weeks at 100°F, 120°F and 140°, respectively. The shortest shelf life for any of the nine FSR items studied was 24 weeks at 100°F (Honey BBQ Sandwich), 6 weeks at 120°F (Applesauce, Bacon Cheddar Sandwich, Italian-Style Sandwich and Honey BBQ Sandwich) and 2 weeks at 140°F (Applesauce).

Importance of the Item on the Menu

The FSR items were also chosen based on their importance on the menu. Therefore, one primary item from each of the three FSR menus (Bacon Cheddar Pocket Sandwich – Menu 1, Italian-Style Sandwich – Menu 2 and Honey BBQ Beef Sandwich – Menu 3), one secondary item common to all menus (Applesauce) and one breakfast-type item (Filled French Toast Pocket – Menu 1) were chosen for this part of the project.

Table 25. First Strike Ration Menus (source: NSRDEC)

Menu 1	Menu 2	Menu 3
Filled French Toast Pocket	Brown Sugar Cinnamon Toaster Pastry	Lemon Poppy seed Pound Cake
Bacon Cheddar Pocket Sandwich	Italian-Style Sandwich	Honey BBQ Beef Sandwich
Pepperoni Pocket Sandwich	Chunk Chicken (Tyson, 7 oz)	Albacore Tuna (Starkist, 3 oz)
	Tortillas	Tortillas
Cheese Spread, Jalapeno	Peanut Butter	Cheese Spread, Plain
Wheat Snack Bread	Crackers, Plain	Crackers, Plain
ERGO Drink	ERGO Drink	ERGO Drink
ERGO Drink	ERGO Drink	ERGO Drink
Mini HooAH! Mocha	Mini HooAH! Apple Cinnamon	Mini HooAH! Mocha
Mini HooAH! Chocolate	Mini HooAH! Cran-Rasp	Mini HooAH! Cran-Rasp
Dessert Bar, Peanut Butter	Dessert Bar, Mocha	Dessert Bar, Choc Banana Nut
Beef Snack, Sweet BBQ	Beef Snack, Sweet BBQ	Beef Snack, Sweet BBQ
Beef Snack, Teriyaki	Beef Snack, Teriyaki	Beef Snack, Teriyaki
Applesauce, CHO Enhanced	Applesauce, CHO Enhanced	Applesauce, CHO Enhanced
FSR Nut Fruit Mix, Type III	FSR Nut Fruit Mix, Type III	FSR Nut Fruit Mix, Type III
Gum, Stay Alert	Gum, Stay Alert	Gum, Stay Alert
	Mayonnaise, Fat Free	Mayonnaise, Fat Free
	Hot Sauce	Hot Sauce

Filled French Toast Pocket consists of flour, corn syrup, hydrogenated vegetable shortening, glycerol, sugar, dextrose, imitation maple syrup, yeast, salt, tapioca starch, corn starch, sucrose ester, artificial and natural flavor, gum arabic, calcium sulfate, xanthan gum, cinnamon, cocoa, lecithin, sorbic acid, FD&C yellow #5, locust bean gum.

Nutrition Facts: serving size 99 g (3.5 oz), 290 calories (80 calories from fat), 9 g total fat (3 g from saturated fat, 1.5 g trans fat), 360 mg sodium, 50 g total carbohydrates (2 g dietary fiber, 19 g sugars) and 8 g protein.

Bacon Cheddar Pocket Sandwich is prepared from bread and cured bacon and contains the following ingredients: bread (enriched flour [wheat flour, niacin, reduced iron, thiamine mononitrate, riboflavin, folic acid], water, cheddar-flavored flakes [hydrolyzed vegetable oil, corn syrup solids, wheat flour, milk, maltodextrin, salt, lactic acid, enzyme-modified cheese; milk, salt, enzyme, natural flavors, sodium citrate, sodium carbonate, disodium phosphate, annatto as a color agent], partially hydrogenated soybean and cottonseed oil, glycerol, yeast, salt, sucrose ester, dough conditioners [dextrose, flour diacetyl tartaric acid esters of mono- and diglyceride, mono- and diglycerides, ascorbic acid, fungal alpha amylase, L-cysteine

hydrochloride, azodicarbonamide], gum Arabic, butter flavor [modified food starch, maltodextrin, natural and artificial flavors, partially hydrogenated soybean oil, water, soy lecithin], glucono-delta-lactone, calcium sulfate, xanthan gum, sorbic acid) and bacon (cured with water, salt, hickory smoke flavor, sugar, dextrose, sodium erythorbate, sodium nitrite).

Nutrition Facts: serving size 1 package (88 g), 320 calories (140 calories from fat), 15 g total fat (5 g from saturated fat, 3 g trans-fat, 20 mg cholesterol), 580 mg sodium, 31 g total carbohydrates (3 g dietary fiber) and 11 g protein.

Applesauce CHO Enhanced, known as Zapplesauce, consists of apples, maltodextrin, water, sugar and ascorbic acid as vitamin C source. It was originally designed to increase the endurance of the soldiers by adding higher amounts of maltodextrin, which can preserve glycogen in the muscles and liver.

Nutrition Facts: serving size 4.5 oz (128 g), 130 calories (0 calories from fat), 0 g total fat (0 g from saturated fat, 0 mg cholesterol), 0 mg sodium, 33 g total carbohydrates (2 g dietary fiber, 19 g sugars) and 0 g protein.

Italian-Style Sandwich, which is prepared from bread, tomato sauce, marinated cooked sausage, pepperoni, and mozzarella cheese powder, contains the following ingredients: bread (enriched flour [wheat flour, niacin, reduced iron, thiamine mononitrate, riboflavin, folic acid], water, cheddar-flavored flakes [hydrolyzed vegetable oil, corn syrup solids, wheat flour, milk, maltodextrin, salt, lactic acid, enzyme-modified cheese; milk, salt, enzyme, natural flavors, sodium citrate, sodium carbonate, disodium phosphate, annatto as a color agent], partially hydrogenated soybean and cottonseed oil, glycerol, yeast salt, sucrose ester, dough conditioners [dextrose, flour diacetyl tartaric acid esters of mono- and diglyceride, mono- and diglycerides, ascorbic acid, fungal alpha amylase, L-cysteine hydrochloride, azodicarbonamide], gum Arabic, butter flavor [modified food starch, maltodextrin, natural and artificial flavors, partially hydrogenated soybean oil, water, soy lecithin], glucono-delta-lactone, calcium sulfate, xanthan gum, sorbic acid); tomato sauce (tomato paste [tomatoes, tomato juice, salt, citric acid], glycerol, parmesan/Romano cheese [pasteurized cow's milk, culture, salt, enzymes], olive oil, sugar, garlic powder, dried onions, spices, salt); marinated cooked sausage (Italian sausage [pork, salt water, dextrose, spices and flavorings, monosodium glutamate, sodium nitrite] rice syrup, glycerol, water, salt, spices); pepperoni (pork, beef, salt, water, dextrose, paprika, spices and flavorings, lactic acid starter culture, oleoresin of paprika, sodium erythorbate, sodium nitrite, BHA, BHT); mozzarella cheese powder (mozzarella cheese [pasteurized milk, cultures, salt, enzymes], disodium phosphate). The Italian-Style Sandwich has a high protein content made up of about 21% meat.

Nutrition Facts: serving size 1 sandwich (100 g), 340 calories (130 calories from fat), 14 g total fat (4.5 g from saturated fat, 2.5 g trans-fat, 15 mg cholesterol), 750 mg sodium, 32 g total carbohydrates (3 g dietary fiber, 2 g sugars) and 10 g protein.

Honey BBQ Beef Sandwich, which is prepared from bread and barbecued beef, contains the following ingredients: bread (enriched flour [wheat flour, niacin, reduced iron, thiamine mononitrate, riboflavin, folic acid], water, cheddar-flavored flakes [hydrolyzed vegetable oil, corn syrup solids, wheat flour, milk, maltodextrin, salt, lactic acid, enzyme-modified cheese; milk, salt, enzyme, natural flavors, sodium citrate, sodium carbonate, disodium phosphate, annatto as a color agent], partially hydrogenated soybean and cottonseed oil, glycerol, yeast salt, sucrose ester, dough conditioners [dextrose, flour diacetyl tartaric acid esters of mono- and diglyceride, mono- and diglycerides*, ascorbic acid, f*ungal alpha amylase, L-cysteine hydrochloride, azodicarbonamide], gum Arabic, butter flavor [modified food starch, maltodextrin, natural and artificial flavors, partially hydrogenated soybean oil, water, soy lecithin], glucono-delta-lactone, calcium sulfate, xanthan gum, sorbic acid); barbecued beef (beef, tomato paste [tomato paste, salt, citric acid], brown sugar, mustard, glycerol, honey, molasses, spices, and flavorings, beef broth, partially hydrogenated soybean oil, salt, partially polished brown rice syrup, vinegar flavor [sodium diacetate, citric acid, potassium citrate, glucona-delta-lactone], Worcestershire sauce [distilled vinegar, molasses, corn syrup, water, salt, caramel coloring, sugar, spices, anchovies, flavoring, tamarind, dried onions, smoke flavoring, sodium phosphate]). The Honey BBQ Beef Sandwich has a high protein content and contains about 21% meat.

Nutrition Facts: serving size 1 package (100 g), 320 calories (80 calories from fat), 9 g total fat (3 g from saturated fat, 2.5 g trans-fat, 40 mg cholesterol), 700 mg sodium, 29 g total carbohydrates (3 g dietary fiber, 2 g sugars) and 21 g protein.

3.2.2 Storage Conditions

For the storage conditions, four discrete temperature points were chosen: 85°F, 95°F, 130°F and 100°F (Figure 126). These time-temperature combinations were chosen based on conditions that can be encountered in real-life handling and distribution of FSR rations:

3.2.2.1 Storage Temperature And Duration At Origin

85°F is a typical value for a temperature-controlled warehouse, and since one of the temperatures used for the shelf-life study was 80°F, a different temperature was chosen to validate the algorithm for any temperature that can be encountered in a real-life operation. A two-week storage period was chosen because FSR rations are typically made-to-order, and so their storage time is shorter compared to that of MRE rations. Therefore, two weeks was assumed to be a good representation of a real storage period.

3.2.2.2 Shipping Temperature And Duration

Based on a prior shipping temperature study performed by NSRDEC, the average shipping duration was approximately four weeks, and the average minimum and maximum temperatures recorded were near 95°F.

3.2.2.3 Storage Temperature And Duration At Destination

Two different time-temperature scenarios were chosen based on conditions that can be encountered in desert-like areas:

a) In the first scenario, FSR items were stored for two weeks at 130°F so that a significant change in the quality could be measured. This temperature was considered a high temperature but different from the highest temperature used in the shelf-life study (140°F), where samples were stored at constant temperatures (Section 2).

b) In the second scenario, FSR items were stored for 30 weeks at 100°F in order to estimate the remaining shelf life. The model then predicted the shelf life assuming that the average temperature of the product was 100°F for the remainder of the storage.

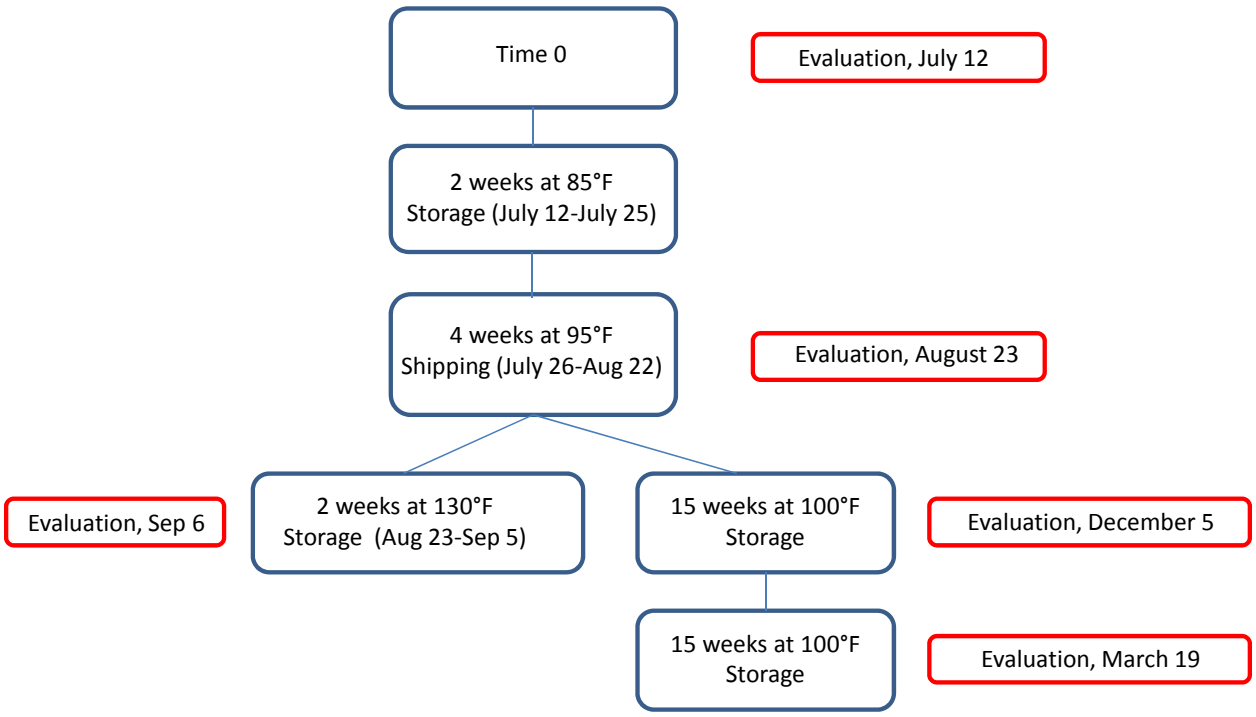


Figure 126. FSR Shipping simulation and evaluation schedule. Scenario A = 2 weeks at 85°F plus 4 weeks at 95°F plus 2 weeks at 130°F; Scenario B = 2 weeks at 85°F plus 4 weeks at 95°F plus 30 weeks at 100°F

Physicochemical evaluations were conducted using three replicated samples/packages per individual FSR item for initial quality evaluation (Time 0) and then again during a 30-week storage period following the schedule shown in Figure 126 (Scenario A = 2 weeks at 85°F plus 4 weeks at 95°F plus 2 weeks at 130°F; Scenario B = 2 weeks at 85°F plus 4 weeks at 95°F plus 30 weeks at 100°F). The schedule used for the physicochemical evaluations was synchronized with the sensory panel schedule so that when the panelists considered the samples unacceptable we

would be able to terminate the experimental part for the physicochemical analysis. Before the physicochemical evaluation was performed, samples were removed from their respective temperatures and held under ambient conditions until all reached the same temperature.

3.2.3 Quality Evaluations

For each of the five FSR items chosen for this study, the physical and compositional attributes measured were selected based on significant correlations found between sensory attributes and quantitative quality attributes measured by physical or chemical methods (Phase I). That is, for each FSR item only the physicochemical attributes that correlated significantly with sensory data were measured (Table 26).

Table 26. Physicochemical attributes measured for each selected FSR item

	Applesauce	Italian Style	Honey BBQ	Bacon Cheddar	French Toast
Color	x	x	x	x	x
Texture	x			x	x
Water activity	x	x			x
Moisture content			x		
Sugars	x	x	x	x	x
Ascorbic acid	x				
Peroxide value				x	x
pH		x	x	x	x
Titratable acidity		x	x	x	
Soluble solids content		x	x		x

3.2.3.1 Physical Evaluation

Color. Surface color measurements were taken on three replicated samples of each FSR sample, at five different points, with a hand-held tristimulus reflectance colorimeter (Model CR-300, Minolta Co., Ltd., Osaka, Japan) equipped with a glass light-protection tube with an 8 mm aperture (CR-A33a, Minolta Co., Ltd., Osaka, Japan) using standard illuminant D65 (Figure 59). Color was recorded using the CIE-L*a*b* uniform color space (CIE-Lab), L* (lightness), a* (redness) and b* (yellowness) values. The numerical values of a* and b* were converted into hue angle ($h°_{ab} = \tan^{-1}b^*/a^*$) and chroma [$C^*_{ab} = ([a^*]^2+[b^*]^2)^{1/2}$].

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Texture. Textural analysis of each FSR sample was performed using the TA.XT Plus Texture Analyzer (Texture Technologies Corp., Scarsdale, NY) (Figure 59). Maximum peak force for compression and shear testing was expressed as kg-force (kgf).

Filled French Toast Pocket, Bacon Cheddar Pocket Sandwich, Honey BBQ Beef Sandwich and Italian-Style Sandwich were sheared using a knife probe for 25 mm distance at a speed of 10 mm/s with a 1 g contact force. Maximum peak force was obtained from five readings on each of the three replicated samples per temperature.

The texture of Applesauce was evaluated using a flat probe, which compressed 50 mL of Applesauce in a 100 mL plastic container for 50 mm distance at a speed of 10 mm/s with a 1 g contact force. Maximum peak force was obtained by taking five readings on each of the three replicated samples per temperature.

3.2.3.2 Compositional Analysis

Moisture Content. Moisture content was determined by the standard gravimetric method. A 5 g homogenized sample was spread evenly over the bottom of a metal dish, weighed, and dried 24 h at 80°C in a laboratory oven (Model: 40GC, Quincy Lab Inc., Chicago, IL). Dry samples were cooled in desiccators, then weighed, and final weight was subtracted from initial weight to obtain the moisture content. Triplicates were taken from three FSR samples per temperature.

Water Activity. Water activity was performed using the dew point technique with an AquaLab 4TE water activity meter (Decagon device Inc., WA, USA). A 2 g homogenized sample was weighed in a disposable plastic cup and placed into the chamber of the water activity meter for measurement. Three replicates per item per temperature were used.

Titratable Acidity, Soluble Solids Content (SSC) and pH. Samples were homogenized using a hand-held homogenizer (BioMixerBamix, Biospec, Switzerland) or a commercial blender (Model HBB908, Hamilton Beach Inc., NC, USA). A 5 g aliquot of each sample was mixed thoroughly with 45 mL deionized water in a 50 mL polypropylene screw cap tube. After vortexing for 30 s, samples were centrifuged at 6500 rpm for 20 min in a centrifuge (Hermle Z200A, Labnet, Edison, NJ, USA). The supernatant was decanted from the centrifuge tubes for TA, SSC and pH measurements. Then 6.0 g of each supernatant was weighed into 50 mL beakers and diluted with 50 mL distilled water. The titratable acidity was determined by titration with 0.1 N NaOH to an end point of pH 8.1 with an automatic titrimeter (Titroline 96, SCHOTT-GERÄTE GmbH, Germany). The pH of samples was determined using a pH meter (Accumet model 15, Fisher Scientific, CO, USA), previously calibrated with a pH of 4 and 7. The soluble solids content (SSC) of the resulting clear samples was measured with a digital refractometer (Palette PR-101, 0-45 Brix, Atago Co. LTD, Tokyo) (Figure 59).

Quantification of Ascorbic Acid (Vitamin C) by HPLC. This procedure was only performed on samples that contained significant amounts of ascorbic acid: Applesauce, Bacon Cheddar Pocket Sandwich, Italian-Style Sandwich and Honey BBQ Beef Sandwich. Samples were homogenized

using a hand-held homogenizer (BioMixerBamix, Biospec, Switzerland) or a commercial blender (Model HBB908, Hamilton Beach Inc., NC, USA). Then 2 g of each homogenized sample was weighed in a 50 mL plastic bottle, and 20 mL metaphosphoric acid mixture (6% HPO_3, containing 2 N acetic acid) was added. The samples were filtered (0.22 µm filter) prior to HPLC analysis. Ascorbic acid analysis was conducted using a Hitachi LaChromUltra UHPLC system with a diode array detector and a LaChromUltra C18 4.6µm column (2 × 50 mm) (Hitachi, Ltd., Tokyo, Japan). The analysis was performed under isocratic mode at a flow rate of 1 mL/min with a detection of 254 nm. The sample injection volume was 5 µL. The mobile phase used was buffered potassium phosphate monobasic (KH_2PO_4, 0.5%, w/v) at pH 2.5, with metaphosphoric acid (HPO_3, 0.1%, w/v). The retention time of ascorbic acid peak was 2.48 min. After comparison of retention time with the ascorbic acid standards, the peak was identified. The amount of total ascorbic acid was quantified using calibration curves obtained from different concentrations of ascorbic acid standards. Three samples per item per temperature were used for each time with duplicate HPLC injections.

Quantification of Individual and Total Sugar Profile by HPLC. This procedure was the same for all FSR items evaluated except for Applesauce, for which the ether and boiling steps were omitted. The procedure for Applesauce samples can be found in the second paragraph below.

An aliquot of 5 g from each homogenized sample was mixed thoroughly with 45 mL petroleum ether in a 50 mL polypropylene screw-cap tube. After vortexing for 30 s, samples were centrifuged at 6000 rpm for 10 min. The ether was discarded, and 45 mL distilled water was added. The samples were placed into a boiling water bath for 25 min and vortexed every 5-7 min. Subsequently, the samples were cooled to room temperature and centrifuged at 6000 rpm for 10 min. The supernatant was decanted from the centrifuge tubes and filtered through a 0.45 µm nylon syringe into labeled amber glass vials. Individual and total sugar analyses were conducted using a Hitachi HPLC system with an RI-refractive index detector and a 300 mm × 8 mm Shodex SP0810 column (Shodex, Colorado Springs, CO) with a SP-G guard column (2 mm x 4 mm). An isocratic solvent delivery of water was run at 1.0 mL/min. The sample injection volume was 5 µL. Several standards including maltodextrin, sucrose, glucose and fructose were run to identify sample peaks. After comparison of retention time with standards, the peaks were identified. The amount of total sugar was quantified using calibration curves obtained from different concentrations of standards. Three samples per FSR item per temperature were used for each time with duplicate HPLC injections.

An aliquot of 5 g per Applesauce sample was mixed thoroughly with 45 mL distilled water in a 50 ml polypropylene screw-cap tube. After vortexing or mixing for 30 s, samples were centrifuged at 6000 rpm for 10 min. The supernatant was decanted from the centrifuge tubes and filtered through a 0.45 µm nylon syringe into labeled amber glass vials. Individual and total sugar analyses were conducted using a Hitachi HPLC system with a RI-refractive index detector and a 300 mm × 8 mm Shodex SP0810 column (Shodex, Colorado Springs, CO) with a SP-G guard column (2 mm × 4 mm). An isocratic solvent delivery of water was run at 1.0 mL/min. The sample injection volume was 5 µL. Several standards including maltodextrin, sucrose, glucose and fructose were run to identify sample peaks. After comparison of retention time with the

standards, the peaks were identified. The amount of total sugar was quantified using calibration curves obtained from different concentrations of standards. Three samples per Applesauce item per temperature were used for each time with duplicate HPLC injections.

Lipid Oxidation. The Peroxide Value (PV) method was used to measure the primary oxidation products and an index to quantify the amount of hydrogen peroxide in FSR products (note that this method measures only primary oxidation products that do not cause rancid flavors). For sandwiches that contained a defined bread and meat part, such as Bacon-Cheddar, Beef BBQ and Italian, the PV was measured in the whole sandwich and in the meat part of the sandwich.

Approximately 1 g of each homogenized item was transferred to a 15 mL disposable glass test tube, homogenized for 1 min with 3mL of chloroform/methanol (2:1) using a Biohomogenizer, and 7 mL of chloroform/methanol (2:1) was added and mixed with 3 mL of 0.5 % NaCl solution. The mixture was vortexed for 30 s and then centrifuged at 2000 rpm for 10 min in a cold room at 5°C. The chloroform phase was removed, and a 2 mL volume was made to 10 ml using chloroform/methanol (2:1). A 50 µl aliquot of thiocyanate/Fe2+ solution was added, and then the sample was inverted three times with parafilm. The thiocyanate/Fe2+ solution was made immediately before use by mixing 1 volume of thiocyanate solution (3.94 M ammonium thiocyanate) with 1 volume of Fe2+ solution (obtained from the supernatant of a mixture of 3 ml of 0.144 M BaCl2 in 0.4 M HCl and 3 ml of freshly prepared 0.144 M FeSO4). The samples were incubated for 10 min at room temperature, and the absorbance was measured at 500 nm. A standard curve was prepared using cumenehydroperoxide.

Although there is no certain threshold for PV in the literature, some researchers have reported the level of PV depending on the type of food analyzed. For example, the limiting PV values reported to be critical for acceptability of roasted peanuts or peanut oil were 20-30 meq/kg (Evranuz, 1993; St. Angelo et al., 1977; Balasubramanyam et al., 1983; Narasimhan et al., 1986); crude fish oil was 7-8 meq /kg (Huss, 1988); bread sticks were 11.4-14.2 meq/kg (Calligaris, 2008); and biscuits were 13-18 meq/kg (Calligaris, 2007).

3.3 Results

3.3.1 Applesauce, CHO Enhanced

3.3.1.1 Physical Characteristics

Appearance and Color

As the temperature and time increased, the characteristic yellowish appearance of Applesauce changed; the color darkened, becoming dark yellow or more orange than yellow (Figure 127). After 2 weeks at 85°F plus 4 weeks at 95°F the color of Applesauce was still acceptable compared to the initial color of the sample, but then it darkened when exposed for two additional weeks at 130°F or for 30 additional weeks at 100°F. Quantitative color measurement validated the visual observations; that is, the L* value and hue angle decreased (darker color, less bright yellow and more orange) while the chroma increased (more vivid color) as the temperature and exposure time increased (Table 27). However, the decrease in L* value and in

hue angle (darker color) was higher in samples exposed for 30 additional weeks at 100°F compared to those exposed for two additional weeks at 100°F.

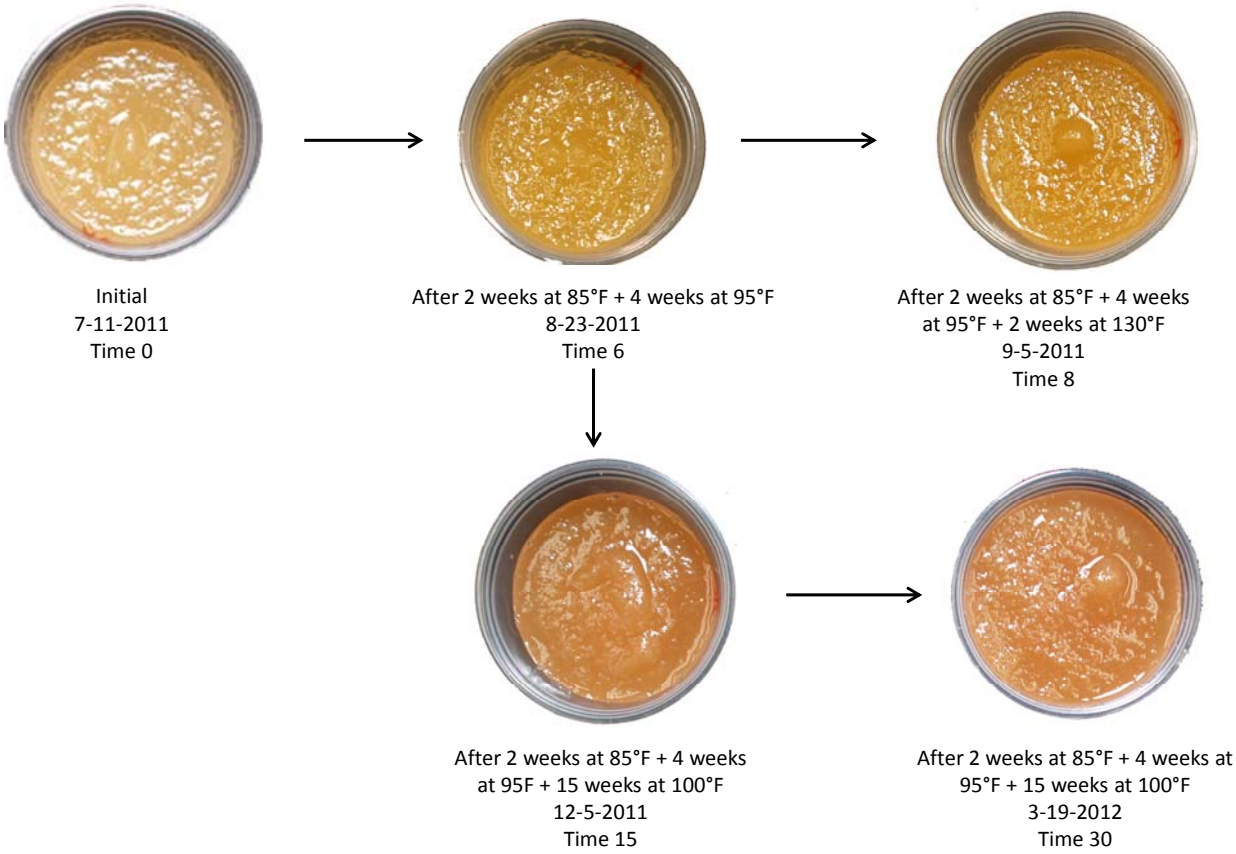


Figure 127. Changes in the appearance of Applesauce when exposed to non-constant temperatures normally encountered during supply chain operations

Texture

Overall, exposure of Applesauce to fluctuating high temperatures caused a change in the texture of the puree (Table 27). The firmness of the applesauce exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 2 weeks at 130°F decreased by approximately 9%, whereas the firmness of Applesauce exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 30 weeks at 100°F decreased by approximately 19%. This decrease in firmness was translated by a thinner or watery texture (loss of consistency of the puree), particularly in samples exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 30 weeks at 100°F.

3.3.1.2 Compositional Analysis

Water Activity

Compared to initial values, no change was observed in the water activity (a_w) of Applesauce samples exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 2 weeks at 130°F. However, a slight increase was observed in water activity of Applesauce samples exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 30 weeks at 100°F (Table 28). The increase in water activity

resulted in more free water availability, thus causing the watery appearance and decreased consistency of the apple puree.

Individual and Total Sugar Profiles

Sucrose levels decreased significantly due to the hydrolysis of this sugar into glucose and fructose (Table 29). Thus, after exposure of the samples for 2 weeks at 85°F plus 4 weeks at 95°F plus 2 weeks at 130°F or after exposure for 2 weeks at 85°F plus 4 weeks at 95°F plus 15 weeks at 100°F, there were no detected levels of sucrose in the samples. Exposure to both of the fluctuating high temperature regimes also resulted in increased glucose and maltodextrin contents, whereas, compared to initial values, concentrations of fructose remained practically the same. Applesauce is an FSR item enhanced in maltodextrin for increased performance; therefore initial levels are higher compared to commercial applesauce products. In this study, maltodextrin increased after exposure to high temperature regimes, and it is possible that this increase might have been caused by the degradation of more complex carbohydrates such as pectin or starch, which are common compounds in apple products. Overall, the total sugar content decreased due to the decrease in sucrose.

Ascorbic Acid

The ascorbic acid (vitamin C) is a key component in Applesauce, as it not only prevents oxidation and browning reactions in food but is also a source of vitamin C to the diet. In the case of Applesauce, ascorbic acid is added to increase the vitamin C content of the food. In this study, the ascorbic acid (AA) content decreased significantly regardless of the temperature regime the samples were exposed to (Table 30). However, compared to initial values, the decrease in AA was smaller (36% decrease) in samples exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 2 weeks at 130°F than in samples exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 30 weeks at 100°F (59% decrease).

3.3.2 Bacon Cheddar Pocket Sandwich

3.3.2.1 Physical Characteristics

Appearance and Color

As the temperature and exposure time increased, the color of Bacon Cheddar Pocket Sandwiches changed from a light to a darker brown (Figure 128). Overall, development of browning occurred after exposure for 2 weeks at 85°F plus 4 weeks at 95°F and was intensified by the exposure for an additional 2 weeks at 130°F or for an additional 30 weeks at 100°F. The development of the brown color could have been caused by non-enzymatic browning due to exposure of the samples to high temperatures. A decrease in L* and hue angle values (darker more brownish) and an increase in chroma (more vivid) validated the visual subjective observations of color changes from a light to a darker brown (Table 27).

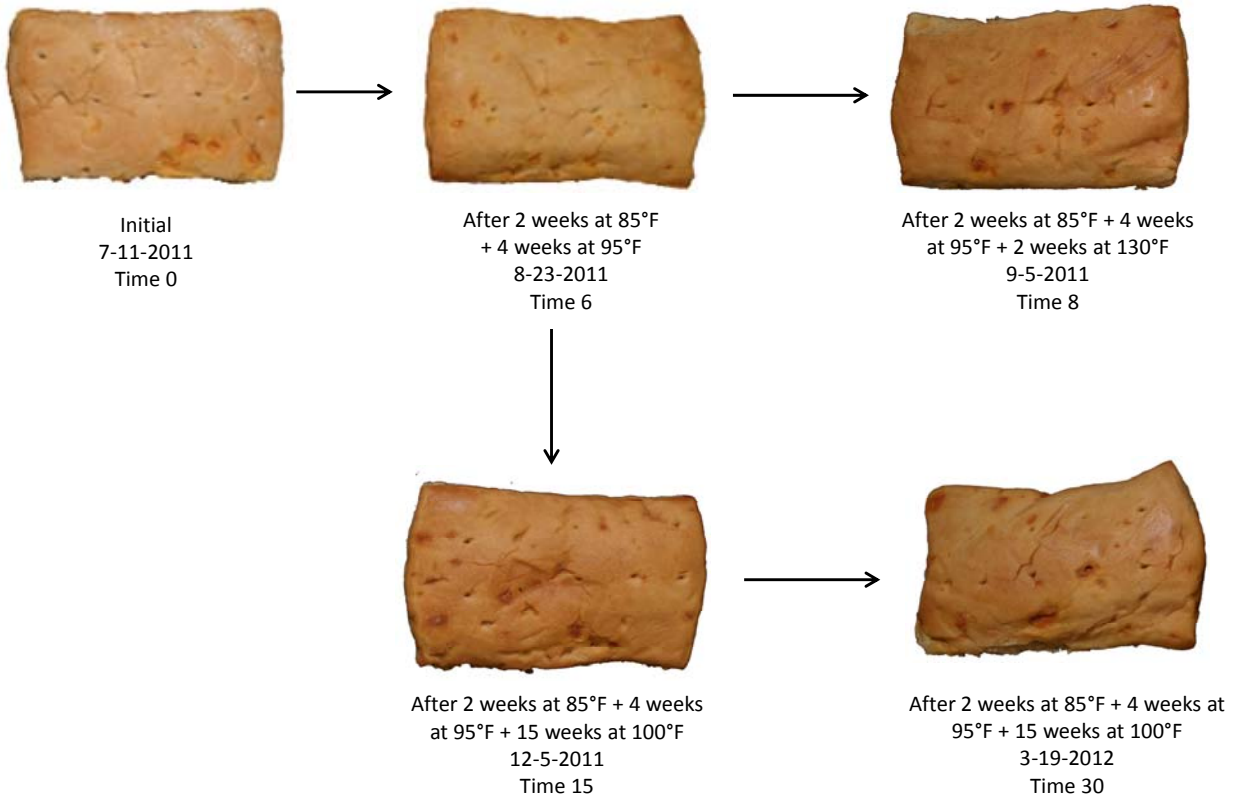


Figure 128. Changes in the appearance of Bacon Cheddar Pocket Sandwich when exposed to non-constant temperatures normally encountered during supply chain operations

Texture

The texture of the samples changed significantly during exposure to both temperature regimes, and at the end of the simulated shipping period the sandwiches were less firm compared to initial values (Table 27). However, the highest decrease (44% decreased in firmness) was observed in samples exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 30 weeks at 100°F

compared to those exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 2 weeks at 130°F (16% decrease in firmness).

3.3.2.2 Compositional Analysis

pH and Titratable Acidity

The pH of the sandwiches slightly decreased after exposure to both fluctuating high temperature regimes, but at the end of the simulated shipping period the pH of the samples exposed to the different regimes was not different (Table 28). The acidity of the sandwiches remained practically unchanged after exposure to both of the simulated shipping periods.

Individual and Total Sugar Profiles

There was an increase in the concentrations of sucrose and maltodextrin and a marked decrease in fructose for samples exposed both for 2 weeks at 85°F plus 4 weeks at 95°F plus 2 weeks at 130°F and for 2 weeks at 85°F plus 4 weeks at 95°F plus 30 weeks at 100°F (Table 29). The dramatic decrease in fructose to non-detectable values contributed to the decrease in the total sugar content.

Lipid Oxidation

Peroxide value was measured on both the whole sandwich (bread and meat) and the meat only, during exposure of the sandwiches to both fluctuating high temperature regimes (Table 30). Although the peroxide value increased after exposure of the samples to both regimes, the level of lipid oxidation was reasonably low. In terms of overall quality, the lipid oxidation that occurred during exposure of the Bacon Cheddar Sandwich to simulated shipping was not considered critical, as the levels remained low, considering a range of 7-30 meq/kg as the limit of acceptability reported in the literature for different foods (in Materials and Methods).

3.3.3 Filled French Toast Pocket

3.3.3.1 Physical Characteristics

Appearance and Color

In general, the color of French Toast Pockets turned from a light to a dark brown, regardless of the fluctuating temperature regime the samples were exposed to (Figure 129). Although from visual observations it was not evident that the samples exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 2 weeks at 130°F were less dark than those exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 30 weeks at 100°F, quantitative color measurements showed that samples from the first temperature regime were lighter (higher L* values and hue angle values and lower chroma values) than the samples from the second temperature regime (lower L* and hue angle values and higher chroma values) (Table 27).

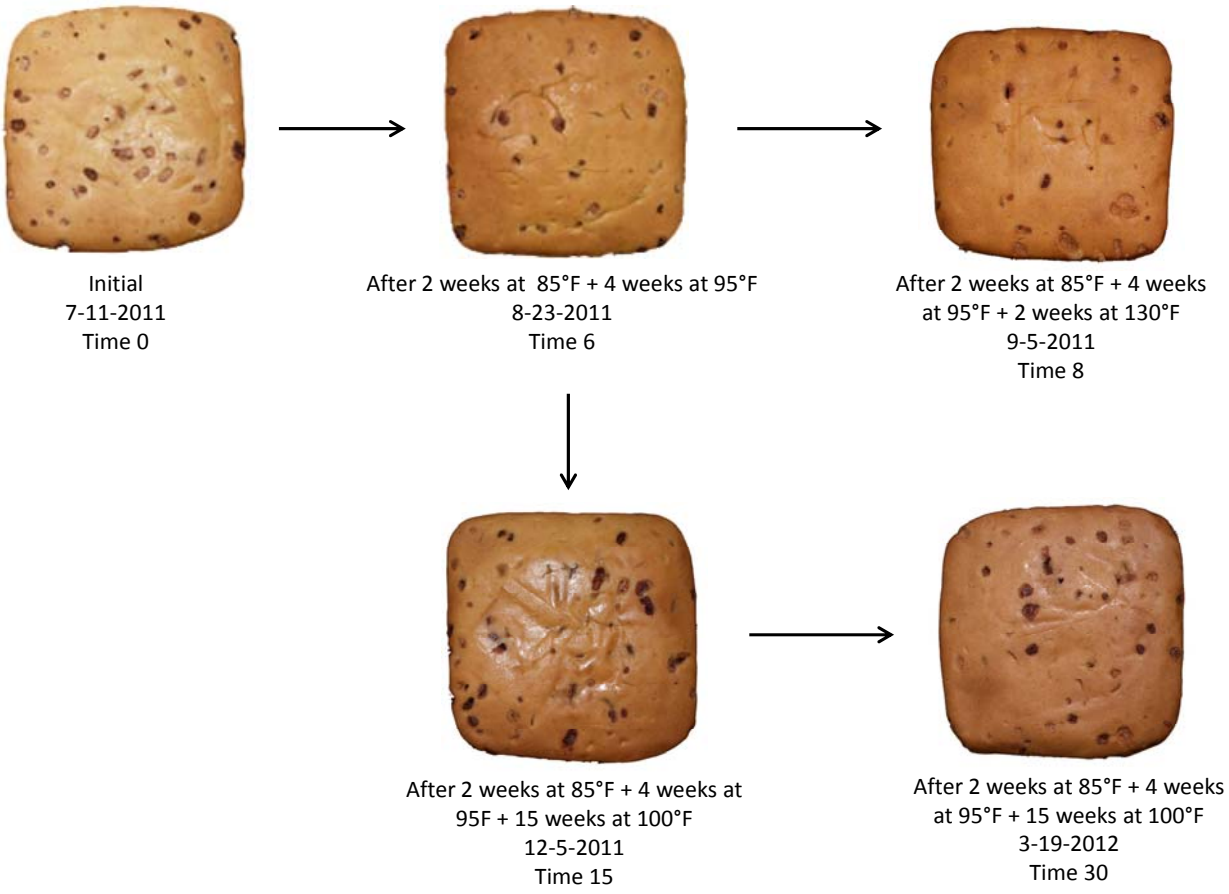


Figure 129. Changes in the appearance of Filled French Toast Pocket when exposed to non-constant temperatures normally encountered during supply chain operations

Texture

Overall, firmness of French Toast samples decreased regardless of the temperature regime becoming softer with increasing temperature and exposure time (Table 27). However, the decrease in firmness was higher (14% softer than at the beginning of the simulation) in samples exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 30 weeks at 100°F compared to those exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 2 weeks at 130°F (2% softer than at the beginning of the simulation).

3.3.3.2 Compositional Analysis

Water Activity

Water activity increased regardless of the temperature regime (Table 28). This might have been caused by the fact that at the end of each respective simulating shipping period there was more free water in the food matrix or that water migrated from one layer of the product to the other. Samples exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 30 weeks at 100°F had a slightly higher water activity than those exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 2 weeks at 130°F. The increase in water activity may also have contributed to the increased softness of the samples.

pH and Soluble Solids Content

The pH of Filled French Toast Pocket samples showed a decreasing trend, regardless of the temperature regime (Table 28). During the shipping simulation where samples were exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 2 weeks at 130°F, the decrease in pH was lower than in samples that were exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 30 weeks at 100°F. Thus, samples from the second simulated shipping treatment had a lower pH than those exposed to the first shipping simulation. A similar trend was observed for the soluble solids content (SSC) where samples exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 2 weeks at 130°F had a higher SSC than those exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 30 weeks at 100°F (Table 28).

Individual and Total Sugar Profiles

Sucrose was the major sugar measured in Filled French Toast Pocket (Table 29). While sucrose, glucose and total sugar concentrations decreased, the fructose and maltodextrin concentrations increased regardless of the temperature regime. The increase in fructose may have resulted from the hydrolysis of sucrose, and the increase in maltodextrin may have resulted from the conversion of more complex polysaccharides present in the food to maltodextrin. The decrease in sucrose, glucose and total sugars was, however, higher in samples exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 30 weeks at 100°F compared to those exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 2 weeks at 130°F. Overall, at the end of the shipping simulation, samples from the shorter temperature regime had a higher total sugar content than those from the longer temperature regime.

Lipid Oxidation

The degree of lipid oxidation was measured using the peroxide value (PV) assay to monitor the primary oxidation products formed. Table 30 shows the level of PV in Filled French Toast Pocket in samples from the two different simulated shipping regimes. At the end of each regime, the level of lipid oxidation was reasonably low regardless of the treatment. However, samples exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 2 weeks at 130°F had lower PV values than those exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 30 weeks at 100°F. In terms of overall quality, the lipid oxidation that occurred during storage of Filled French Toast Pocket was not considered critical, as the levels remained quite low (0.60-1.74 meq/kg), considering a range of 7-30 meq/kg as the limit of acceptability reported in the literature for different foods (in Materials and Methods).

3.3.4 Honey BBQ Beef Sandwich

3.3.4.1 Physical Characteristics

Appearance and Color

In general, as the temperature and exposure time increased, the sandwich became darker, with its color changing from a light brown to a slightly darker brown (Figure 130). Although changes in visual appearance were very subtle and difficult to perceive, the L* value and hue angles decreased and the chroma increased showing that the sandwiches became darker regardless of the temperature regime (Table 27). However, samples exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 2 weeks at 130°F were lighter (higher L* values and hue angles) than those exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 30 weeks at 100°F.

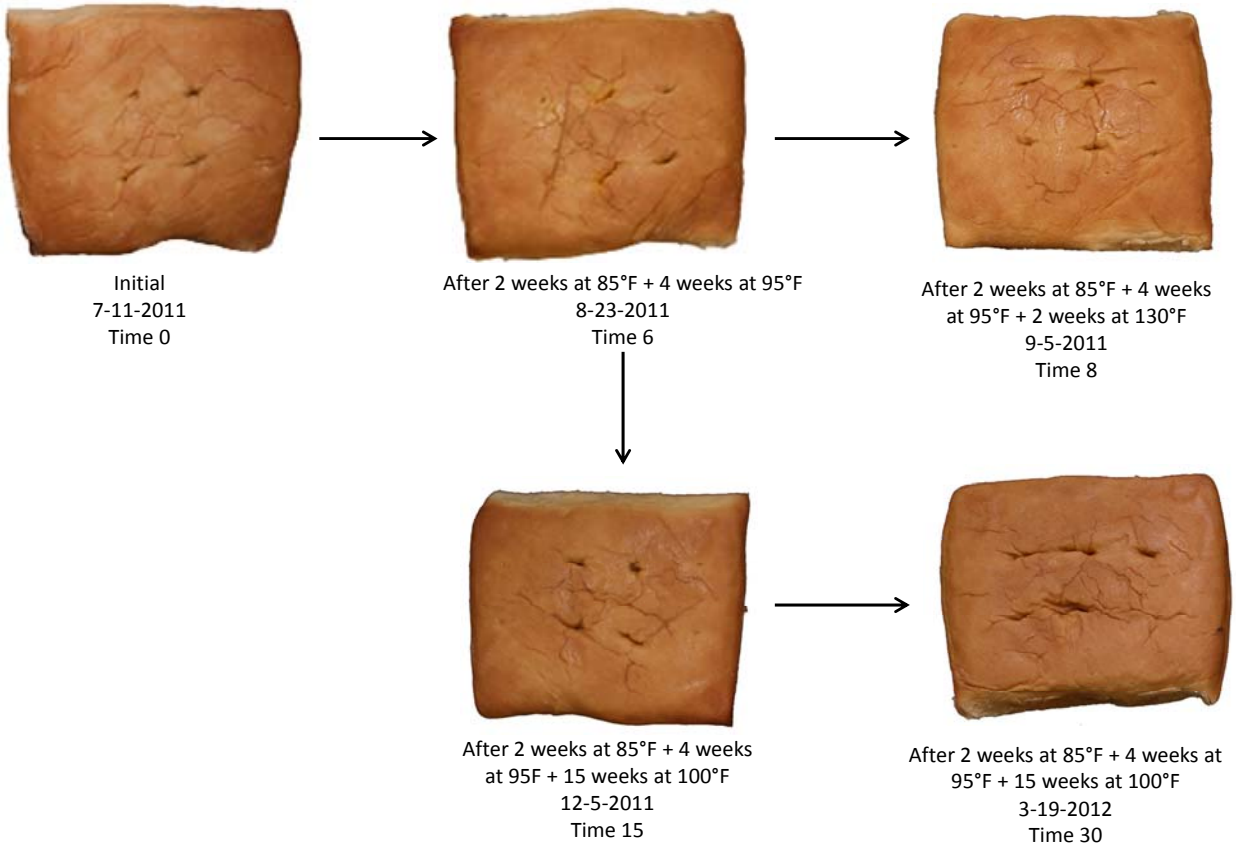


Figure 130. Changes in the appearance of Honey BBQ Beef Sandwich when exposed to non-constant temperatures normally encountered during supply chain operations

3.3.4.2 Compositional Analysis

Moisture Content

The moisture content of Honey BBQ Beef Sandwich decreased regardless of the temperature regime (Table 28). However, the decrease in moisture content in samples exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 30 weeks at 100°F was two-fold higher (24 % decrease) than in samples exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 2 weeks at 130°F (12% decrease).

pH, Titratable Acidity and Soluble Solids Content

The Honey BBQ Beef Sandwich pH decreased regardless of the temperature regime (Table 28), but the decrease was slightly higher in samples exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 30 weeks at 100°F compared to those exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 2 weeks at 130°F. The acidity did not change in samples from the shorter shipping simulation but decreased in those exposed to a longer shipping simulation (Table 28). The soluble solids content (SSC) decreased in samples from the shorter shipping simulation but increased in samples from the longer shipping simulation (Table 28). The increase in SSC for samples exposed to the longest simulation was most likely due to the increase in glucose and maltodextrin (Table 29).

Individual and Total Sugar Profiles

Fructose was the major sugar measured in Honey BBQ Beef Sandwiches, followed by sucrose and maltodextrin (Table 29). During simulated shipping, sucrose and fructose contents decreased whereas glucose and maltodextrin increased, regardless of the temperature regime. However, the decrease in sucrose and fructose were higher (65 and 26% decrease, respectively) in samples exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 30 weeks at 100°F than in samples exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 2 weeks at 130°F (16 and 20% decrease in sucrose and fructose, respectively). Similarly, the increase in glucose and maltodextrin was higher in samples from the longer shipping simulation compared to those from the shorter shipping simulation. The total sugars decreased in Honey BBQ Beef Sandwiches from both the shorter and longer shipping simulation and. The decrease in total sugars was most likely due to the decrease in sucrose and fructose.

3.3.5 Italian-Style Sandwich

3.3.5.1 Physical Characteristics

Appearance and Color

As temperature and exposure time increased, the color of Italian-Style Sandwich changed from a light to a dark brownish regardless of the simulated shipping regime (Figure 131). Sandwiches exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 2 weeks at 130°F appeared slightly darker than those exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 30 weeks at 100°F. However, when color was quantitatively measured, L* values and hue angles were slightly higher (lighter color) in samples from the short temperature treatment compared to those from the longer temperature treatment (Table 27). The chroma was also higher (more vivid color) in samples from the short temperature treatment compared to those from the longer temperature treatment.

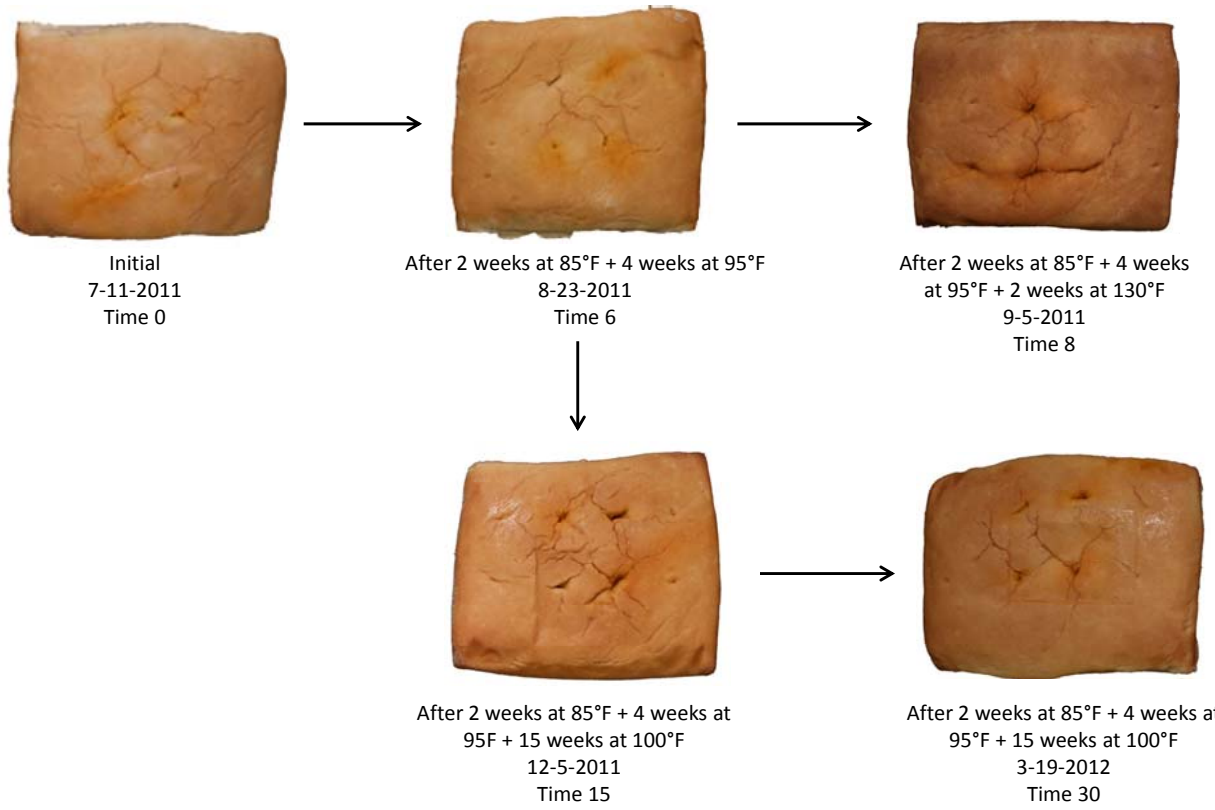


Figure 131. Changes in the appearance of Italian-Style Sandwich when exposed to non-constant temperatures normally encountered during supply chain operations

3.3.5.2 Compositional Analysis

Water Activity

Water activity increased slightly after exposure of Italian-Style Sandwiches to simulated shipping treatments (Table 28). Samples exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 30 weeks at 100°F showed a slightly higher increase in the water activity compared to samples exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 2 weeks at 130°F.

pH, Titratable Acidity and Soluble Solids Content

During exposure of Italian Style-Sandwiches to fluctuating temperature regimes, the pH decreased while the acidity and soluble solids content (SSC) increased, regardless of the temperature regime (Table 28). However, the decrease in pH was lower and the increase in acidity and SSC was higher in samples exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 30 weeks at 100°F than in samples exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 2 weeks at 130°F. The higher increase in the SSC of samples from the longer temperature treatment compared to the shorter temperature treatment (10% versus and 4% increase, respectively) most likely resulted from the higher increase in the individual and total sugar contents of samples exposed for 30 weeks at 100°F compared to those exposed for 2 weeks at 130°F (Table 29).

Individual and Total Sugar Profiles

The Italian-Style Sandwich individual and total sugar contents increased during exposure to fluctuating temperature regimes, regardless of the exposure time and temperature (Table 29). However, the increase in individual and total sugars was higher in samples exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 30 weeks at 100°F compared to those exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 2 weeks at 130°F. After the 30-week exposure at 100°F there was an increase of about 180% in the total sugar content of samples exposed to the longer temperature regime compared to a 98% increase in samples exposed to the shorter temperature regime. The highest decrease was observed in the fructose content, which increased by nine-fold compared to initial values.

Table 27. Color attributes (L* value, chroma and hue angle) of FSR items exposed to simulated storage and shipping conditions

	Time (weeks)[a]	L* value	Chroma	Hue	Texture (kgf)
Applesauce					
	0	29.57	5.11	68.98	0.103
	6	29.13	6.02	66.60	0.102
	8	27.92	8.17	55.30	0.094
	15	26.82	7.91	58.44	0.086
	30	25.18	8.55	51.55	0.083
Bacon Cheddar					
	0	64.48	30.41	77.90	10.51
	6	61.34	31.38	76.32	10.30
	8	56.37	33.14	73.46	8.88
	15	57.75	31.79	71.36	6.59
	30	57.65	39.90	73.32	5.84
French Toast					
	0	60.06	31.69	73.41	5.68
	6	59.70	32.52	72.42	5.65
	8	59.02	33.44	72.07	5.55
	15	56.32	34.13	68.28	5.39
	30	56.15	36.14	65.05	4.88
Honey BBQ					
	0	59.20	30.92	73.40	*
	6	58.55	32.48	66.34	*
	8	56.81	34.48	66.31	*
	15	55.70	35.07	64.89	*
	30	54.22	36.13	64.16	*
Italian Style					
	0	62.22	39.62	72.86	*
	6	61.45	38.75	70.90	*
	8	57.20	36.28	66.93	*
	15	57.17	34.37	66.27	*
	30	56.11	32.15	65.16	*

[a]Time 0 = Initial
Time 6 = 2 weeks at 85°F + 4 week at 95°F (common to both temperature scenarios)
Time 8 = 2 weeks at 85°F + 4 week at 95°F + 2 weeks at 130°F
Time 15 = 2 weeks at 85°F + 4 week at 95°F + 15 weeks at 100°F
Time 30 = 2 weeks at 85°F + 4 week at 95°F + 15 weeks at 100°F + 15 weeks at 100°F
(*) Not measured

Table 28. Moisture content, water activity, pH, acidity and soluble solids content of FSR items exposed to simulated storage and shipping conditions

	Time (weeks)[a]	MC (%)[b]	a_w[c]	pH	Acidity (%)	SSC (%)[d]
Applesauce	0	*	0.97	*	*	*
	6	*	0.97	*	*	*
	8	*	0.97	*	*	*
	15	*	0.97	*	*	*
	30	*	0.98	*	*	*
Bacon Cheddar	0	*	*	5.18	0.04	*
	6	*	*	5.27	0.04	*
	8	*	*	5.07	0.04	*
	15	*	*	4.93	0.06	*
	30	*	*	5.07	0.04	*
French Toast	0	*	0.84	5.29	*	3.23
	6	*	0.85	5.22	*	3.18
	8	*	0.85	5.03	*	3.18
	15	*	0.87	5.03	*	3.13
	30	*	0.87	4.96	*	2.50
Honey BBQ	0	35.60	*	4.74	0.07	2.30
	6	31.92	*	4.73	0.07	2.40
	8	31.43	*	4.68	0.07	2.40
	15	31.27	*	4.68	0.07	2.45
	30	26.91	*	4.60	0.09	2.48
Italian Style	0	*	0.85	4.96	0.04	1.90
	6	*	0.86	4.94	0.05	1.98
	8	*	0.86	4.86	0.05	1.98
	15	*	0.86	4.86	0.05	2.05
	30	*	0.87	4.75	0.07	2.10

[a]Time 0 = Initial
Time 6 = 2 weeks at 85°F + 4 week at 95°F (common to both temperature scenarios)
Time 8 = 2 weeks at 85°F + 4 week at 95°F + 2 weeks at 130°F
Time 15 = 2 weeks at 85°F + 4 week at 95°F + 15 weeks at 100°F
Time 30 = 2 weeks at 85°F + 4 week at 95°F + 15 weeks at 100°F + 15 weeks at 100°F
[b]MC = Moisture content
[c]a_w = Water activity
[d]SSC = Soluble solids content
(*) Not measured

Table 29. Sugar content of FSR items exposed to simulated storage and shipping conditions

	Time (weeks)[a]	Sucrose (g/100g)	Glucose (g/100g)	Fructose (g/100g)	Total Sugars (g/100g)	Maltodextrin (g/100g)
Applesauce	0	1.48	4.02	8.54	14.04	5.69
	6	2.46	3.70	8.11	14.27	5.75
	8	ND	5.26	8.52	13.78	6.32
	15	ND	5.41	8.82	14.23	6.31
	30	ND	5.15	8.51	13.66	6.67
Bacon Cheddar	0	1.50	ND	1.30	2.80	4.15
	6	2.09	ND	1.96	4.05	4.34
	8	1.87	ND	ND	1.87	4.60
	15	2.25	ND	0.62	2.88	4.46
	30	1.98	ND	ND	1.98	4.58
French Toast	0	8.34	5.92	6.27	20.52	3.80
	6	8.14	5.62	6.40	20.16	3.82
	8	7.96	5.51	6.42	19.90	4.23
	15	6.77	4.82	6.83	18.42	4.23
	30	6.27	4.34	7.66	18.27	4.63
Honey BBQ	0	3.44	1.67	4.40	9.51	3.09
	6	3.14	1.79	4.13	9.06	3.66
	8	2.90	2.47	3.50	8.87	3.78
	15	1.60	2.51	3.35	7.46	3.81
	30	1.22	2.59	3.25	7.07	4.16
Italian Style	0	1.05	1.02	0.31	2.39	3.83
	6	1.06	1.08	0.95	3.09	3.86
	8	1.50	1.70	1.53	4.73	4.10
	15	1.78	1.71	1.85	5.34	4.34
	30	2.08	1.80	2.85	6.73	4.49

[a]Time 0 = Initial
Time 6 = 2 weeks at 85°F + 4 week at 95°F (common to both temperature scenarios)
Time 8 = 2 weeks at 85°F + 4 week at 95°F + 2 weeks at 130°F
Time 15 = 2 weeks at 85°F + 4 week at 95°F + 15 weeks at 100°F
Time 30 = 2 weeks at 85°F + 4 week at 95°F + 15 weeks at 100°F + 15 weeks at 100°F
(ND) Not detected

Table 30. Ascorbic acid content and peroxide values of FSR items exposed to simulated storage and shipping conditions

	Time (weeks)[a]	Ascorbic Acid (mg/100g)	Peroxide Value (meq/kg)	
			Whole	Meat
Applesauce	0	137.03	*	*
	6	125.46	*	*
	8	87.72	*	*
	15	78.02	*	*
	30	55.74	*	*
Bacon Cheddar	0	*	1.61	1.81
	6	*	1.82	2.78
	8	*	0.73	1.91
	15	*	2.14	2.18
	30	*	1.81	2.39
French Toast	0	*	1.17	*
	6	*	1.72	*
	8	*	1.85	*
	15	*	1.91	*
	30	*	2.27	*

[a]Time 0 = Initial
Time 6 = 2 weeks at 85°F + 4 week at 95°F (common to both temperature scenarios)
Time 8 = 2 weeks at 85°F + 4 week at 95°F + 2 weeks at 130°F
Time 15 = 2 weeks at 85°F + 4 week at 95°F + 15 weeks at 100°F
Time 30 = 2 weeks at 85°F + 4 week at 95°F + 15 weeks at 100°F + 15 weeks at 100°F
(*) Not measured

3.4 General Conclusions

FSR items such as Applesauce, Bacon Cheddar Pocket Sandwich, Filled French Toast Pocket, Honey BBQ Beef Sandwich and Italian-Style Sandwich were exposed to two shipping simulations consisting of two different scenarios that had in common a first step in which the samples were exposed to the same time and temperature conditions (2 weeks at 85°F plus 4 weeks at 95°F) followed by one additional step in which: (1) samples were exposed to a higher temperature for a shorter duration (2 weeks at 130°F), and (2) samples were exposed to a lower temperature for a longer period of time (30 weeks at 100°F).

Overall, the appearance and physicochemical properties of all FSR items were negatively affected by the fluctuating temperature regimes used to simulate shipping and handling conditions encountered during distribution of combat rations. Compared to initial data obtained before the samples were exposed to shipping conditions, at the end of the simulations all FSR items had a darker color, were softer, had a lower moisture content and higher water activity, and had a lower pH and higher acidity and soluble solids content. Sugar profiles changed and either increased or decreased depending on the FSR items and individual sugars measured. For example, the total sugar content decreased in Bacon Cheddar, French Toast and Honey BBQ, whereas it decreased in Applesauce and Italian-Style Sandwich. Lipid oxidation increased and ascorbic acid decreased significantly in Applesauce.

When the two different shipping scenarios were compared (Table 31), data showed that the longer exposure time to a lower temperature was more detrimental to the overall quality of the FSR items analyzed than a shorter exposure time to a higher temperature. In general, samples exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 2 weeks at 130°F had a lighter color, were firmer, had a lower acidity and peroxide value and had a higher ascorbic acid content than samples that were exposed for 2 weeks at 85°F plus 4 weeks at 95°F plus 30 weeks at 100°F.

As also concluded in Phase I of this project, exposure to high temperatures for long periods of time resulted in critical changes in color, texture and chemical composition of all FSR items evaluated. For example, softening in bread-based products and decreased consistency in Applesauce were most likely related to a decrease in moisture content, while an increase in water activity resulted in more free water available for chemical reactions to occur such as hydrolysis/oxidation of some compounds such as sugar and ascorbic acid.

In summary, fluctuating temperatures that are often encountered during shipping and handling of FSR rations and food products in general are difficult to avoid; however, results from this study suggest that, when unavoidable, shorter exposure times (i.e., no longer than 2 weeks) to higher temperatures are less detrimental to the overall quality of FSR rations than longer exposure times to lower temperatures.

Table 31. FSR appearance and physicochemical attributes: comparison between two different shipping scenarios

	Scenario A 2 weeks at 85°F plus 4 weeks at 95°F plus 2 weeks at 130°F	**Scenario B** 2 weeks at 85°F plus 4 weeks at 95°F plus 30 weeks at 100°F
Appearance		
Applesauce	Lighter color	Darker color
Bacon Cheddar	Lighter color	Darker color
French Toast	Lighter color	Darker color
Honey BBQ	Lighter color	Darker color
Italian Style	Lighter color	Darker color
L* value		
Applesauce	Higher (lighter)	Lower (darker)
Bacon Cheddar	Lower (darker)	Higher (lighter)
French Toast	Higher (lighter)	Lower (darker)
Honey BBQ	Higher (lighter)	Lower (darker)
Italian Style	Higher (lighter)	Lower (darker)
Chroma		
Applesauce	Lower (less vivid)	Higher (more vivid)
Bacon Cheddar	Lower (less vivid)	Higher (more vivid)
French Toast	Lower (less vivid)	Higher (more vivid)
Honey BBQ	Lower (less vivid)	Higher (more vivid)
Italian Style	Higher (more vivid)	Lower (less vivid)
Hue angle		
Applesauce	Higher (lighter color)	Lower (darker color)
Bacon Cheddar	Higher	Lower
French Toast	Higher	Lower
Honey BBQ	Higher	Lower
Italian Style	Higher	Lower
Texture		
Applesauce	Firmer more viscous	Less firm more liquid
Bacon Cheddar	Firmer	Softer
French Toast	Firmer	Softer
Moisture Content		
Honey BBQ	Higher	Lower
Water activity		
Applesauce	Lower (same as initial)	Higher
French Toast	Lower	Higher
Italian Style	Lower	Higher
pH		
Bacon Cheddar	Same	Same
French Toast	Higher	Lower
Honey BBQ	Higher	Lower
Italian Style	Higher	Lower
Acidity		
Bacon Cheddar	Same	Same
Honey BBQ	Lower	Higher
Italian Style	Lower	Higher
Soluble solids content		
French Toast	Higher	Lower
Honey BBQ	Lower	Higher
Italian Style	Lower	Higher

Table 31. FSR appearance and physicochemical attributes: comparison between two different shipping scenarios (continued)

	Scenario A 2 weeks at 85°F plus 4 weeks at 95°F plus 2 weeks at 130°F	**Scenario B** 2 weeks at 85°F plus 4 weeks at 95°F plus 30 weeks at 100°F
Sucrose		
Applesauce	Same (not detected)	Same (not detected)
Bacon Cheddar	Lower	Higher
French Toast	Higher	Lower
Honey BBQ	Higher	Lower
Italian Style	Lower	Higher
Glucose		
Applesauce	Higher	Lower
Bacon Cheddar	Not detected	Not detected
French Toast	Higher	Lower
Honey BBQ	Lower	Higher
Italian Style	Lower	Higher
Fructose		
Applesauce	Same	Same
Bacon Cheddar	Same (not detected)	Same (not detected)
French Toast	Lower	Higher
Honey BBQ	Higher	Lower
Italian Style	Lower	Higher
Total sugars		
Applesauce	Higher	Lower
Bacon Cheddar	Lower	Higher
French Toast	Higher	Lower
Honey BBQ	Higher	Lower
Italian Style	Lower	Higher
Maltodextrin		
Applesauce	Lower	Higher
Bacon Cheddar	Higher	Lower
French Toast	Lower	Higher
Honey BBQ	Lower	Higher
Italian Style	Lower	Higher
Ascorbic acid		
Applesauce	Higher	Lower
Peroxide value - whole		
Bacon Cheddar	Lower	Higher
French Toast	Lower	Higher
Peroxide value - meat		
Bacon Cheddar	Lower	Higher

4 Physical And Compositional Attributes Of MRE Items During Storage At Different Temperatures

4.1 Introduction

Meals Ready-to-Eat (MRE) are considered the main individual combat ration of military sustenance for U.S. Armed Forces and are designed to provide individual food subsistence during operations for up to 21 days where food services are not available. Three MRE rations provide the necessary daily calories (3,900 calories; 1,300 per meal) and nutrients (13% protein, 34% fat and 52% carbohydrates) to the deployed soldiers. To provide flexibility and diversity of choice there are 24 menus available, composed by a variety of food items (Table 32). According to the NSRDEC, each component has a shelf life of 3 years at 80°F (27°C) or 6 months at 100°F (38°C). However, MRE rations may be exposed to adverse temperature conditions, particularly when shipped to desert-like areas where temperature can easily reach 140°F (60°C). When exposed to abuse temperatures, some of the MRE menu components may undergo chemical degradation, resulting in changes in the sensory attributes and nutritional value. Such undesirable changes ultimately lead to poor menu acceptance by the soldiers as well as insufficient nutrient intake. The objectives of this work were (1) to study the effect of different storage temperatures: refrigerated (40°F), ambient (80°F) and extreme (100, 120 and 140°F) temperatures, which are temperatures within the range normally encountered in temperate and warm regions of the world (i.e., subtropical, tropical or arid areas), on the physical and compositional quality of seven selected items from three MRE menus; and (2) to generate quantitative data to validate the sensory data used in the design of the shelf-life predicting model.

4.2 Materials And Methods

4.2.1 MRE Items

From the 24 available MRE menus at the time of this study (Reference MRE 31, 2011 Date of Pack), seven individual components were identified by the NSRDEC Combat Feeding Directorate as a representative cross section of shelf-life-sensitive MRE menu items (Table 32). The following items were selected for the study; Beef Ravioli in Meat Sauce; Cheese Spread with Jalapenos; Nut Raisin Mix; Pork Sausage in Cream Gravy; Chipotle Snack Bread; Chunky Peanut Butter; and Mango Peach Applesauce (not shown in Table 32). These components represent a balance of primary vs. secondary components based on their specific nutritional contribution to the overall ration menu and will provide relevant quality attribute changes (degradation) as they are environmentally stressed in order to effectively construct a functional shelf life model.

Table 32. Menus for Meals Ready to Eat (source: NSRDEC)

Menu #1	Menu #2	Menu #3
Chili with beans	Chicken fajita	**Beef ravioli**
Cheese spread, plain	Refried beans	Toaster pastry 1/
Corn bread	Brownie	Cookies I 4/
Crackers, plain	Cheese spread, plain	**Cheese spread, Jalapeno**
Toaster pastry 1/	Tortillas	Crackers, plain
Dairy shake 1/	Drink, cappuccino, Irish Cr.	Candy, caffeine mints
Spice, red pepper	Spice, seasoning blend	Beverage, carb fortified, orange,
Accessory packet A	Accessory packet B	Hot sauce
Spoon	Spoon	Accessory packet C, Spoon
Flameless ration heater	Flameless ration heater	Flameless ration heater
Hot beverage bag	Hot beverage bag	Hot beverage bag
Menu #4	**Menu #5**	**Menu #6**
Pork sausage, maple	Chicken, tomato, feta	Beef patty
Granola, milk, blueberries	Cornbread stuffing	Cheese spread, bacon
Peanut butter, smooth	Fruit, dried 1/	Snack crackers, filled 1/
Jam 1/	Cheese spread, plain	**Nut raisin mix**
Crackers, plain	Crackers, veg	Snack bread, wheat, twin pack
Maple muffin top	Candy II 2/	Beverage, carb fortified 1/
Beverage, sugar free, orange, vit. C and	Beverage, carbo electro 1/	BBQ sauce
Syrup	Accessory packet A	Accessory packet A
Accessory packet A	Spoon	Spoon
Spoon	Flameless ration heater	Flameless ration heater
Flameless ration heater	Hot beverage bag	Hot beverage bag
Hot beverage bag		
Menu #7	**Menu #8**	**Menu #9**
Brisket entree	Meatballs marinara sauce	Beef stew
Biscuit	Mashed potatoes, garlic	Peanut butter, smooth
Cookies 4/	Cheese spread, plain	Jelly 1/
Cheese spread, plain	Tortillas	Snack bread, wheat
Crackers, plain	Nuts 1/	Filled bakery, apple turnover
Candy I 2/	First Strike™ bar 1/	Cocoa, hazelnut
Cocoa	Beverage, carb fortified 1/	Hot sauce
Accessory packet B	Butter granules	Accessory packet B
Spoon	Accessory packet C	Spoon
Flameless ration heater	Spoon	Flameless ration heater
Hot beverage bag	Flameless ration heater	Hot beverage bag
	Hot beverage bag	
Menu #10	**Menu #11 - Vegetarian**	**Menu #12 - Vegetarian**
Chili and macaroni	Vegetable lasagna	Penne spicy pasta
Beef snacks	Fruit, wet pack 1/	Fruit, wet pack 1/
Dessert, pudding 1/	Cake 3/	Muffin top, choc. banana
Cheese spread, Jalapeno	Peanut butter, smooth	Snack bread, wheat
Crackers, plain	Snack bread, wheat	Peanut butter, smooth
Candy III 2/	Drink, cappuccino, Fr. Van.	Beverage, carbo electro 1/
Beverage, carbo electro 1/	Hot sauce	Hot sauce
Spice, red pepper	Accessory packet B	Accessory packet A
Accessory packet A	Spoon	Spoon
Spoon	Flameless ration heater	Flameless ration heater
Flameless ration heater	Hot beverage bag	Hot beverage bag
Hot beverage bag		

Table 32. Menus for Meals Ready to Eat (continued)

Menu #13 - Vegetarian	**Menu #14 - Vegetarian**	**Menu #15**
Cheese tortellini	Ratatouille	Southwest beef, black beans
Apples, spiced	Snack, bake sn cracker 1/	Rice, Mexican
First Strike™ bar 1/	Cake 3/	Snack, filled pretzels 1/
Peanut butter, chunky	Peanut butter, smooth	Cheese spread, plain
Crackers, plain	Crackers, plain	Tortillas
Candy II 2/	Beverage, carb fortified 1/	Beverage, carb fortified 1/
Beverage, carbo electro 1/	Spice, seasoning blend	Spice, red pepper
Spice, seasoning blend	Accessory packet A	Accessory packet A
Accessory packet B	Spoon	Spoon
Spoon	Flameless ration heater	Flameless ration heater
Flameless ration heater	Hot beverage bag	Hot beverage bag
Hot beverage bag		
Menu # 16	**Menu #17**	**Menu #18**
Pork rib	**Pork sausage with gravy**	Chicken with noodles
Potato cheddar soup	Granola with banana	Nut raisin mix with choc
Ranger bar 1/	Biscuit	Peanut butter, smooth
Cheese spread, plain	**Cheese spread, Jalapeno**	Snack bread, wheat
Snack bread, wheat, twin pack	Snack bread, wheat	Jam 1/
Candy II 2/	Fruit, dried 1/	Beverage, carb fortified 1/
Beverage, carbo electro 1/	Beverage, carb fortified 1/	Hot sauce
BBQ sauce	Hot sauce	Accessory packet A
Accessory packet B	Accessory packet C	Spoon
Spoon	Spoon	Flameless ration heater
Flameless ration heater	Flameless ration heater	Hot beverage bag
Hot beverage bag	Hot beverage bag	
Menu #19	**Menu #20**	**Menu #21**
Beef roast with vegetables	Spaghetti with meat sauce	Tuna, lemon pepper
Fruit, wet pack 1/	Fruit, dried 1/	Tortillas
Cake 3/	Cheese spread, plain	Cookies ⊢ 4/
Peanut spread, chocolate	Snack, pretzels 1/	Cobbler
Crackers, plain	**Snack bread, chipotle**	Candy I 2/
Cocoa	Candy III 2/	Dairy shake 1/
Accessory packet A	Beverage, carb fortified,orange,	Mayonnaise, fat free
Spoon	Hot sauce	Spice, seasoning blend
Flameless ration heater	Accessory packet A	Accessory packet B
Hot beverage bag	Spoon	Spoon
	Flameless ration heater	
	Hot beverage bag	
Menu #22	**Menu #23**	**Menu #24**
Sloppy Joe	Chicken pesto pasta	Buffalo chicken
Peanut butter, chunky	Cheese spread , plain	Santa Fe rice and beans
Jelly 1/	Snack bread, Italian	Patriotic Cookies
Snack bread, wheat	Snacks, corn nuts	Turkey nuggets
Cinnamon bun	Dessert, pudding 1/	**Cheese spread, Jalapeno**
Candy I 2/	Beverage, carbo electro 1/	Tortillas
Beverage, carbo electro 1/	Spice, red pepper	Drink, cappuccino, Mocha
Hot sauce	Accessory packet A	Accessory packet B
Accessory packet C	Spoon	Spoon
Spoon	Hot beverage bag	Hot beverage bag
Flameless ration heater		
Hot beverage bag		

Table 33. Physical and Compositional Evaluation Schedule

Dates	Weeks	40°F Control	80°F	100°F	120°F	140°F	NOTES
		64 weeks*	64 weeks	54 weeks	20 weeks	10 weeks	
			(every 8 weeks)	(every 6 weeks)	(every 2 weeks)	(every week)	
1-Nov	0	X - Initial Evaluation					**Start 2011**
8-Nov	1					X	
15-Nov	2	X			X	X	
22-Nov	3					X	
29-Nov	4	X			X	X	
6-Dec	5					X	
13-Dec	6	X			X	X	
20-Dec	7					X	
27-Dec	8	X			X	X	
3-Jan	9					X	**2012**
10-Jan	10	X	X	X	X	X	End of 140F
17-Jan	11						
24-Jan	12	X		X	X		
31-Jan	13						
7-Feb	14				X		
14-Feb	15						
21-Feb	16	X	X		X		
28-Feb	17						
6-Mar	18			X	X		
13-Mar	19						
20-Mar	20	X	X	X	X		End of 120F
27-Mar	21						
3-Apr	22						
10-Apr	23						
17-Apr	24	X	X	X			
24-Apr	25						
1-May	26						**6 months**
8-May	27						
15-May	28						
22-May	29						
29-May	30	X		X			
5-Jun	31						
12-Jun	32		X				
19-Jun	33						
26-Jun	34						
3-Jul	35						
10-Jul	36	X		X			
17-Jul	37						
24-Jul	38						
31-Jul	39						
7-Aug	40	X	X				
14-Aug	41						
21-Aug	42			X			
28-Aug	43						

Table 33. Physical and Compositional Evaluation Schedule (Continued)

Dates	Weeks	40°F Control	80°F	100°F	120°F	140°F	NOTES
		64 weeks*	64 weeks	54 weeks	20 weeks	10 weeks	
			(every 8 weeks)	(every 6 weeks)	(every 2 weeks)	(every week)	
4-Sep	44						
11-Sep	45						
18-Sep	46						
25-Sep	47						
2-Oct	48	X	X	X			
9-Oct	49						
16-Oct	50						
23-Oct	51						
30-Oct	52						**12 months**
6-Nov	53						
13-Nov	54	X	X	X			
20-Nov	55						
27-Nov	56						
4-Dec	57						
11-Dec	58						
18-Dec	59						
25-Dec	60						
1-Jan	61						**2013**
8-Jan	62						
15-Jan	63						
22-Jan	64						
29-Jan	65						
5-Feb	66						
12-Feb	67						
19-Feb	68						
26-Feb	69	Taste panel 100F (Feb 25)					
5-Mar	70						
12-Mar	71						
19-Mar	72						
26-Mar	73						
2-Apr	74						
9-Apr	75	Taste panel 100F (April 8)					
16-Apr	76						
23-Apr	77						
30-Apr	78						
7-May	79	Taste panel 100F (May 30)					
14-May	80						
21-May	81						
28-May	82						
4-Jun	83						
11-Jun	84	x	x	x	End for Trail Mix and Bread for 100F		
18-Jun	85						
25-Jun	86	x	x	x	End for PB, PS, MP, BR, CS for 100F		
2-Jul	87						
9-Jul	88	x	x		End all for 40 and 80F		

Note: each (X) corresponds to three samples/packages per MRE item

4.2.2 Storage Conditions

Various storage conditions and timeframes were selected to stress ration components in the laboratory in order to collect data and assess impacts while working within the time constraints of the overall project. These conditions are not unlike what might be encountered in actual operational situations. Three replicated samples/packages per individual MRE item (Beef Ravioli in Meat Sauce, Cheese Spread with Jalapenos, Nut Raisin Mix, Pork Sausage in Cream Gravy, Chipotle Snack Bread, Mango Peach Applesauce and Chunky Peanut Butter) were used for initial quality evaluation. A total of 180 packages per item were distributed among five temperature-controlled rooms that were set at 40°F (control-refrigerated conditions), 80°F, 100°F, 120°F and 140°F (i.e., 51 samples/packages were stored at 40°F, 33 samples/packages were stored at 80°F, 36 samples/packages were stored at 100°F, 30 samples/packages were stored at 120°F and 30 samples/packages were stored at 140°F). Physical and compositional attributes were evaluated during a maximum 88-week storage period following the schedule shown in Table 33. Samples stored at 40°F (control-refrigerated) were evaluated every time samples from another temperature were evaluated. Depending on the MRE item and temperature, the evaluation times were as follows: 10 weeks for all nine MRE items stored at 140°F; 20 weeks for all nine MRE items stored at 120°F; 84 weeks for Nut Raisin Mix and Chipotle Snack Bread stored at 100°F; 88 weeks for Beef Ravioli in Meat Sauce, Cheese Spread with Jalapenos, Pork Sausage in Cream Gravy, Mango Peach Applesauce and Chunky Peanut Butter stored at 100°F; 88 weeks for all MRE items stored at 40 or 80°F. The schedule used for the physicochemical evaluations was synchronized with the sensory panel schedule so that when the panelists considered the samples unacceptable we would be able to terminate the experimental part for the physicochemical analysis.

4.2.3 Quality Evaluations

Physical quality attributes were evaluated for all seven MRE items, and composition was evaluated according to the major components that were considered to be more susceptible to changes and therefore would be good indicators of deterioration. Changes in color, texture, water activity, moisture content, pH acidity and SSC were measured in all seven MRE items (Table 34 and Table 35). Ascorbic acid content was measured only in Chipotle Snack Bread, Mango Peach Applesauce and Chunky Peanut Butter, because these products are enriched with ascorbic acid (AA) to act as an antioxidant and/or to increase their nutrient content. Lipid oxidation was measured in all items except in Mango Peach Applesauce, due to its low content in lipids. Before the evaluation, samples were removed from their respective temperatures and held under ambient conditions until they all had reached the same temperature.

4.2.3.1 Physical Evaluation

Color. Surface color measurements were taken on intact samples of Mango Peach Applesauce, Chipotle Snack Bread, Cheese Spread with Jalapenos and Chunky Peanut Butter, whereas samples of Ravioli in Meat Sauce, Pork sausage in Cream Gravy and Nut Raisin Mix were homogenized with a hand blender before surface color measures were taken. The

homogenizing process was performed to obtain a sample with a more uniform color. Surface color measurements were then taken on three replicated samples of each MRE sample, at five different points, with a handheld tristimulus reflectance colorimeter (Model CR-300, Minolta Co., Ltd., Osaka, Japan) equipped with a glass light-protection tube with an 8 mm aperture (CR-A33a, Minolta Co., Ltd., Osaka, Japan) using standard illuminant D65. Color was recorded using the CIE-L*a*b* uniform color space (CIE-Lab), L* (lightness), a* (redness) and b* (yellowness) values. The numerical values of a* and b* were converted into hue angle ($h°_{ab} = \tan^{-1}b*/a*$) and chroma [$C*_{ab} = ([a*]^2+[b*]^2)^{1/2}$].

Table 34. Selected MRE products, key ingredients, defects likely to occur, and physical and chemical analyses performed for each of the items

	Chipotle Snack Bread	Mango Peach Applesauce	Raisin Trail Mix	Beef Ravioli in Meat Sauce
NSN#	8920-01-550-5325	8915-01-525-9671	8940-01-523-0786	8940-01-426-0553
				
Key ingredients	Enriched bleached flour, partially hydrogenated soybean oil, sugar, 2% or less : ascorbic acid Total fat 6g; total carbohydrates 30g; Sugars 3 g; vitamin C 15%	Apples, sugar, water, ascorbic acid, mango puree, peach puree, Total fat 0g; total carbohydrates 31g; sugars 26g; vitamin C 320%	Peanuts, raisins, walnuts, almonds, filberts, cozen, partially hydrogenated vegetable oil Total fat 27g; total carbohydrates 22g; total sugars 13g; vitamin C 0%	Water, seasoned beef, dextrose, whole milk ricotta cheese, sugar, soybean oil, romano cheese, tomato paste, maltodextrine, parmesan cheese (egg, milk, soy, wheat) Total fat 9 g; total carbohydrates 39g; total sugars 4g; vitamin C 10%
Defects likely to occur	Darkened exterior and interior, heat stressed, blackened herb flecks Odor: Scorched or burnt. Flavor: Scorched or burnt, excessive seasoning/perfumy Texture: dried out, crumbles apart	Extreme darkening. More than slight weeping to extreme runniness or synerisis. Splotchy, swirling effect may be evidence of deterioration but must be evaluated carefully for taste and odor before a valid determination can be made. Odor and flavor: fermented, sour, musty, caramelized Texture: moderate to extreme weeping or syneresis from pulp	All components darkened or clumped together. Nuts crunched or broken Odor and flavor: rancid, stale Texture: hard dry raisins, soft nuts.	Ravioli: broken or mushy, darkened, soft or bloated/ sauce: pasty mostly absorbed, darkened, meat in sauce or filling very dark, oil separation Odor: rancid beef, of tomato Flavor: rancid beef, bitter grassy tomato
Color	x	x	x	x
Texture	x	x	x	x
Water activity	x	x	x	x
Moisture content	x	x	x	x
Sugars	x	x	x	x
Ascorbic acid	x	x		
Peroxide value	x		x	x
pH	x	x	x	x
Titratable acidity	x	x	x	x
Soluble solids content	x	x	x	x

Table 35. Selected MRE products, key ingredients, defects likely to occur, and physical and chemical analyses performed for each of the items

	Pork Sausage in Cream Gravy	Peanut Butter, Chunky	Cheese Spread with Jalapenos
NSN#	8940-01-579-8018	8935-01-545-0853	8940-01-414-6835
			
Key ingredients	Water, pork, sugar, maltodextrine, dextrose, partially hydrogenated soybean or cottonseed oil, chicken fat, chicken meat (milk, soy, wheat) Total fat 22g; total carbohydrates 16g; sugars 2 g; vitamin C 0%	Roasted peanuts, sugar, hydrogenated vegetable oil, vitamin C Total fat 20g; total carbohydrates 10g; sugars 4 g; vitamin C 70%	Cheddar cheese, butter, water Total fat 19g; total carbohydrates 1g; sugars 0g; vitamin C 2%
Defects likely to occur	Darkening/graying of gravy, oiling out, stringiness of gravy, thickening or thinning o gravy Odor: metallic, loss of odor, sour Flavor: metallic, loss of spice flavor, sour Texture: thinning or thickening of gravy, drier crumbly pork, lumpy or string gravy.	Darkening of color, moderate oiling-off Odor: rancid, musty, stale Flavor: moderately bitter, rancid, stale Texture: Moderate peeling off, hard and dry core, or product surrounded by extreme oiling-off. Peanut particles no longer crunchy	Cheese may be curdled and may have excessive oiliness. Odor: old cheddar, scorched milk, sour. Jalapeno cheese spread may have some lessening of jalapeno odor. Flavor: bitter, overcooked/scorched milk, slight metallic, acidic/sour. May have some Lessing of jalapeno flavor. Texture: Curdled, grainy, rubbery, excessively thick or excessively oily (oiled off).
Color	x	x	x
Texture	x	x	x
Water activity	x	x	x
Moisture content	x	x	x
Sugars		x	
Ascorbic acid		x	
Peroxide value	x	x	x
pH	x	x	x
Titratable acidity	x	x	x
Soluble solids content	x	x	x

Texture. Texture analysis of each FSR sample was performed using the TA.XT Plus Texture Analyzer (Texture Technologies Corp., Scarsdale, NY). The maximum peak force for compression and shear testing was expressed as kg-force (kgf).

Chipotle Snack Bread was sheared using a knife probe for 25 mm distance at a speed of 10 mm/s with a 1 g contact force. The maximum peak force was obtained from five readings on each of the three replicated samples per temperature (Figure 132 A).

The texture of Mango Peach Applesauce was evaluated using a flat probe, which compressed 50 mL of Applesauce in a 100 mL plastic container for 50 mm distance at a speed of 10 mm/s with a 1 g contact force. The maximum peak force was obtained by taking five readings on each of the three replicated samples per temperature (Figure 132 B).

The texture of Nut Raisin Mix, Pork Sausage in Cream Gravy and Beef Ravioli in Meat Sauce was performed using a multiple puncture probe. A 50 kg load cell was used with a probe displacement of 10 mm. Maximum peak force was obtained from five readings on each of the three replicated samples per temperature (Figure 132 C)

Spreadability of Cheese Spread with Jalapenos and Chunky Peanut Butter was measured using a spreadability probe. The male and female parts of the probe were aligned prior to the test and the distance was set at 23 mm. The product was filled into the lower cone with a spatula, pressed down to eliminate the air pockets, and then the surface was leveled with a flat knife. The probe was then displaced by 23 mm and the maximum peak force was obtained from five readings on each of the three replicated samples per temperature (Figure 132 D).



Figure 132. TA.XT Plus Texture Analyzer fixtures and probes used to measure the texture of MRE items

4.2.3.2 Compositional Analysis

Moisture Content. Moisture content was determined by the standard gravimetric method. A 5 g homogenized sample was spread evenly over the bottom of a metal dish, weighed and dried 24 h at 80°C in a laboratory oven (Model: 40GC, Quincy Lab Inc., Chicago, IL). Dry samples were cooled in desiccators and then weighed, and the final weight was subtracted from the initial weight to obtain the moisture content. Triplicates were taken from three MRE samples per temperature.

Water Activity. Water activity was performed using the dew point technique with an AquaLab 4TE water activity meter (Decagon device Inc., WA, USA). A 2 g homogenized sample was weighed in a disposable plastic cup and placed into the chamber of the water activity meter for measurement. Three replicates per item per temperature were used.

Titratable Acidity, Soluble Solids Content (SSC) and pH. Samples were homogenized using a handheld homogenizer (BioMixerBamix, Biospec, Switzerland) or a commercial blender (Model HBB908, Hamilton Beach Inc., NC, USA). A 5 g aliquot of each sample was mixed thoroughly with 45 mL deionized water in a 50 mL polypropylene screw-cap tube. After vortexing for 30 s, samples were centrifuged at 6500 rpm for 20 min in a centrifuge (Hermle Z200A, Labnet, Edison, NJ, USA). The supernatant was decanted from the centrifuge tubes for TA, SSC and pH measurements. Then 6 g of each supernatant was weighed into 50 mL beakers and diluted with 50 mL distilled water. The titratable acidity was determined by titration with 0.1 N NaOH to an end point of pH 8.1 with an automatic titrimeter (Titroline 96, SCHOTT-GERÄTE GmbH, Germany). The pH of the samples was determined using a pH meter (Accumet model 15, Fisher Scientific, CO, USA), previously calibrated with a pH of 4 and 7. The soluble solids content (SSC) of the resulting clear samples was measured with a digital refractometer (Palette PR-101, 0-45 Brix, Atago Co. LTD, Tokyo).

Quantification of Ascorbic Acid (Vitamin C) by HPLC. This procedure was only performed on samples that contained significant amounts of ascorbic acid: Chipotle Snack Bread, Mango Peach Applesauce and Chunky Peanut Butter (up to 48 weeks of storage for samples stored at 40, 80 and 100°F, and up to 20 and 10 weeks of storage for samples stored at 120 and 140°F, respectively). Samples were homogenized using a handheld homogenizer (BioMixerBamix, Biospec, Switzerland) or a commercial blender (Model HBB908, Hamilton Beach Inc., NC, USA). Then 2 g of each homogenized sample were weighed into a 50 mL plastic bottle, and 20 mL metaphosphoric acid mixture (6% HPO_3, containing 2 N acetic acid) was added. The samples were filtered (0.22 µm filter) prior to HPLC analysis. Ascorbic acid analysis was conducted using a Hitachi LaChromUltra UHPLC system with a diode array detector and a LaChromUltra C18 4.6µm column (2 × 50 mm) (Hitachi, Ltd., Tokyo, Japan). The analysis was performed under the isocratic mode at a flow rate of 1 ml/min with a detection of 254 nm. The sample injection volume was 5 µL. The mobile phase used was buffered potassium phosphate monobasic (KH_2PO_4, 0.5%, w/v) at pH 2.5, with metaphosphoric acid (HPO_3, 0.1%, w/v). The retention time of the ascorbic acid peak was 2.48 min. After comparison of retention time with the ascorbic acid standards, the peak was identified. The amount of total ascorbic acid was quantified using calibration curves obtained from different concentrations of ascorbic acid standards. Three samples per item per temperature were used with duplicated HPLC injections.

Quantification of Individual and Total Sugar Profile by HPLC. Individual sugars and maltodextrin contents were determined for all MRE items with the exception of Pork Sausage in Cream Gravy and Cheese Spread with Jalapenos, due to the low amount of sugars in these products. Maltodextrin was measured because is added to many of the MRE items. Maltodextrin is produced from starch through partial hydrolysis and consists of D-glucose units connected in chains of variable length. Measurements were taken for up to 48 weeks of storage

for samples stored at 40, 80 and 100°F, and up to 20 and 10 weeks of storage for samples stored at 120 and 140°F, respectively.

The procedure used was the same for all MRE samples except for Mango Peach Applesauce, for which the ether and boiling steps were omitted. The procedure used for Mango Peach Applesauce can be found in the second paragraph below.

An aliquot of 5 g from each homogenized sample was mixed thoroughly with 45 mL petroleum ether in a 50 mL polypropylene screw-cap tube. After vortexing for 30 s, samples were centrifuged at 6000 rpm for 10 min. The ether was discarded, and 45 mL distilled water was added. The samples were placed into a bath of boiling water for 25 min and vortexed every 5–7 min. Subsequently, the samples were cooled to room temperature and centrifuged at 6000 rpm for 10 min. The supernatant was decanted from the centrifuge tubes and filtered through a 0.45 µm nylon syringe into labeled amber glass vials. Individual and total sugar analyses were conducted using a Hitachi HPLC system with an RI-refractive index detector and a 300 mm × 8 mm Shodex SP0810 column (Shodex, Colorado Springs, CO) with an SP-G guard column (2 mm x 4 mm). An isocratic solvent delivery of water was run at 1.0 mL/min. The sample injection volume was 5 µL. Several standards, including maltodextrin, sucrose, glucose and fructose, were run to identify sample peaks. After comparison of retention time with standards, the peaks were identified. The amount of total sugar was quantified using calibration curves obtained from different concentrations of standards. Three samples per item per temperature were used with duplicated HPLC injections.

An aliquot of 5 g per Mango Peach Applesauce sample was mixed thoroughly with 45 mL distilled water in a 50 ml polypropylene screw-cap tube. After vortexing or mixing for 30 s, samples were centrifuged at 6000 rpm for 10 min. The supernatant was decanted from the centrifuge tubes and filtered through a 0.45 µm nylon syringe into labeled amber glass vials. Individual and total sugar analyses were conducted using a Hitachi HPLC system with an RI-refractive index detector and a 300 mm × 8 mm Shodex SP0810 column (Shodex, Colorado Springs, CO) with an SP-G guard column (2 mm × 4 mm). An isocratic solvent delivery of water was run at 1.0 mL/min. The sample injection volume was 5 µL. Several standards, including maltodextrin, sucrose, glucose and fructose, were run to identify sample peaks. After comparison of retention time with the standards, the peaks were identified. The amount of total sugar was quantified using calibration curves obtained from different concentrations of standards. Three samples per Applesauce item per temperature were used with duplicated HPLC injections.

Lipid Oxidation. The Peroxide Value (PV) method was used to measure the concentration of peroxides and hydroperoxide forms in the initial stage of lipid oxidation. The number of peroxides present in a food reflects its oxidative level and thus the tendency to become rancid. In general, foods with low content in unsaturated fatty acids exhibit a low rate of oxidation. Although there is no certain threshold for PV in the literature, others have reported that the level of PV depends on the type of food analyzed. For example, the limiting PV values reported to be critical for acceptability of roasted peanuts or peanut oil were 20–30 meq/kg (Evranuz,

1993; St. Angelo et al., 1977; Balasubramanyam et al., 1983; Narasimhan et al., 1986); crude fish oil was 7–8 meq /kg (Huss, 1988); bread sticks were 11.4–14.2 meq/kg (Calligaris, 2008); and biscuits were 13–18 meq/kg (Calligaris, 2007).

Lipid oxidation was determined for all MRE samples except for Mango Peach Applesauce samples, which have practically no lipid content.

Approximately 1 g of each homogenized item was transferred to a 15 ml disposable glass test tube, homogenized for 1 min with a 3 mL chloroform/methanol (2:1) mixture using a Biohomogenizer, and a 7 mL chloroform/methanol (2:1) mixture was added and mixed with 3 mL of 0.5 % NaCl solution. The mixture was vortexed for 30 s and then centrifuged at 2000 rpm for 10 min in a cold room at 5°C. The chloroform phase was removed, and a 2 mL volume was brought to 10 ml using a chloroform/methanol (2:1) mixture. A 50 µl aliquot of thiocyanate/Fe^{2+} solution was added to the sample, which was then inverted three times. The thiocyanate/Fe^{2+} solution was prepared immediately before use by mixing 1 volume of thiocyanate solution (3.94 M ammonium thiocyanate) with 1 volume of Fe^{2+} solution (obtained from the supernatant of a mixture of 3 ml of 0.144 M $BaCl_2$ in 0.4 M HCl and 3 ml of freshly prepared 0.144 M $FeSO_4$). The samples were incubated for 10 min at room temperature, and the absorbance was measured at 500 nm. A standard curve was prepared using cumenehydroperoxide.

4.3 Results

4.3.1 Beef Ravioli In Meat Sauce

4.3.1.1 Physical Characteristics

Appearance and Color

Dramatic changes in the color of Beef Ravioli in Meat Sauce (BR) from a light red to a dark brownish-red occurred when the food was exposed to temperatures above 80°F, particularly in those exposed at 120 and 140°F (Figure 133). The initial light red color of BR changed to a dark red after 10 weeks at 140°F and after 20 weeks at 120°F. Less noticeable color changes were observed for samples exposed for 86 weeks at 100°F. The color of samples stored at ambient (80°F) and refrigerated (40°F) temperatures was also slightly darker after 86 weeks. Note that differences between appearance and instrumental color measurements may be due to the fact that the samples were homogenized prior to color measurements (see Material and Methods section).

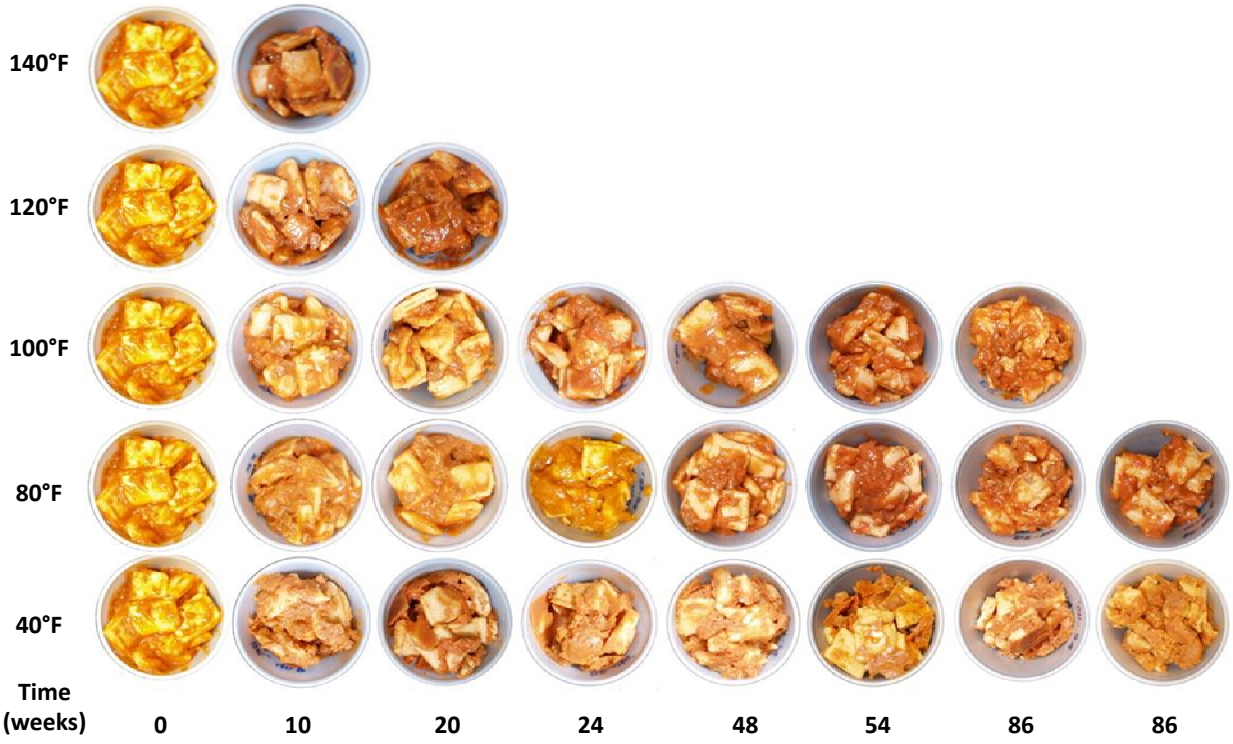


Figure 133. Changes in the appearance of Beef Ravioli in Meat Sauce during storage at 40, 80, 100, 120 and 140°F

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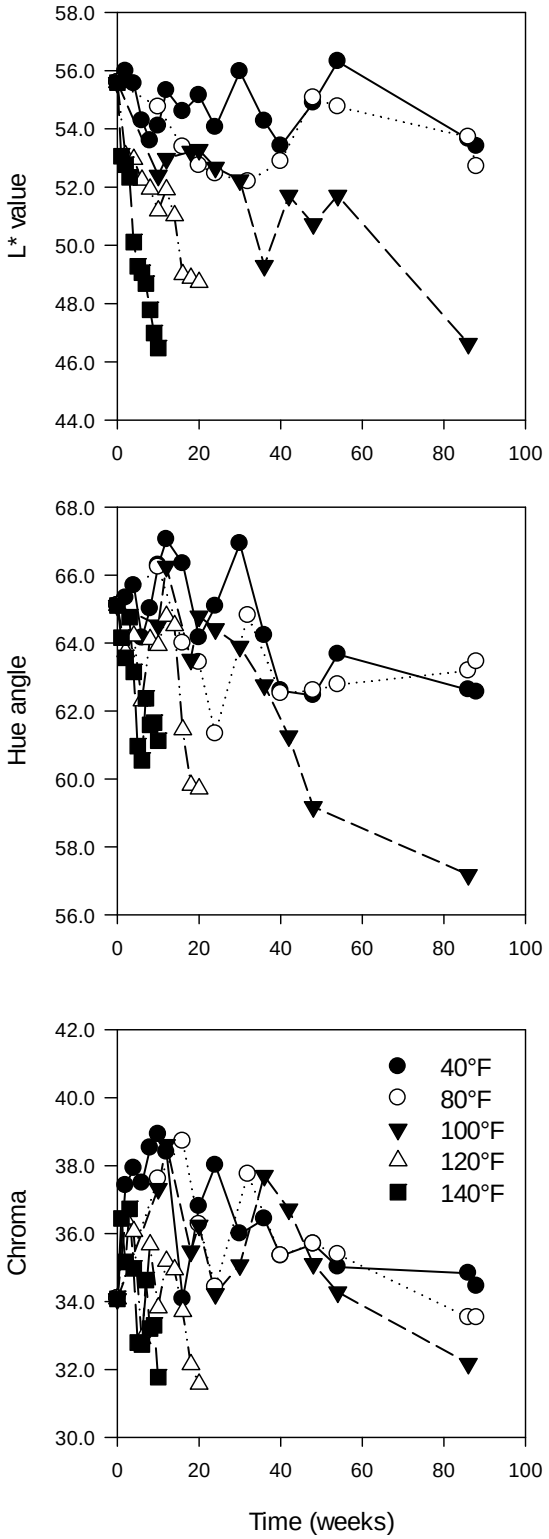


Figure 134. Changes in color attributes (L*, chroma and hue) of Beef Ravioli in Meat Sauce during storage period at 40, 80, 100, 120 and 140°F

As noted in the visual observations, color darkening of BR samples was translated by a decrease in L* values, regardless of the storage temperature (Figure 134). Samples stored at 140°F showed the greatest decrease in L* values (55.6 to 46.5) during storage, whereas BR stored at 40°F showed the least decrease in L* values (55.6 to 53.4). Thus, samples stored at 140°F were darker than those maintained under refrigerated conditions. Chroma values of BR slightly decreased in samples stored above 40°F, reflecting a decrease in the vividness of the color (Figure 133). After 10 weeks of storage, the color of BR samples exposed to 140°F was less vivid than initially, whereas there was practically no change in the chroma values of BR samples stored at 40°F. In respect to hue angle values, these decreased (darker red color) during storage regardless of the temperature (Figure 134). However, the decrease in hue values was higher in samples stored above 80°F.

Texture

Important textural changes were observed in BR samples stored at different temperatures (Figure 135). Softening was observed in BR samples stored at 80, 100, 120 and 140°F, whereas samples stored at 40°F were significantly firmer than those stored at higher temperatures. Even though samples were equilibrated to ambient temperature, so that the temperature at the time of analysis would be the same for all samples, exposure of BR samples to refrigerated temperatures may have contributed to irreversible dryness and toughening of the pasta. BR samples stored at 40°F also appeared less fluid than those exposed to higher temperatures (Figure 133). Finally, the greatest decrease in firmness (softer samples) was observed for BR samples stored at 140°F.

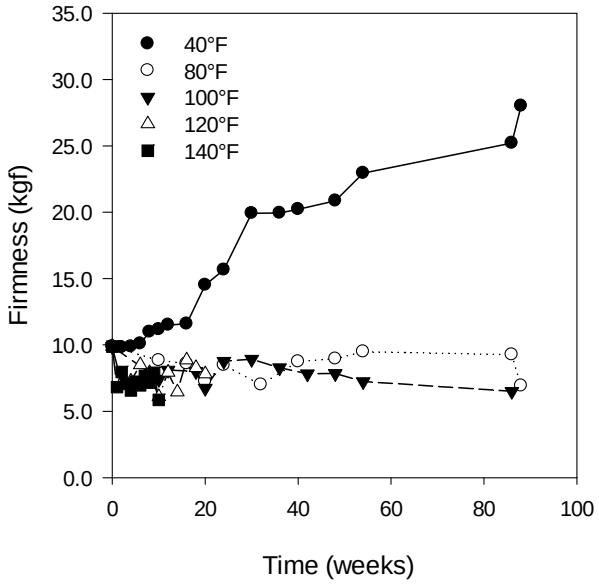


Figure 135. Changes in the texture of Beef Ravioli in Meat Sauce during storage at 40, 80, 100, 120 and 140°F

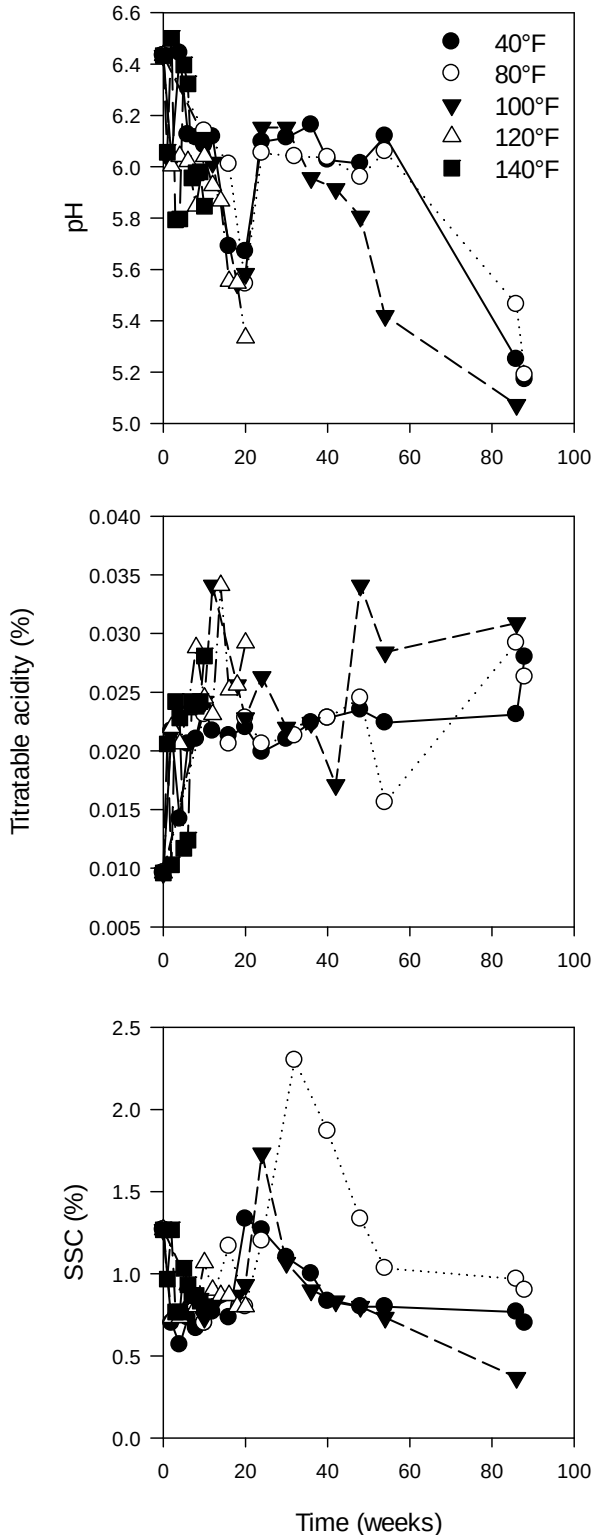


Figure 136. Changes in pH, titratable acidity and soluble solids content of Beef Ravioli in Meat Sauce during storage at 40, 80, 100, 120 and 140°F. SSC = Soluble solids content

4.3.1.2 Compositional Analysis

pH, Titratable Acidity and Soluble Solids Content

The Beef Ravioli pH decreased and acidity increased during storage, regardless of the temperature (Figure 136). Although the greatest decrease in pH was observed in samples stored at 40°F and the lowest decrease was in BR samples stored at 140°F, at the end of each storage period, the acidity of the samples was the same (0.03%). Therefore, it seems that changes in the pH were not large enough to produce major changes in the acid content of the food. A decrease in the soluble solids content (SSC) was observed in BR samples irrespective of the temperature (Figure 136). Although the SSC decreased (37% decrease from initial values) in samples exposed to 120 and 140°F, after 10 and 20 weeks of storage, respectively, there was no difference in the SSC of the BR samples. Compared to samples stored at 40 and 80°F, samples stored at 100°F showed the greatest decrease in SSC (71%) after 86 weeks of storage. Overall, the decrease in SSC of BR was probably due to the almost complete hydrolysis of simple sugars such as sucrose, glucose and fructose. In fact, these sugars were most of the time not detected by the HPLC technique used.

Water Activity and Moisture Content

There was practically no change or very minor changes in the water activity of BR after exposure to the different temperatures (Figure 137). After exposure to 40, 100 and 120°F for 88, 84 and 20 weeks, respectively, water activity measured at the end of storage was not different from that measured before the samples were stored. In BR samples stored at 80 and 140°F, there was a slight decrease in water activity (from 0.99 to 0.88). The moisture content increased by about 3%, regardless of the storage temperature (Figure 136), yet such an increase might have not been great enough to affect the water activity of BR samples.

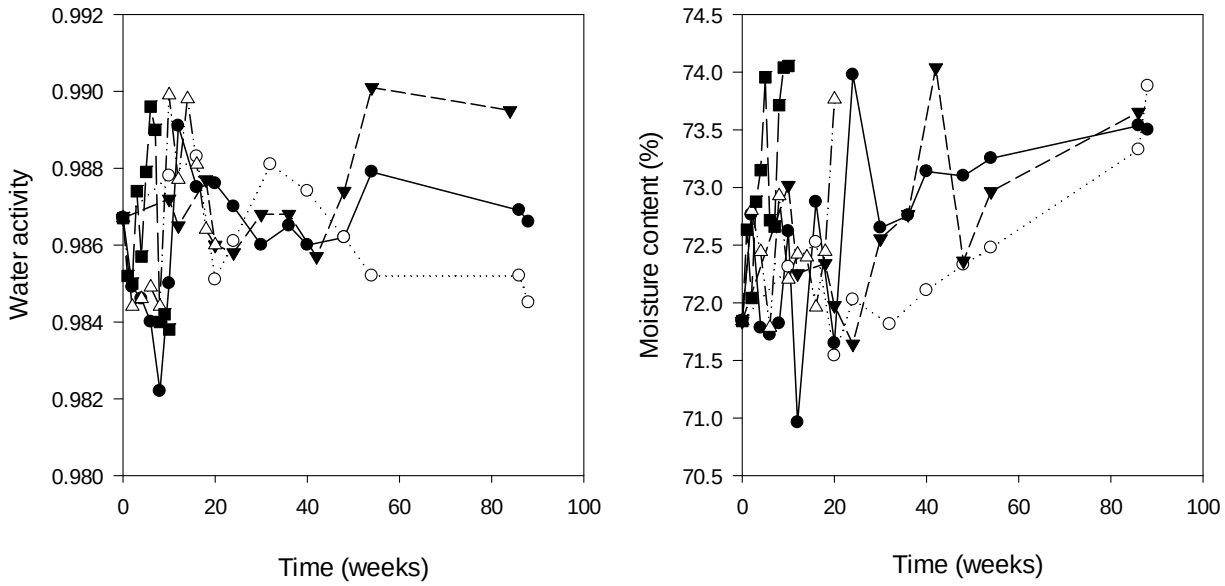


Figure 137. Changes in moisture content and water activity of Beef Ravioli in Meat Sauce during storage at 40, 80, 100, 120 and 140°F

Maltodextrin

Maltodextrin was the only carbohydrate detected in BR samples by the HPLC method used (Figure 138). BR is enriched with maltodextrin, and that was most likely the reason why this compound was detected (initial content: 4.3 g 100 g^{-1}). However, the initial amount of maltodextrin in BR samples was significantly reduced after exposure to different temperatures. For example, after approximately 8 to 10 weeks, the lowest maltodextrin concentration was measured in samples stored at 140°F, whereas the highest amount was measured in samples stored at 40°F. After 40 weeks, the maltodextrin content of samples stored at 40 and 80°F was not different.

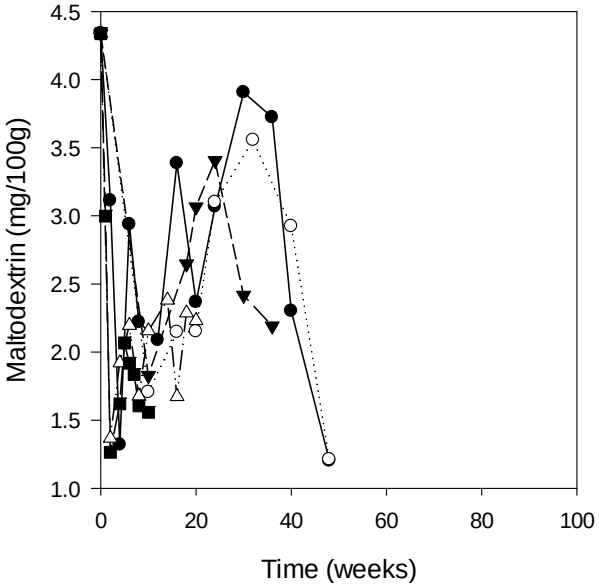


Figure 138. Changes in maltodextrin content of Beef Ravioli in Meat Sauce during storage at 40, 80, 100, 120 and 140°F

Lipid Oxidation

Peroxide value (PV), used as a measure of primary lipid oxidation, fluctuated during storage, particularly in BR samples exposed to 100°F (Figure 139). In general, PV decreased in samples stored at 40, 80 and 140°F, whereas it increased in BR samples stored at 100°F and 120°F. These results are somehow unexpected, particularly the decrease in PV in samples exposed to 140°F. Some possible explanations may be the relatively short exposure time to 140°F, not enough to cause changes in the saturated fatty acids and thus resulting in an increase in PV values (saturated fatty acids are very stable to lipid oxidation). However, longer exposure times for BR samples stored at 100 and 120°F may have been enough to cause peroxide formation and thus the increase in the PV values.

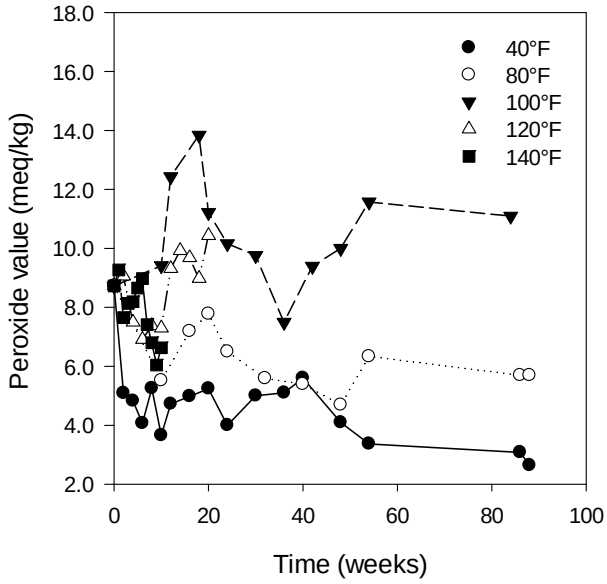


Figure 139. Changes in the peroxide value of Beef Ravioli in Meat Sauce during storage at 40, 80, 100, 120 and 140°F

4.3.1.3 Summary Of The Results For Beef Ravioli In Meat Sauce

Below is a summary of the changes that occurred in the appearance (Table 36) and in the different physical (Table 38) and compositional attributes (Tables 39 and 40) measured in Beef Ravioli in Meat Sauce samples at the beginning and end of storage:

- Appearance: the higher the temperature, the darker the color of the samples.
- L* value: decreased (darker color) for all temperatures.
- Chroma: decreased for all temperatures above 40°F (duller color).
- Hue: decreased for all temperatures (deeper red color).
- Texture: decreased (softening) in temperatures above 40°F and increased in samples stored at 40°F.
- Moisture content: increased for all temperatures.
- Water activity: decreased in samples stored at 80 and 140°F, and was the same as initial values for samples stored at 40, 100 and 120°F.
- pH: decreased for all temperatures.
- Acidity: increased for all temperatures.
- Soluble solids content: decreased for all temperatures.
- Peroxide value: decreased in samples stored at 40, 80 and 140°F, and increased in samples stored at 100 and 120°F.
- Maltodextrin: decreased for all temperatures.

4.3.2 Chipotle Snack Bread

4.3.2.1 Physical Characteristics

Appearance and Color

The visual color of Chipotle Snack Bread (SB) changed during storage regardless of the temperature (Fig 140). However, SB samples stored at temperatures higher than 80°F tended to appear darker than those exposed to lower temperatures. Although the differences in appearance of SB stored at different temperatures are difficult to perceive in Figure 140, when color was instrumentally measured, quantitative results showed that L* values decreased (darker color) during storage, regardless of the temperature (Figure 141). However, the higher the temperature was, the more dramatic the decrease was in L* values, meaning that at the end of the storage period, samples exposed to 140°F were darker than those stored at lower temperatures. Chroma values also decreased during storage, regardless of the temperature, as the color of SB became less vivid and duller (Figure 141). Finally, hue angle values also decreased during storage, regardless of the temperature (Figure 141). The greatest decrease in hue angle values was observed in samples stored at temperatures higher than 80°F, meaning that the color changed from a light brown to a darker brownish color.

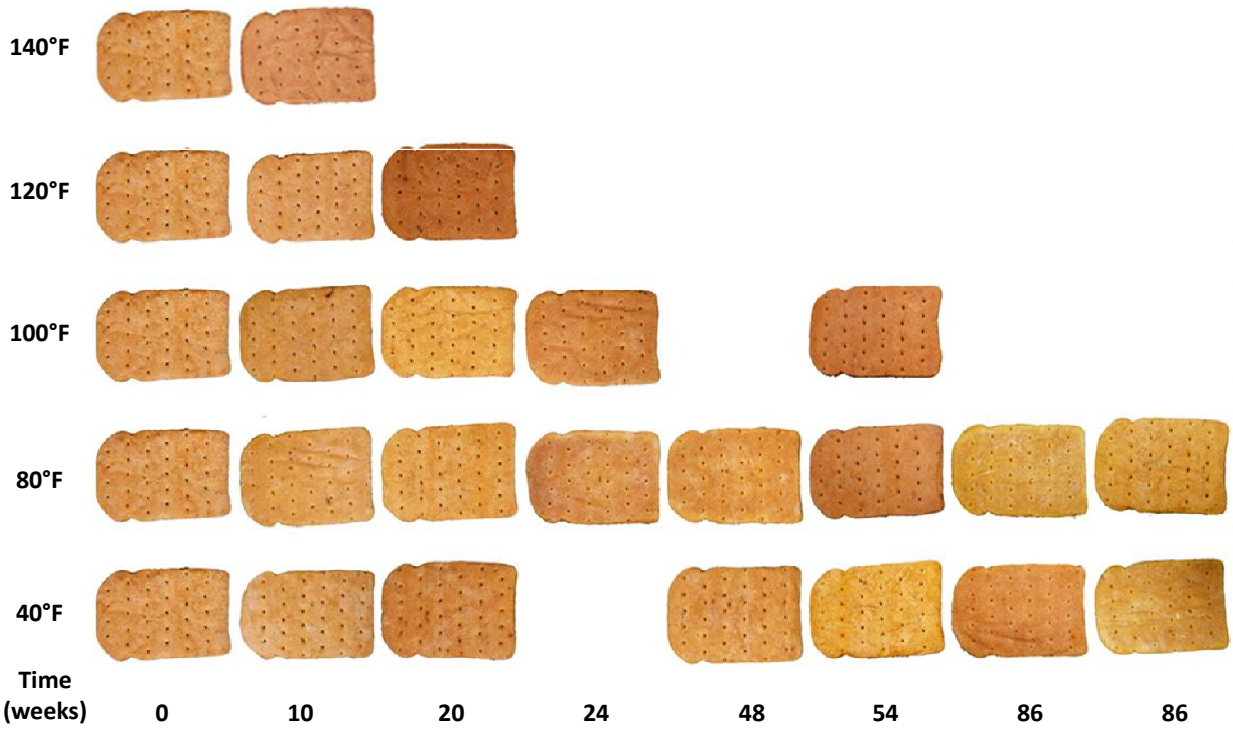


Figure 140. Changes in the appearance of Chipotle Snack Bread during storage at 40, 80, 100, 120 and 140°F

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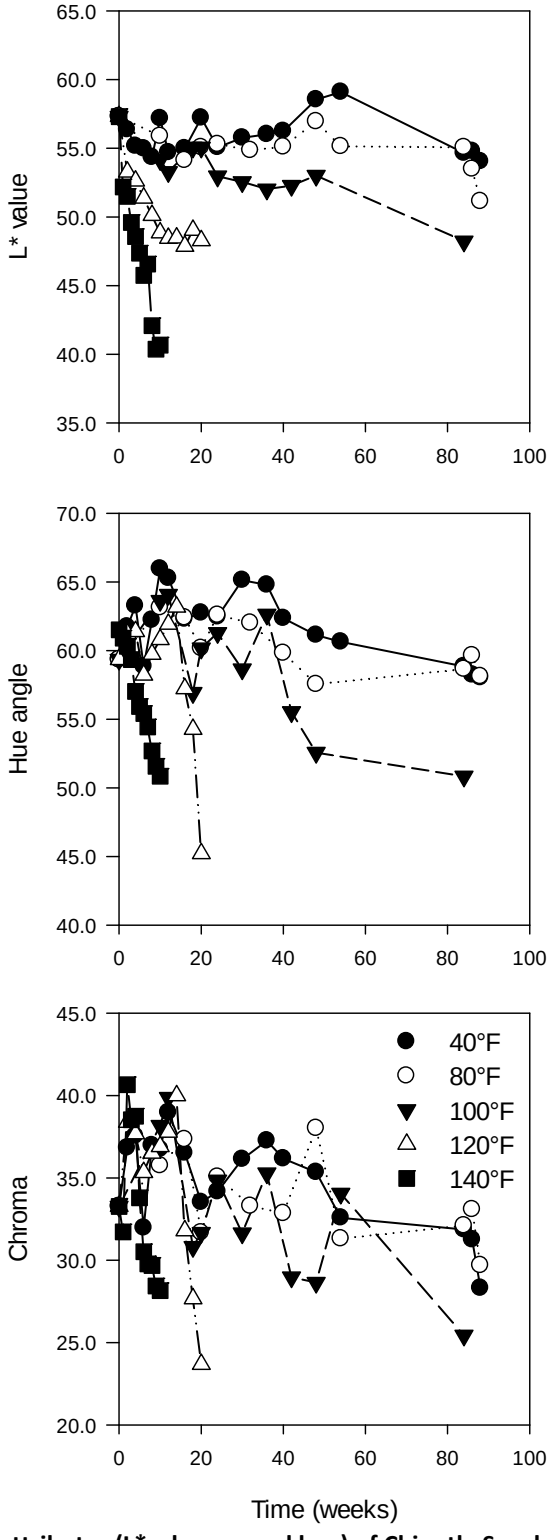


Figure 141. Changes in color attributes (L*, chroma and hue) of Chipotle Snack Bread during storage at 40, 80, 100, 120 and 140°F

Texture

Texture of SB changed during storage, regardless of the temperature (Figure 142). The SB samples tended to toughen during storage with samples exposed at 140°F showing the greatest increase in texture (84% increase; harder samples). The least increase in texture was observed for samples stored at 80°F (21% increase in texture). Storage at 40°F did not prevent SB from hardening, as after 88 weeks samples were tougher (39% increase in texture) than those exposed to 80°F for the same period of time.

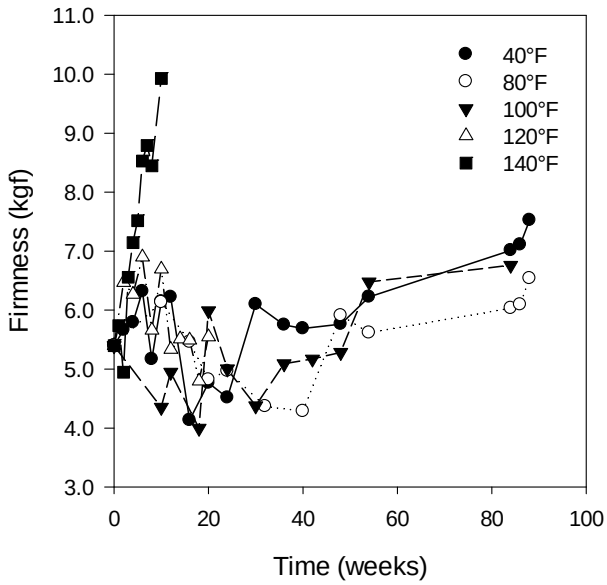


Figure 142. Changes in the texture of Chipotle Snack Bread during storage at 40, 80, 100, 120 and 140°F

4.3.2.2 Compositional Analysis

pH, Titratable Acidity and Soluble Solids Content

The pH of SB samples decreased during storage, regardless of the temperature (Figure 122). The greatest decrease in pH was observed in samples stored for 84 weeks at 100°F, and the least decrease was observed in samples stored for 88 weeks at 40°F. As a result of the decrease in the pH of SB samples, acidity increased regardless of the storage temperature (Figure 143). However, the greatest increase in acidity was observed in samples stored at 140°F for 10 weeks, whereas the least increase was observed in samples stored at 40°F for 88 weeks. The soluble solids content of SB decreased during storage regardless of the storage temperature (Figure 143). However, the decrease was greatest in samples exposed at 40°F than in those exposed to higher temperatures.

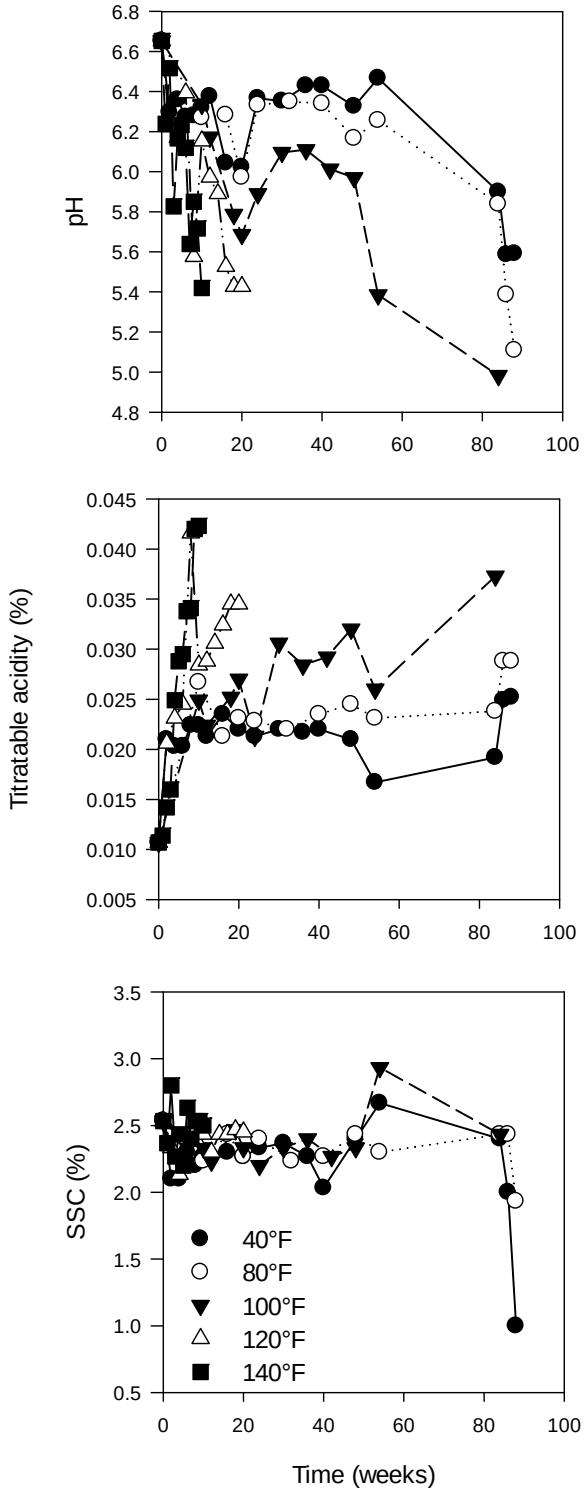


Figure 143. Changes in pH, titratable acidity and soluble solids content of Chipotle Snack Bread during storage at 40, 80, 100, 120 and 140°F

Water Activity and Moisture Content

Water activity slightly decreased in SB samples exposed at 40, 80, 100 and 140°F and was the same as initial values for samples exposed to 120°F (144). The moisture content, on the other hand, decreased in SB samples stored at 40, 80 and 100°F and increased in samples stored at 120 and 140°F. Most likely the decrease observed in the moisture content in samples exposed to temperatures lower than 120°F resulted in the decrease (0.01-0.02) in water activity. However, it appears that the increase in moisture content observed in SB samples stored at 120 and 140°F was not sufficient to cause an increase in the water activity values. The greatest decrease in moisture content was observed in samples stored at 40°F (14% decrease), compared to samples stored at 80 or 100°F (10% decrease).

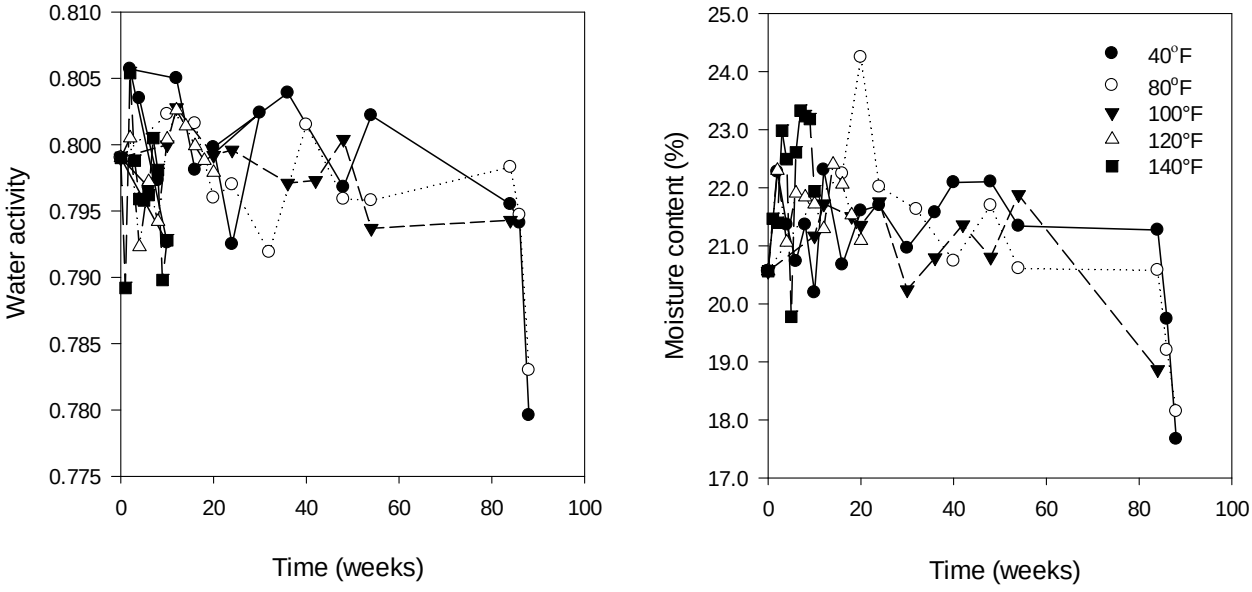


Figure 144. Changes in moisture content and water activity of Chipotle Snack Bread during storage at 40, 80, 100, 120 and 140°F

Individual and Total Sugar Profiles

Sucrose and glucose contents increased in SB samples stored at 40, 80 and 100°F but decreased in samples exposed to 120 and 140°F (Figure 145). On the other hand, the fructose content increased during storage, regardless of the temperature. It is possible that the decrease observed in the sucrose content of samples stored at 120 and 140°F resulted from the breakdown of this sugar into fructose and thus caused the increase in fructose. The increase observed in the total sugar content resulted from the increase in the individual sugars. The maltodextrin content decreased during storage regardless of the temperature (Figure 145). The decrease in maltodextrin may have contributed to the increase in glucose content in samples stored at temperatures lower than 120°F.

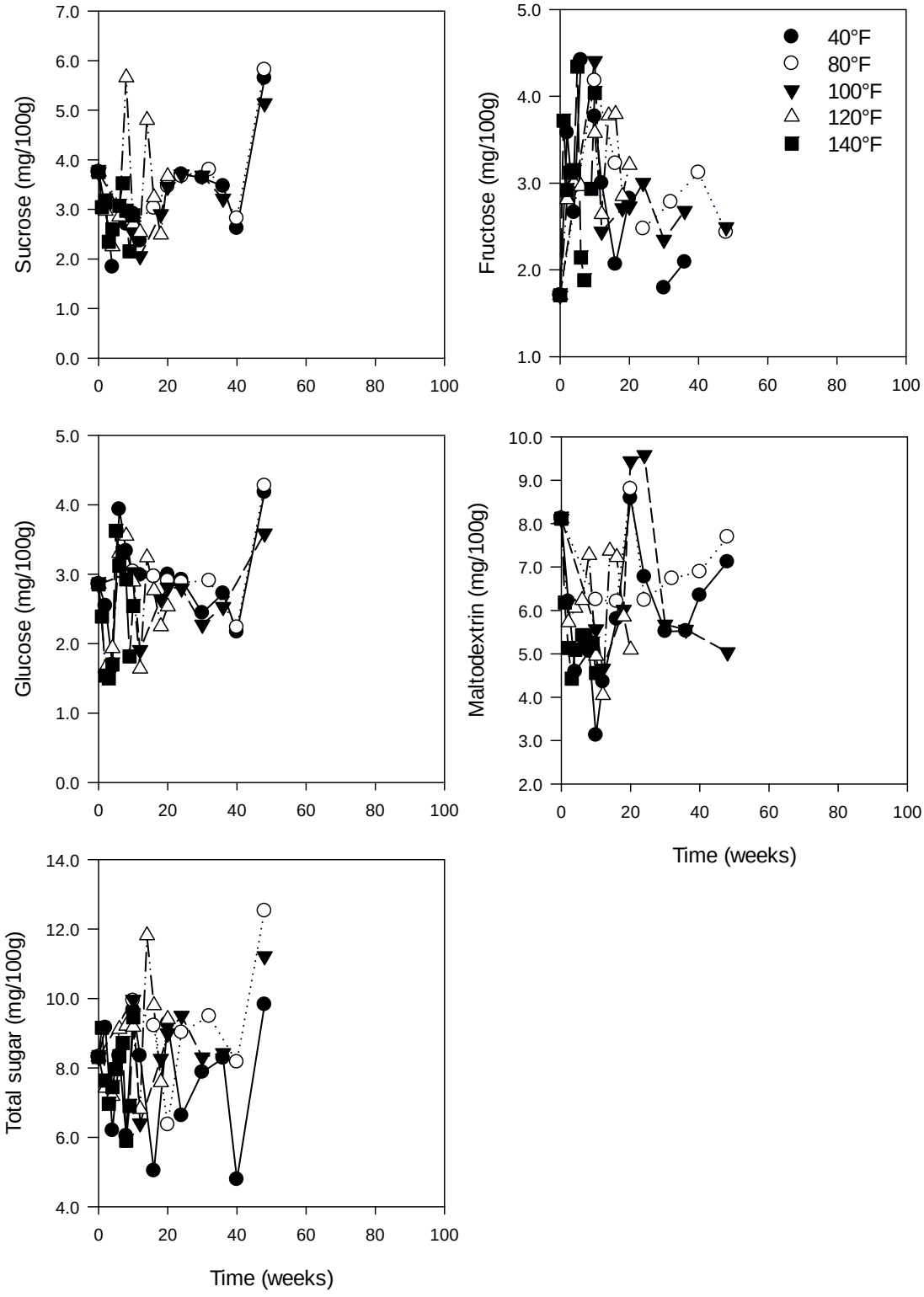


Figure 145. Changes in sugar profiles and maltodextrin content of Chipotle Snack Bread during storage at 40, 80, 100, 120 and 140°F

Ascorbic Acid

Chipotle Snack Bread is enriched with ascorbic acid mostly to act as a fat antioxidant, but it can also contribute to an increase in the vitamin content of the food. Because ascorbic acid is very susceptible to chemical degradation, particularly when exposed to high temperatures, it is considered a good marker for food quality. In SB, ascorbic acid decreased regardless of the storage temperature (Figure 146). However, it seems that the exposure time had a more adverse impact on ascorbic acid degradation than the temperature did. Besides, refrigerated storage did not seem to help reduce losses as, after 48 days at 40°F, the ascorbic acid content was lower (0.92 mg $10g^{-1}$) than in samples exposed for 20 or 10 weeks at 120 and 140°F (1.67 and 1.33 mg 100^{-1}), respectively. The same behavior was previously observed in samples of FSR items such as Bacon Cheddar, Italian, and BBQ sandwiches (see previous discussion or poster presented at the 2013 IFT shown in Appendix B).

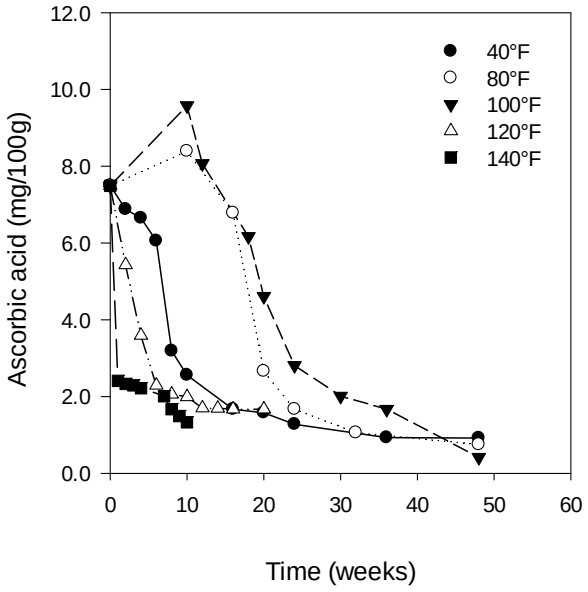


Figure 146. Changes in ascorbic acid content of Chipotle Snack Bread during storage at 40, 80, 100, 120 and 140°F

Lipid Oxidation

The peroxide value decreased during storage regardless of the temperature (Figure 147). The results suggest that SB lipids are very stable and resistant to oxidation, most likely due to the high content in saturated fatty acids from partially hydrogenated soybean oil. Further, the characteristics of the food matrix, the low water activity and the addition of antioxidants such as ascorbic acid may have prevented the formation of peroxides.

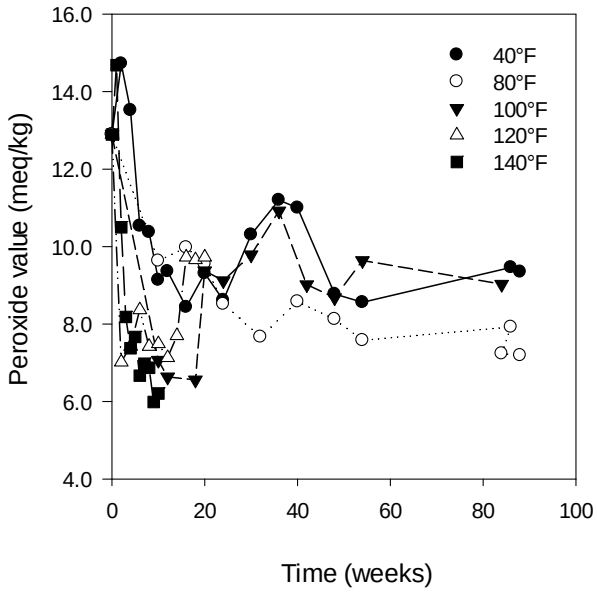


Figure 147. Changes in the peroxide value of Chipotle Snack Bread during storage at 40, 80, 100, 120 and 140°F.

4.3.2.3 Summary Of The Results For Chipotle Snack Bread

Below is a summary of the changes that occurred in the appearance (Table 36) and in the different physical (Table 38) and compositional attributes (Tables 39 and 40) measured in Chipotle Snack Bread samples at the beginning and end of storage:

- Appearance: the higher the temperature, the darker the color of the samples.
- L* value: decreased (darker color) for all temperatures.
- Chroma: decreased for all temperatures (duller color).
- Hue: decreased for all temperatures (deeper brownish color).
- Texture: increased (hardening) for all temperatures.
- Moisture content: decreased in samples stored at 40, 80 and 100°F, and increased in samples stored at 120 and 140°F.
- Water activity: decreased in samples stored at 40, 80, 100 and 140°F, and was the same as initial values for samples stored at 120°F.
- pH: decreased for all temperatures.
- Acidity: increased for all temperatures.
- Soluble solids content: decreased in samples stored at 40, 80 and 100°F, and increased in samples stored at 120 and 140°F.
- Ascorbic acid: decreased for all temperatures.
- Peroxide value: decreased for all temperatures.
- Sucrose: increased in samples stored at 40, 80 and 100°F, and decreased in samples stored at 120 and 140°F.
- Glucose: increased in samples stored at 40, 80 and 100°F, and decreased in samples stored at 120 and 140°F.

- Fructose: increased for all temperatures.
- Total sugars: increased for all temperatures.
- Maltodextrin: decreased for all temperatures.

4.3.3 Chunky Peanut Butter

4.3.3.1 Physical Characteristics

Appearance and Color

Although in Figure 148 the appearance of Chunky Peanut Butter (PB) seems to have changed significantly during storage, an instrumental color analysis showed that changes were very slight, particularly in samples stored at temperatures lower than 120°F. Thus, a quantitative color analysis showed that L* values of samples stored at 40, 80 and 100°F for 88 and 86 weeks were similar to the L* values measured at time 0 (Figure 149), whereas the L* value of samples stored at 120 and 140°F for 20 and 10 weeks, respectively, decreased (darker color) compared to initial values. Hue angles decreased during storage, meaning that the color changed from a light to a deeper yellow, but the values were similar regardless of the temperature. There was also either a slight decrease or practically no change in chroma values of PB, meaning that the color became slightly duller.

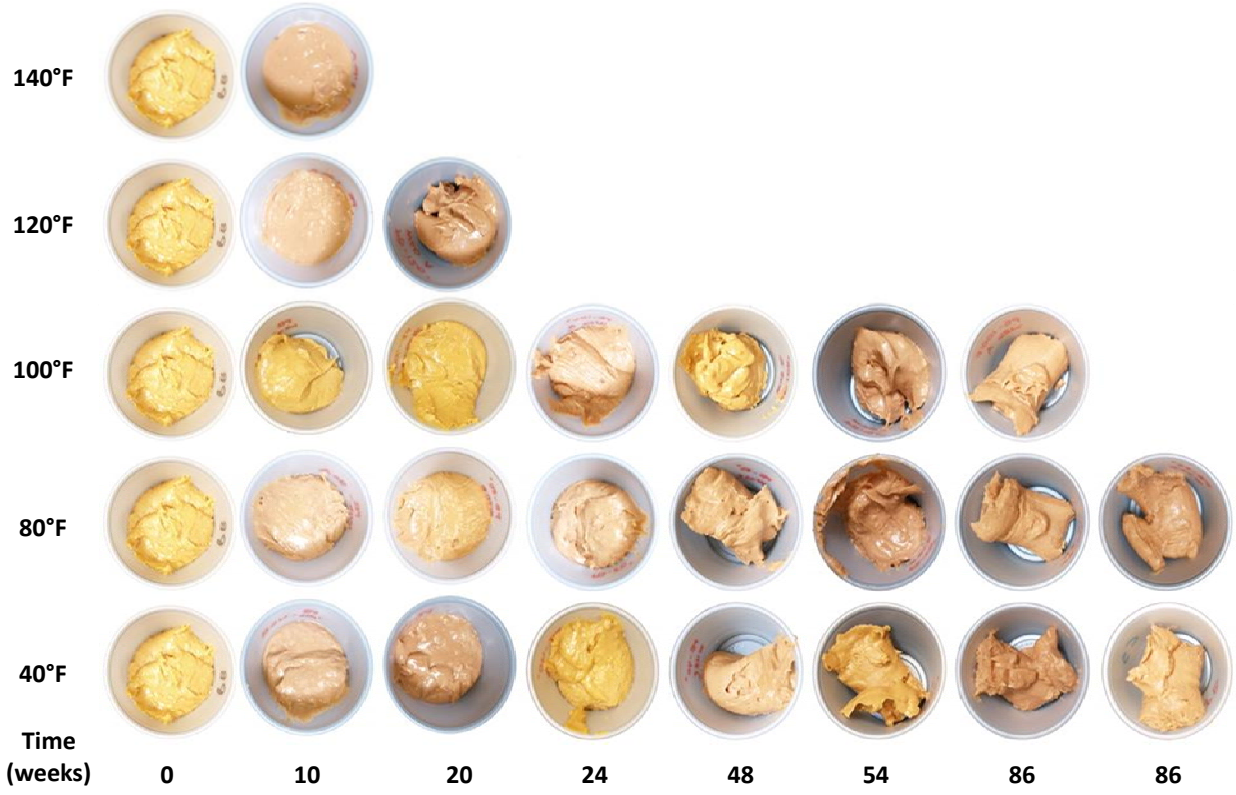


Figure 148. Changes in the appearance of Chunky Peanut Butter during storage at 40, 80, 100, 120 and 140°F

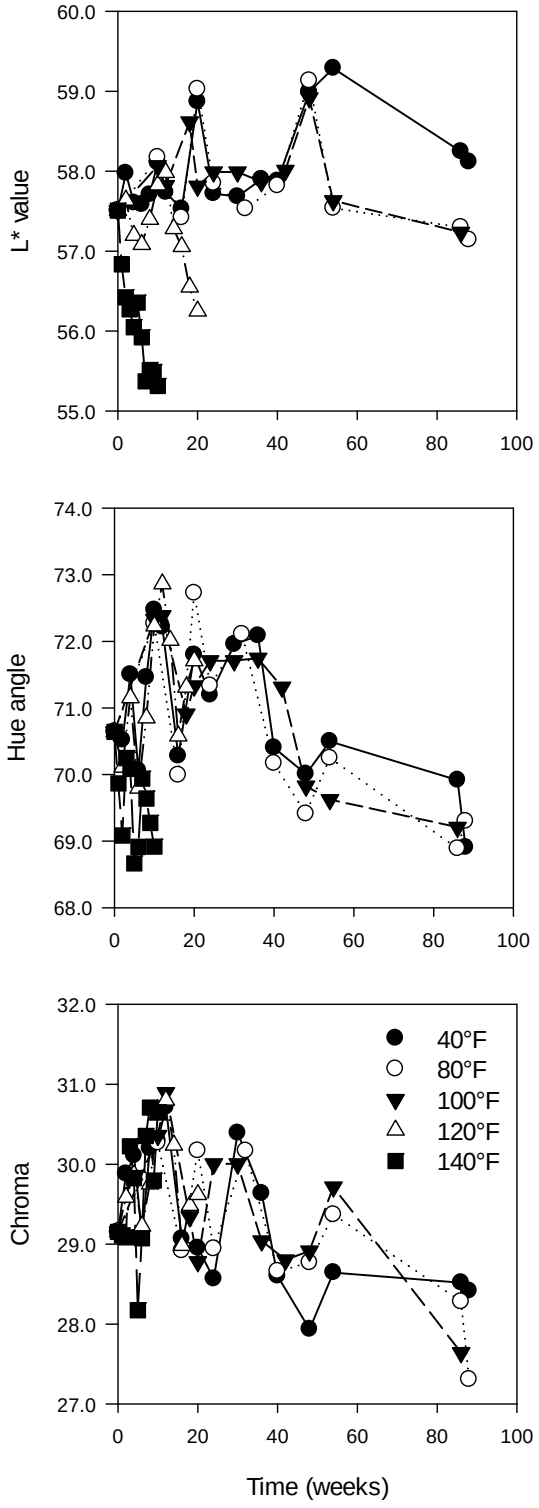


Figure 149. Changes in color attributes (L*, chroma and hue) of Chunky Peanut Butter during storage at 40, 80, 100, 120 and 140°F

Texture

The total amount of force required to perform the shearing process decreased with storage, regardless of the temperature, meaning that PB samples became softer, more spreadable (Figure 150). However, softening was greater in samples stored at temperatures below 120°F. Thus, the spreadability of PB samples stored at 120 and 140°F was lower than that of samples exposed to higher temperatures.

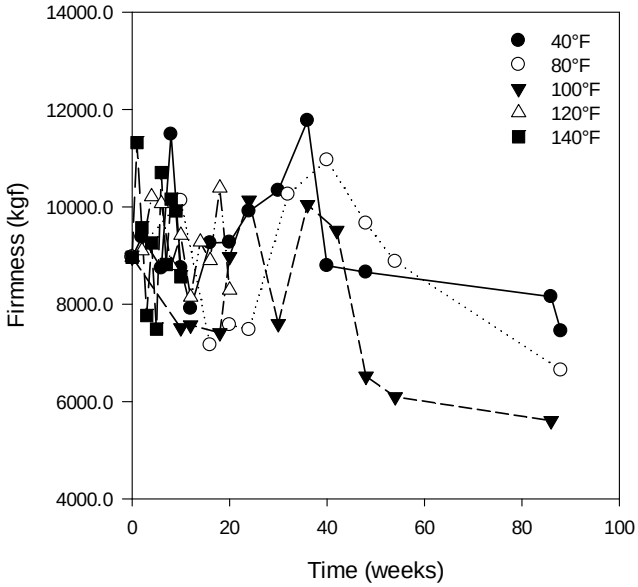


Figure 150. Changes in the texture of Chunky Peanut Butter during storage at 40, 80, 100, 120 and 140°F

4.3.3.2 Compositional Analysis

pH, Titratable Acidity and Soluble Solids Content

During storage, the pH of PB decreased regardless of the temperature (Figure 151). After 88, 86 and 20 weeks at 80, 100 and 120°F, respectively, the pH of PB samples was similar. Likewise, after 88 and 10 weeks at 40 and 140°F, respectively, the pH of PB samples was practically the same. Thus, exposure of PB to high temperatures for a short period of time seemed to have a similar effect on pH than exposure to refrigerated temperatures for a longer exposure period. Nevertheless, changes in the pH of PB did not seem to cause major changes in the acidity of the samples (Figure 151). At the end of each respective storage period, the acidity of PB samples was either 0.01 higher (40, 100 and 120°F) or the same compared to initial values (80 and 140°F). The soluble solids content decreased during storage regardless of the temperature (Figure 151). However, the SSC decrease was higher (approximately 39%) in samples stored between 80 and 120°F compared to those stored at 40 and 140°F (13 and 21%, respectively).

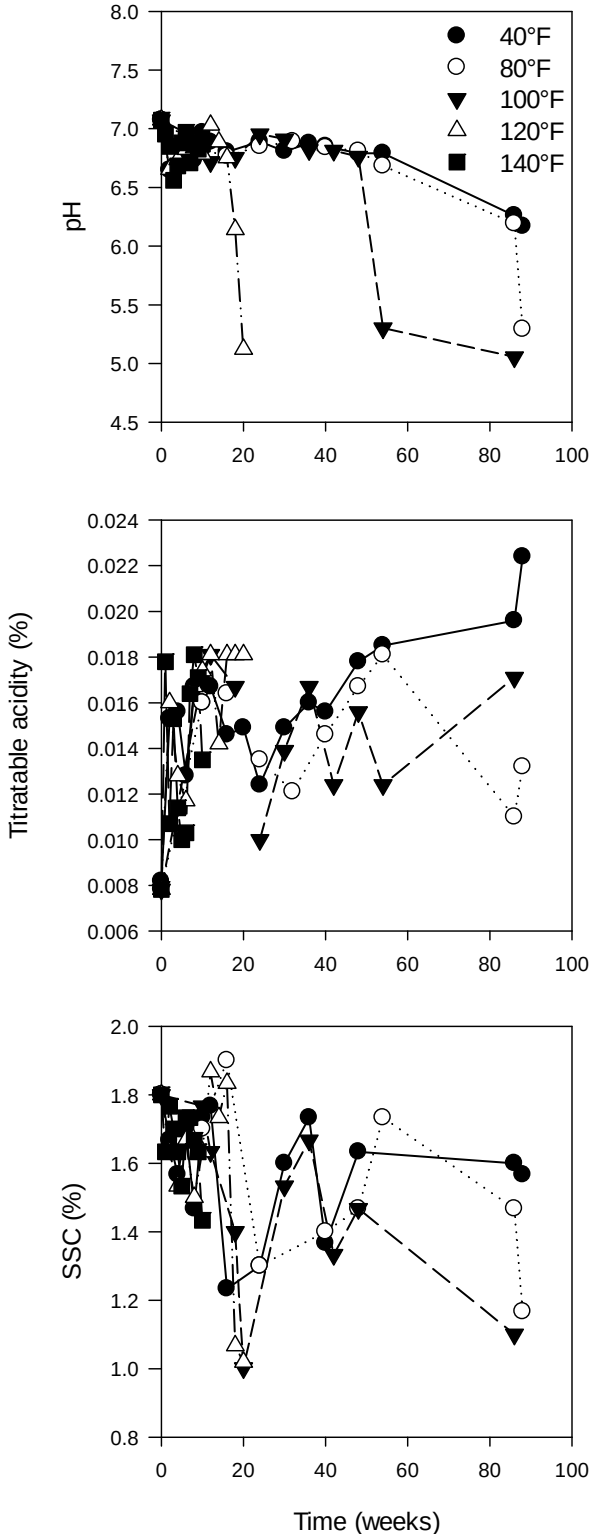


Figure 151. Changes in pH, titratable acidity and soluble solids content of Chunky Peanut Butter during storage at 40, 80, 100, 120 and 140°F

Water Activity and Moisture Content

Water activity decreased in PB samples stored at 80°F or above but remained the same in samples stored at 40°F (Figure 152). The moisture content decreased during storage regardless of the temperature (Figure 152). Since MRE packages are impermeable to water vapor, loss of moisture content with small changes in water activity may indicate that superficial, more available water might have been used in chemical reactions.

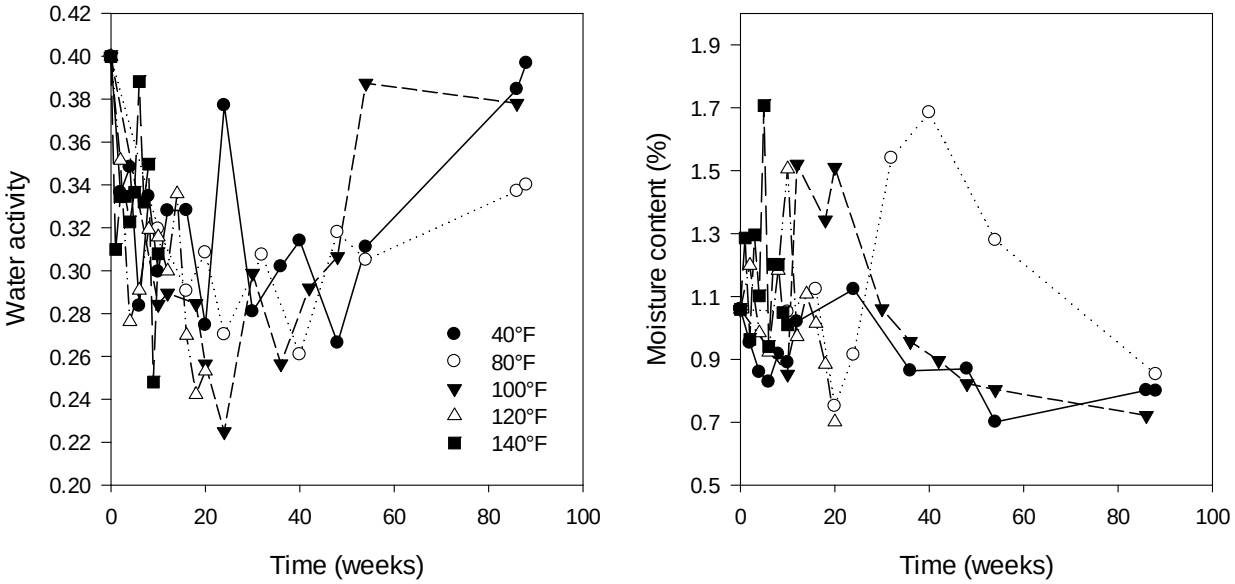


Figure 152. Changes in moisture content and water activity of Chunky Peanut Butter during storage at 40, 80, 100, 120 and 140°F

Sucrose

Sucrose was the only sugar detected in PB samples. During storage, the sucrose content decreased, regardless of the temperature (Figure 153). The decrease was greater in samples stored at 40 and 80°F (22 and 25%, respectively) than in samples stored at higher temperatures (approximately 9% decrease). After 48 weeks at 40 and 80°F, the sucrose content was similar in PB samples. Likewise, after 36, 20 and 10 weeks, the sucrose content was similar for samples stored at 100, 120 and 140°F, respectively.

Ascorbic Acid

Ascorbic acid is a powerful antioxidant and therefore is usually added to foods to prevent them from lipid oxidation. MRE-Peanut Butter showed a relatively high initial ascorbic acid content (147 mg 100 g^{-1}), which also makes this product a good source of vitamin C. However, under adverse storage conditions and even under refrigerated conditions, ascorbic acid degradation may occur very fast. In this study, refrigeration did not have a beneficial effect in retaining ascorbic acid because PB samples stored for 48 weeks at 40°F lost approximately 50% of their initial content (Figure 154). PB samples stored at 80°F retained better ascorbic acid compared to those stored at other temperatures (decreased by 34% after 48 weeks). At 140°F, the decrease was the greatest, and after 10 weeks, the ascorbic acid content was reduced by 62%.

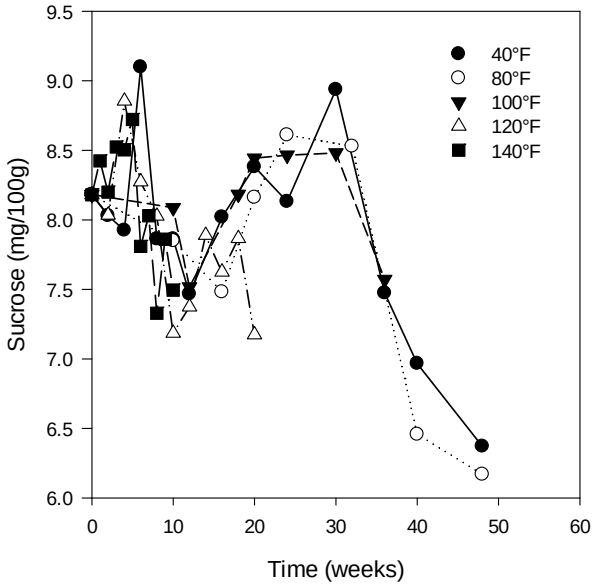


Figure 153. Changes in the sucrose content of Chunky Peanut Butter during storage at 40, 80, 100, 120 and 140°F

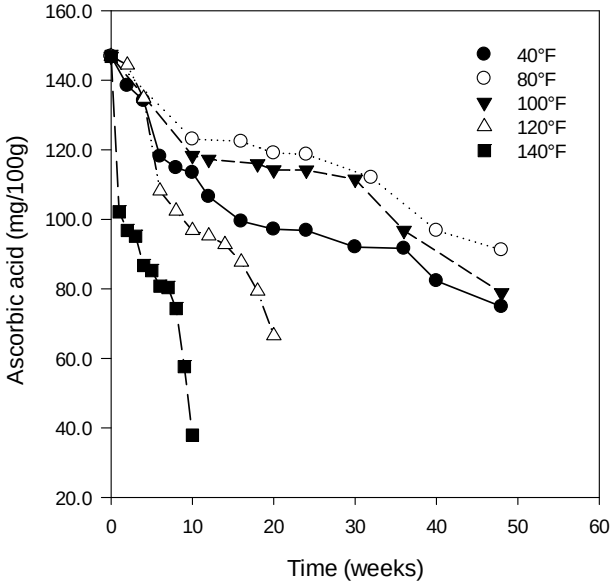


Figure 154. Changes in the ascorbic acid content of Chunky Peanut Butter during storage at 40, 80, 100, 120 and 140°F

Lipid Oxidation

The peroxide value decreased during storage regardless of the temperature (Figure 155). The results suggest that PB lipids were very stable and resistant to oxidation. The high content in saturated fatty acids and the high levels of ascorbic acid that may have prevented form lipid oxidation and thus make this product very stable and resistant to lipid oxidation.

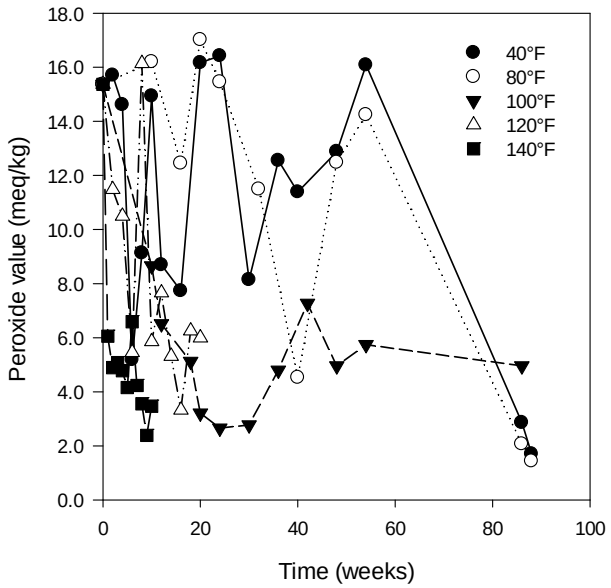


Figure 155. Changes in the peroxide value of Chunky Peanut Butter during storage at 40, 80, 100, 120 and 140°F.

4.3.3.3 Summary Of The Results For Chunky Peanut Butter

Below is a summary of the changes that occurred in the appearance (Table 36) and in the different physical (Table 38) and compositional attributes (Tables 39 and 40) measured in Chunky Peanut Butter samples at the beginning and end of storage:

- Appearance: the higher the temperature, the darker the color of the samples.
- L* value: slightly increased in samples stored at 40°F, remained similar in samples stored at 80 and 100°F and slightly decreased (darker color) in samples stored at 120 and 140°F.
- Chroma: decreased in samples stored at 40, 80 and 100°F (duller color), and slightly increased in samples stored at 120 and 140°F.
- Hue: decreased slightly in all samples (deeper brownish color) except for those stored at 120°F, which increased slightly.
- Texture: decreased (softer more spreadable) for all temperatures.
- Moisture content: decreased for all samples.
- Water activity: decreased for all samples except for those stored at 40°F, for which there was no change from initial values.
- pH: decreased for all temperatures.
- Acidity: increased in samples stored at 40, 100 and 120°F, and remained the same in samples stored at 80 and 140°F.
- Soluble solids content: decreased for all temperatures.
- Ascorbic acid: decreased for all temperatures.
- Peroxide value: decreased for all temperatures
- Sucrose: decreased for all temperatures.

4.3.4 Cheese Spread With Jalapenos

4.3.4.1 Physical Characteristics

Appearance and Color

Appearance of Cheese Spread with Jalapenos (CS) changed during storage (Figure 156). The CS samples became slightly darker, very crumbly and not spreadable, particularly when exposed to temperatures higher than 80°F. An instrumental color analysis showed that L* values decreased regardless of the temperature, but the decrease was greater at 140°F than at lower temperatures (Figure 157). The chroma and hue angle values also decreased during storage regardless of the temperature, meaning that CS samples became duller, with a deeper yellowish color (Figure 157). The decrease in hue angle values was greater at temperatures above 80°F.

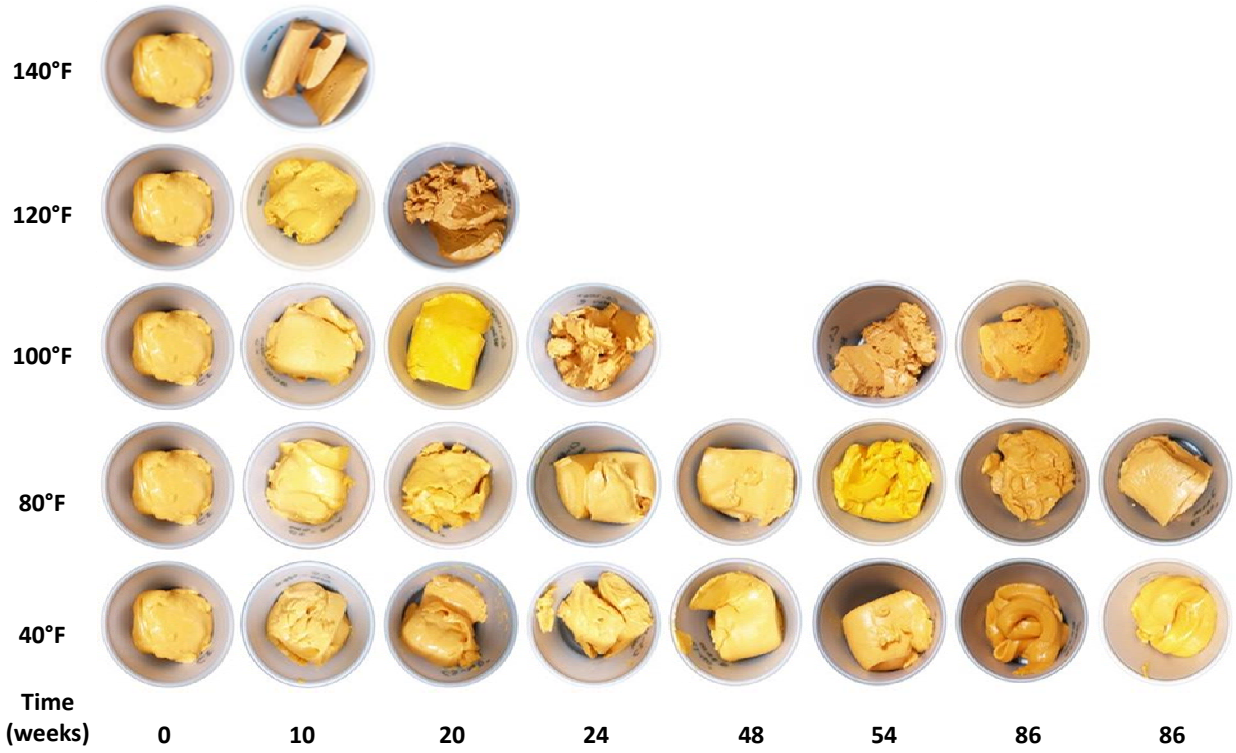


Figure 156. Changes in the appearance of Cheese Spread with Jalapenos during storage at 40, 80, 100, 120 and 140°F

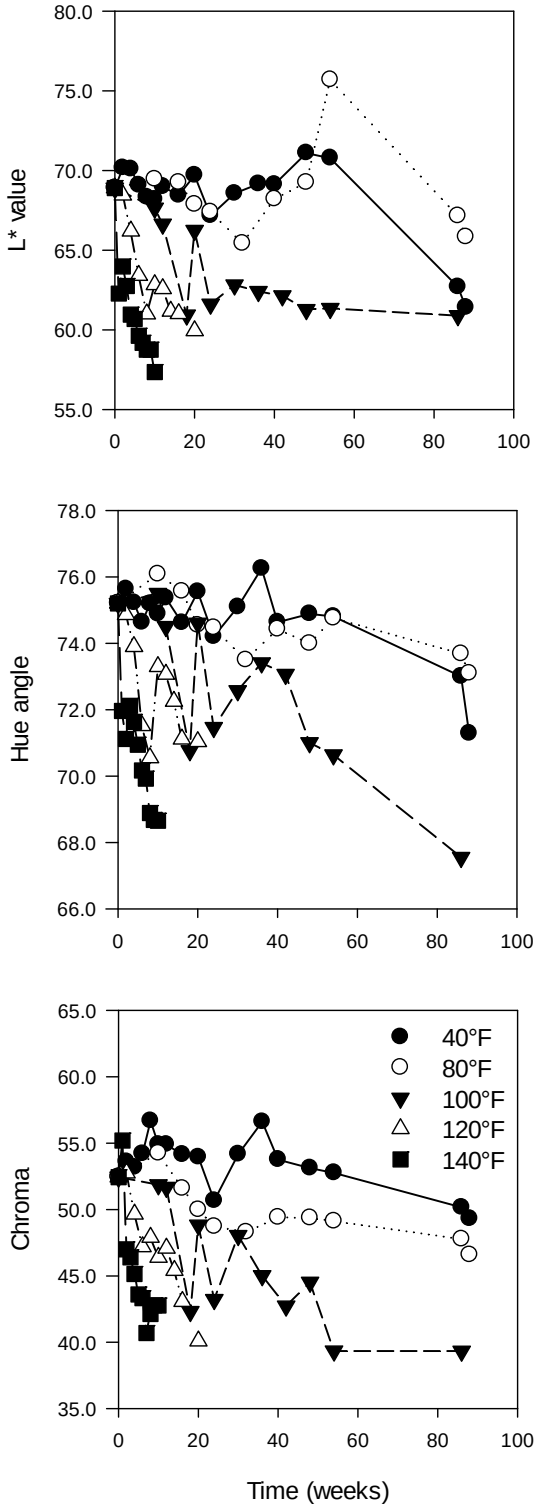


Figure 157. Changes in color attributes (L*, chroma and hue) of Cheese Spread with Jalapenos during storage at 40, 80, 100, 120 and 140°F

Texture

As observed visually, the spreadability of CS samples significantly decreased during storage (increase in firmness values) regardless of the temperature (Figure 158). In CS samples stored at 140°F there was a dramatic increase in firmness (increased 300% from initial values) as a result of a dry, crumbled texture with no adhesive capacity and a complete lack of spreading capacity. Changes in texture were less dramatic and similar in samples stored at 100 and 120°F (130 and 141% increase in firmness). The least increase in firmness was observed in samples stored for 88 weeks at 80°F (20% increase) followed by those stored at 40°F (43% increase).

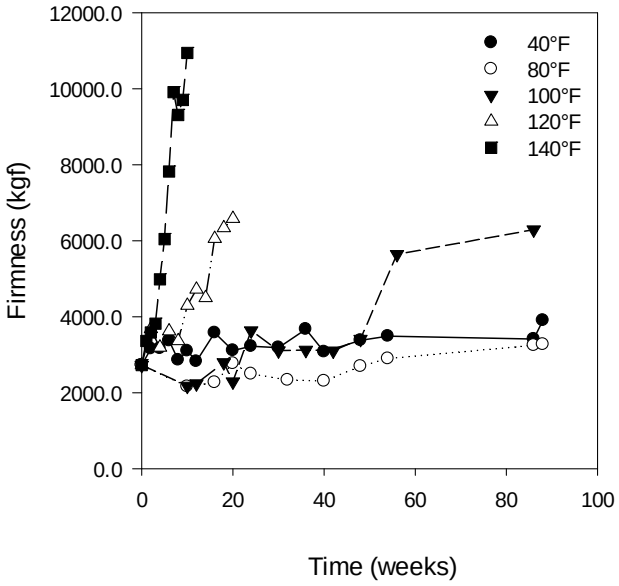


Figure 158. Changes in the texture of Cheese Spread with Jalapenos during storage at 40, 80, 100, 120 and 140°F

4.3.4.2 Compositional Analysis

pH, Titratable Acidity and Soluble Solids Content

During storage, the pH of CS decreased, whereas acidity increased, regardless of the temperature (Figure 159). An increase in acidity was identical (0.09%) and slightly higher in samples stored at 120 and 140°F compared to the acidity of samples stored at 40, 80 and 100°F. The acidity of samples stored below 120°F was similar (0.08%). The soluble solids content (SSC) decreased during storage, regardless of the temperature (Figure 159). A decrease in SSC was the least in samples stored at 40°F (22%) and the greatest in samples stored at 100°F (79%). Exposure to high temperatures had a less pronounced effect on SSC than exposure at 80 and 100°F.

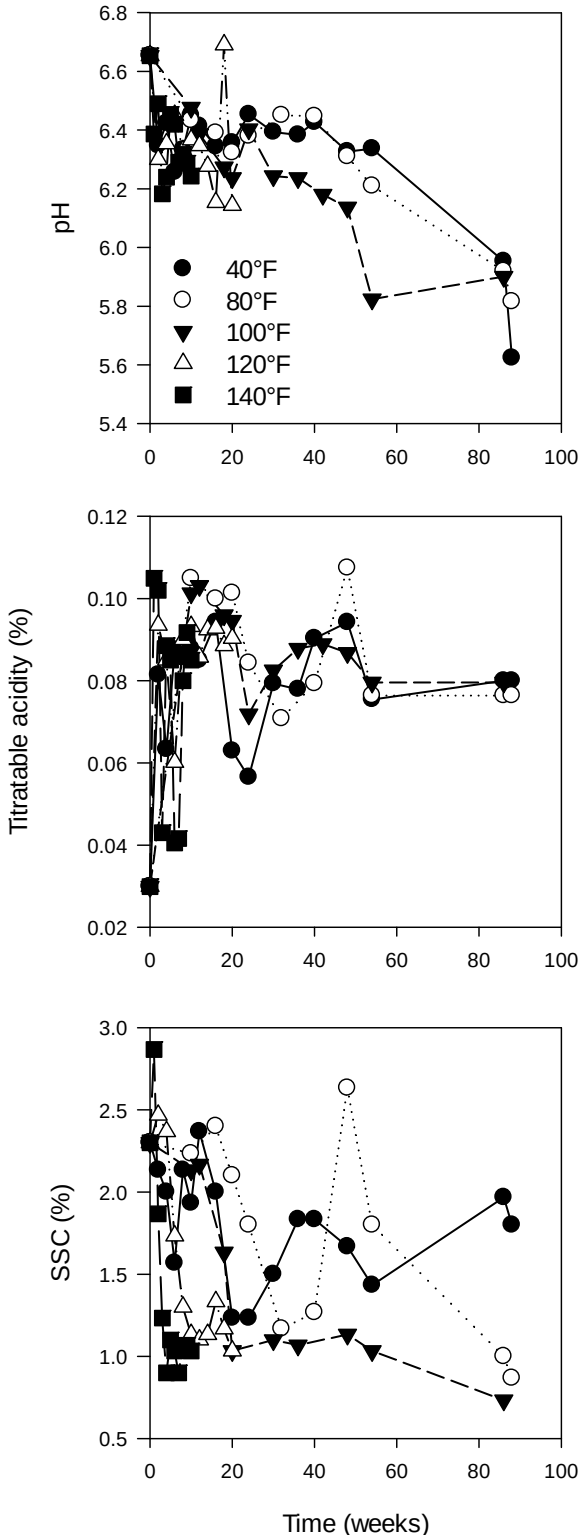


Figure 159. Changes in pH, titratable acidity and soluble solids content of Cheese Spread with Jalapenos during storage at 40, 80, 100, 120 and 140°F

Water Activity and Moisture Content

During storage there were practically no changes in the water activity of CS, which was relatively high (0.94). However, moisture content decreased during storage regardless of the temperature (Figure 160). The decrease was slight and similar between temperatures ranging from approximately 6% in samples stored at 40 and 80°F to approximately 4% in samples stored at higher temperatures.

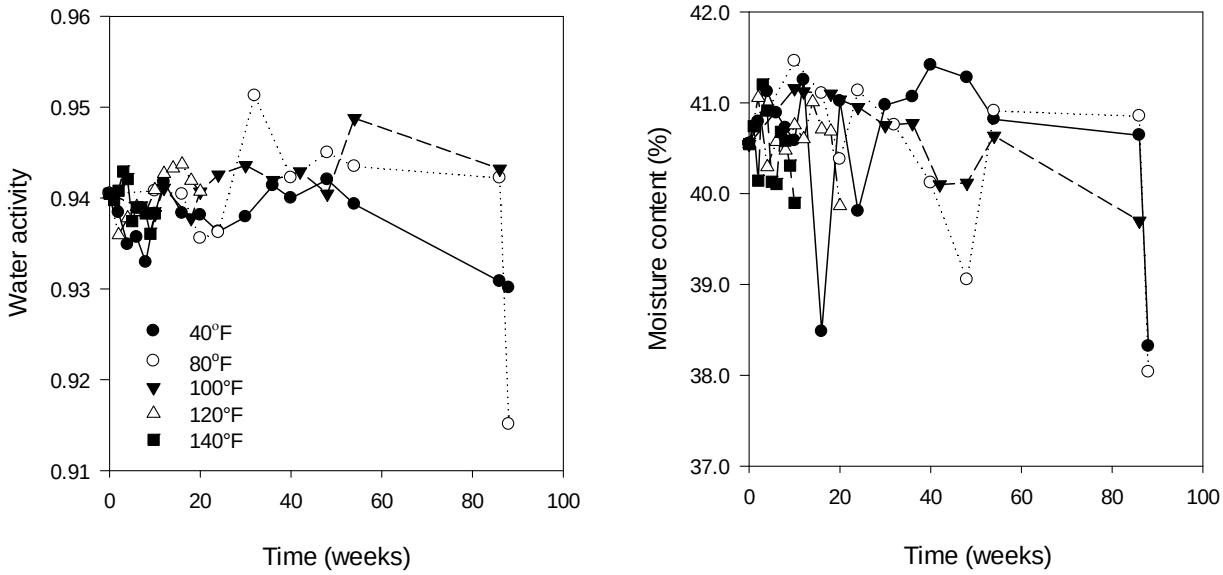


Figure 160. Changes in moisture content and water activity of Cheese Spread with Jalapenos during storage at 40, 80, 100, 120 and 140°F

Lipid Oxidation

Peroxide value (PV) decreased in samples exposed to 40, 80, 100 and 120°F but increased in samples exposed at 140°F (Figure 161). Thus, CS can be considered very stable to lipid oxidation if maintained at temperatures below 140°F. However, at 140°F, peroxide formation tended to increase and so the possibility of becoming rancid would be higher.

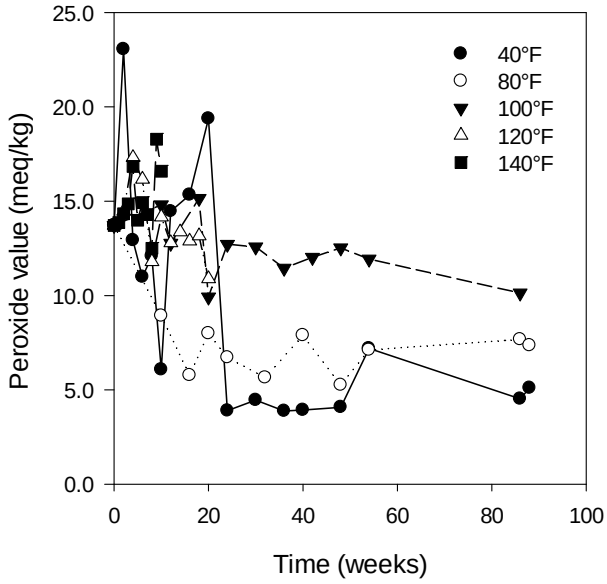


Figure 161. Changes in the peroxide value of Cheese Spread with Jalapenos during storage at 40, 80, 100, 120 and 140°F

4.3.4.3 Summary Of The Results For Cheese Spread With Jalapenos

Below is a summary of the changes that occurred in the appearance (Table 36) and in the different physical (Table 38) and compositional attributes (Tables 39 and 40) measured in samples of Cheese Spread with Jalapenos at the beginning and end of storage:

- Appearance: the higher the temperature, the darker the color of the samples.
- L* value: decreased for all temperatures (darker color).
- Chroma: decreased for all temperatures (dull color).
- Hue: decreased for all temperatures (browning).
- Texture: increased (less spreadable) for all temperatures.
- Moisture content: decreased for all samples.
- Water activity: decreased in samples stored at 40 and 80°F and remained the same for samples stored at 100, 120 and 140°F.
- pH: decreased for all temperatures.
- Acidity: increased for all temperatures.
- Soluble solids content: decreased for all temperatures.
- Peroxide value: decreased in samples stored at 40, 80, 100 and 120°F and increased in samples stored at 140°F.

4.3.5 Mango Peach Applesauce

4.3.5.1 Physical Characteristics

Appearance and Color

Changes in the color of Mango Peach Applesauce (MP) were very dramatic, particularly at temperatures higher than 80°F (Figure 162). After 20 and 10 weeks at 120 and 140°F, respectively, MP samples developed a deep brown color and had a caramel-like appearance. Samples stored at 80 and 100°F also develop a darker color after approximately 54 and 24 weeks of storage, respectively. In samples stored at 40°F, color also changed but MP samples appeared less brownish than those stored at higher temperatures. Similar results were obtained for FSR Applesauce. These intense changes in coloration may have resulted from non-enzymatic browning caused by exposure of MP samples to high temperatures. An instrumental color analysis confirmed the visual results and showed that L* values decreased (darker color) particularly in samples stored at 80°F and above (Figure 163). Exposure to high temperatures resulted in the greatest decrease in the L* values of MP. Hue angle and chroma values also decreased (more brown than yellow and duller color), and again, the higher the temperature, the greater the decrease.

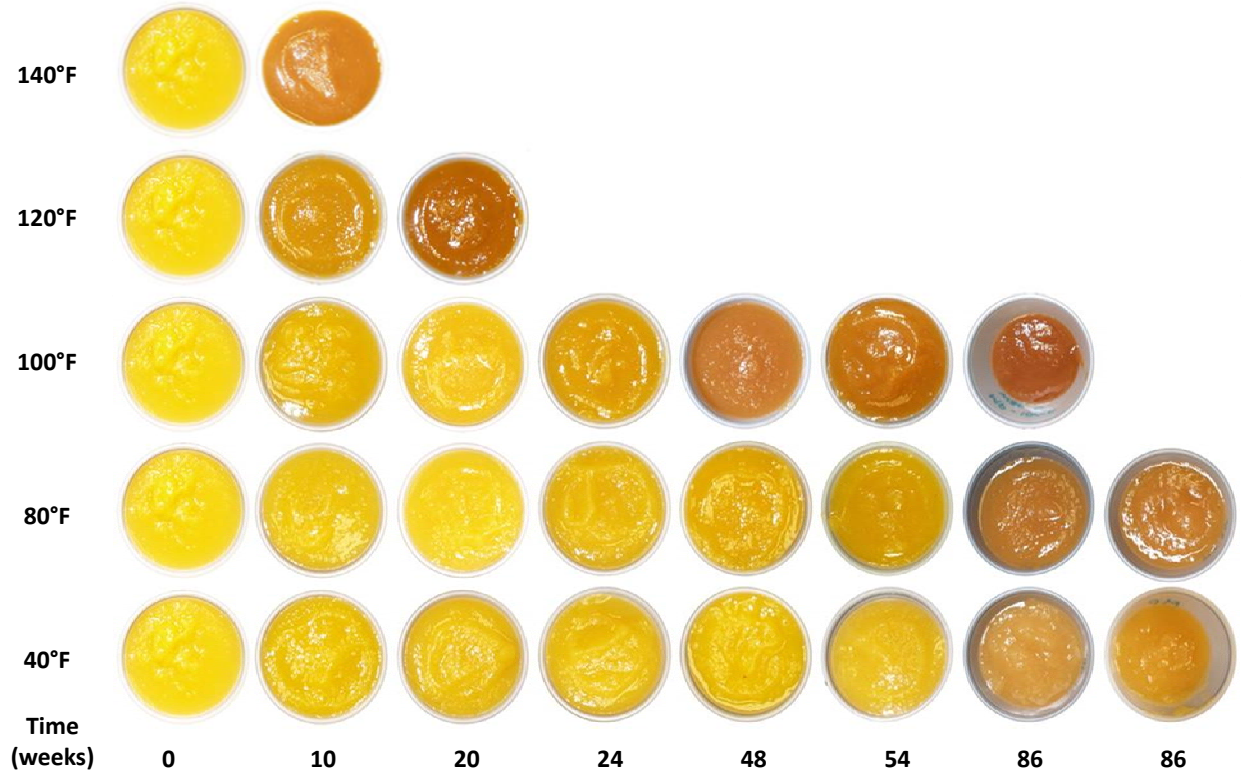


Figure 162. Changes in the appearance of Mango Peach Applesauce during storage at 40, 80, 100, 120 and 140°F

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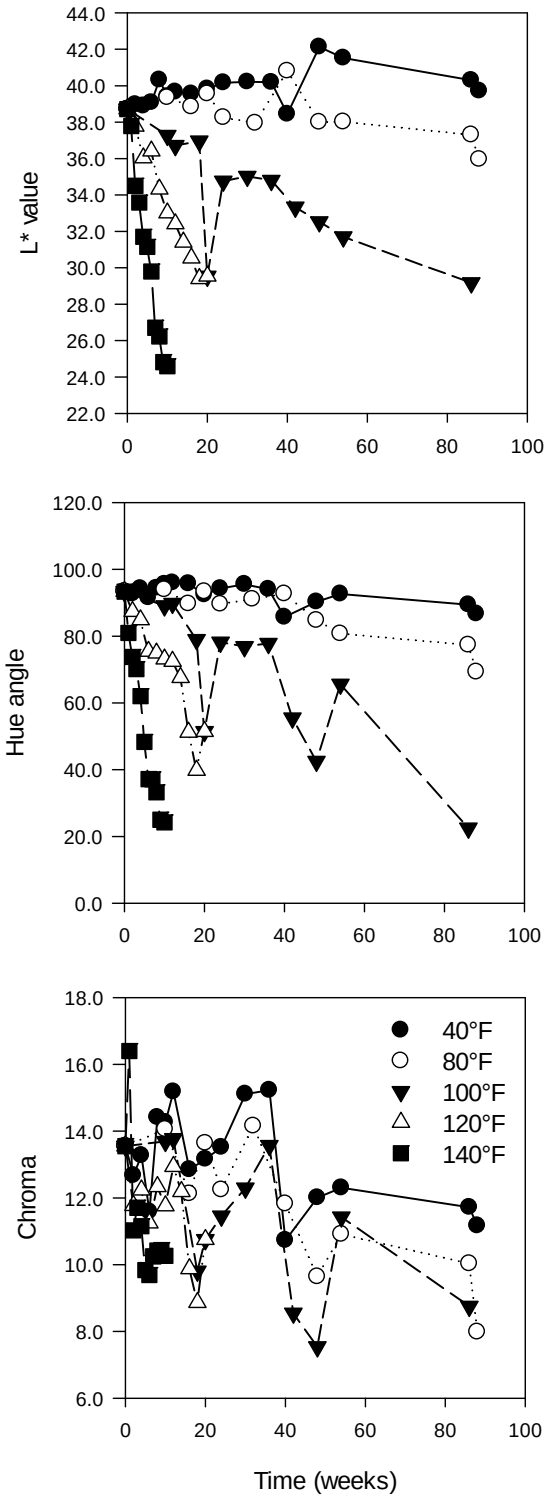


Figure 163. Changes in color attributes (L*, chroma and hue) of Mango Peach Applesauce during storage at 40, 80, 100, 120 and 140°F

Texture

Changes in the consistency of MP were also dramatic, particularly in samples stored at temperatures higher than 100°F (Figure 164). After 10 weeks, samples exposed at 140°F were less consistent and more liquid (38% decrease in firmness) than those stored for 88 weeks at 40 or 80°F, which showed either no change or a 13% decrease in the firmness, respectively.

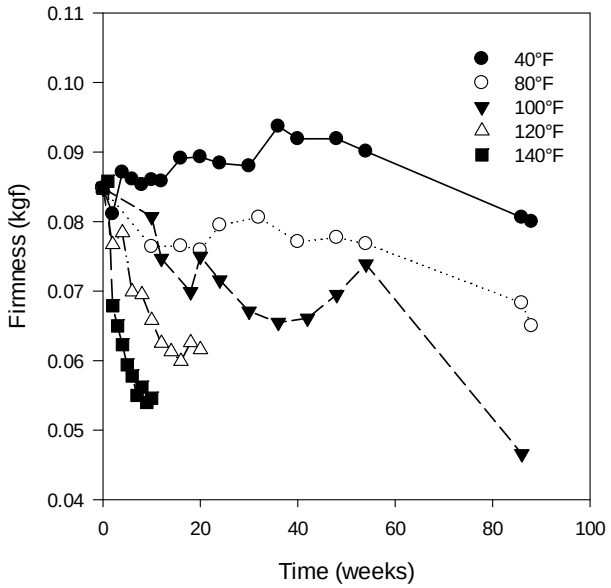


Figure 164. Changes in the texture of Mango Peach Applesauce during storage at 40, 80, 100, 120 and 140°F

4.3.5.2 Compositional Analysis

pH, Titratable Acidity and Soluble Solids Content

During storage, the pH of MP increased, whereas the acidity decreased (Figure 165). However, there was only a slight difference in the pH and acidity of MP between temperatures. There was no difference in the acidity of MP samples exposed for 10 weeks at 140°F or for 88 weeks at 40°F (0.45%). Samples stored at 120°F had the lowest acidity values (0.42%), followed by those stored at 100°F (0.44%) and 80°F (0.48%). The soluble solids content (SSC) of samples stored at 40, 80 and 100°F decreased, whereas the SSC of samples stored at 120 and 140°F increased (Figure 165). The increase in SSC at high temperatures may have resulted from the breakdown of pectin, which is an important component of apple-based products, and from the increase in glucose and fructose (see also Figure 167). The decrease in SSC in samples stored at or below 100°F may have resulted from the decrease in sucrose.

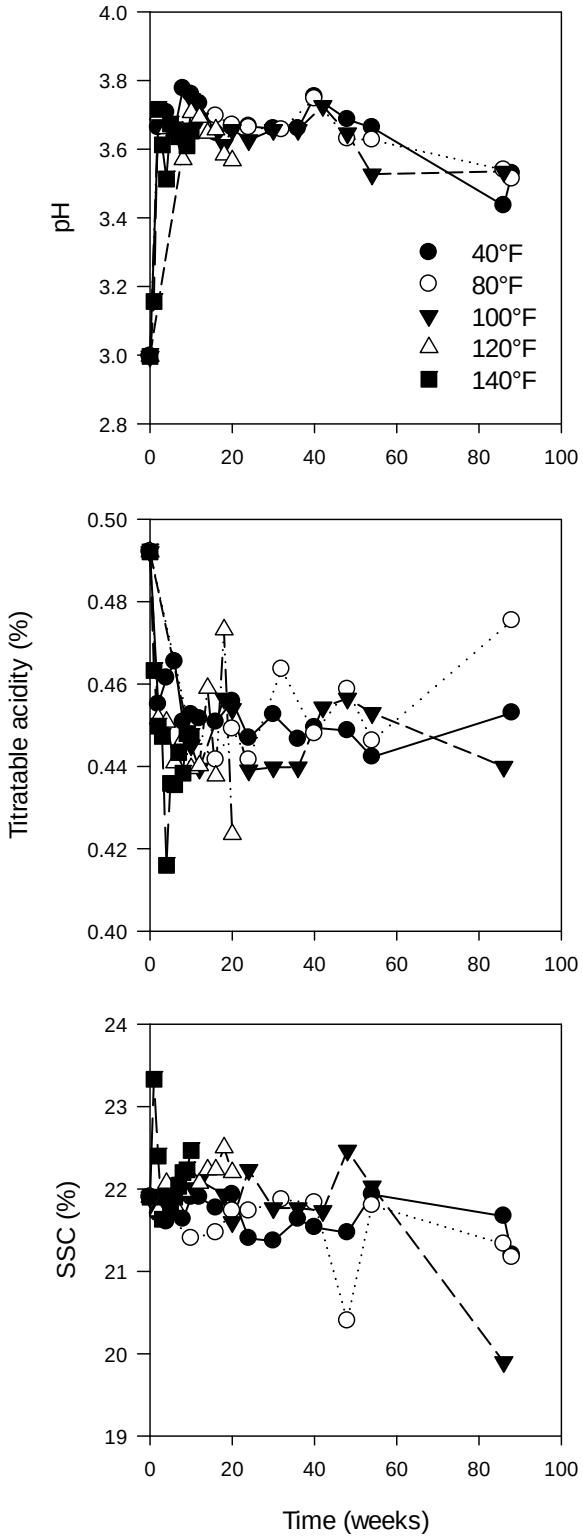


Figure 165. Changes in pH, titratable acidity and soluble solids content of Mango Peach Applesauce during storage at 40, 80, 100, 120 and 140°F

Water Activity and Moisture Content

Water activity decreased during storage regardless of the temperature, but at the end of each storage period, there was no different in the water activity values between temperatures (Figure 166). Moisture content, on the other hand, decreased in MP samples stored at 40 and 80°F but increased in samples stored at higher temperatures (Figure 166). The increase in moisture content in samples stored at and above 100°F may have contributed to the decrease in firmness and to the liquid appearance of MP.

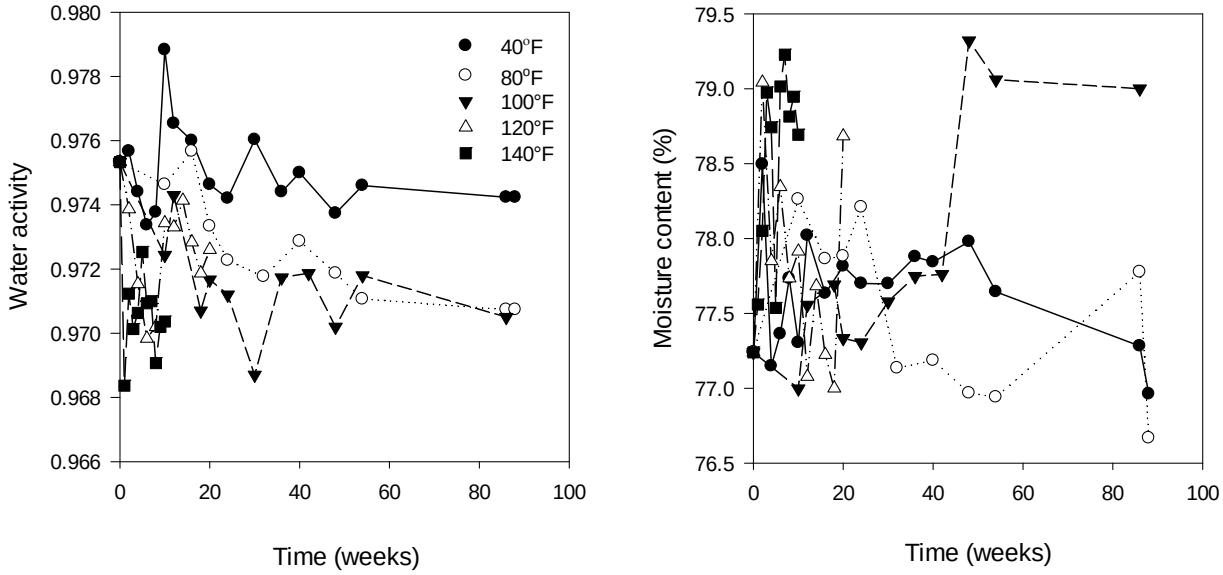


Figure 166. Changes in moisture content and water activity of Mango Peach Applesauce during storage at 40, 80, 100, 120 and 140°F.

Individual and Total Sugar Profiles

The sucrose content decreased dramatically in samples stored above 40°F (Figure 167). After 4 weeks at 120°F and after 1 week at 140°F, there was no detectable sucrose in MP samples. In MP samples stored at 80 and 100°F, the sucrose content decreased by 76% after 48 weeks, whereas it decreased by 39% in samples stored at refrigerated temperatures. The glucose content of MP samples decreased in samples stored at 40 and 100°F but increased in samples stored at 80, 120 and 140°F (Figure 167). The fructose content increased during storage; however, the highest increase in fructose was observed in samples stored at 120°F and 140°F (63 and 49%, respectively). MP samples stored at 80 and 100°F showed the same increase in fructose content (44%), whereas samples stored at 40°F showed the least decreased among temperatures (11%). The increase in fructose was most likely due to the breakdown of sucrose into fructose and glucose (particularly in samples stored at temperatures higher than 80°F). The total sugar content decreased during storage regardless of the temperature, due to the dramatic decrease in sucrose (Figure 167). However, at the end of each respective storage period there was not a marked difference between the total sugar content of MP samples stored at different temperatures. After 10 weeks, however, a decrease in total sugar content was greatest in samples stored at 120 and 140°F than in samples stored at lower temperatures for the same period of time.

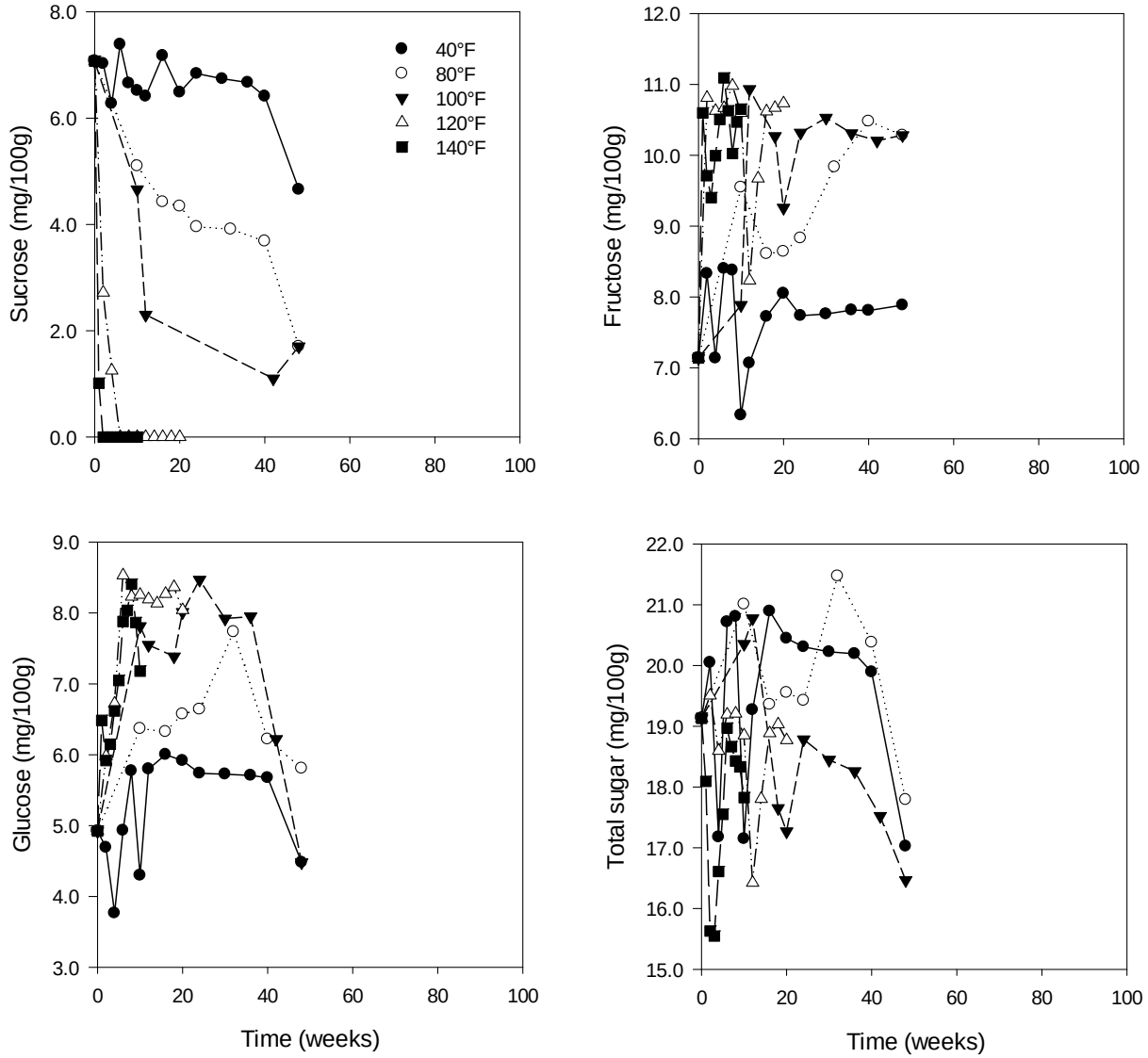


Figure 167. Changes in sugar profiles of Mango Peach Applesauce during storage at 40, 80, 100, 120 and 140°F.

Ascorbic Acid

As seen previously in FSR Applesauce (see prior discussion or poster presented at the IFT 2013 shown in Appendix B), the ascorbic acid of MP significantly decreased during storage regardless of the temperature (Figure 168). However, the greatest decrease in ascorbic acid was found in MP samples stored at 120 and 140°F. Thus, after 20 and 10 weeks, samples exposed to 120 and 140°F had lost 91.9 and 99.7% of their initial ascorbic acid content, respectively. Samples exposed for 48 weeks at 100°F lost approximately 80% of their initial value, whereas the smallest decrease in ascorbic acid was found in refrigerated MP samples (16%); samples stored at 80°F lost approximately 21% of their initial content.

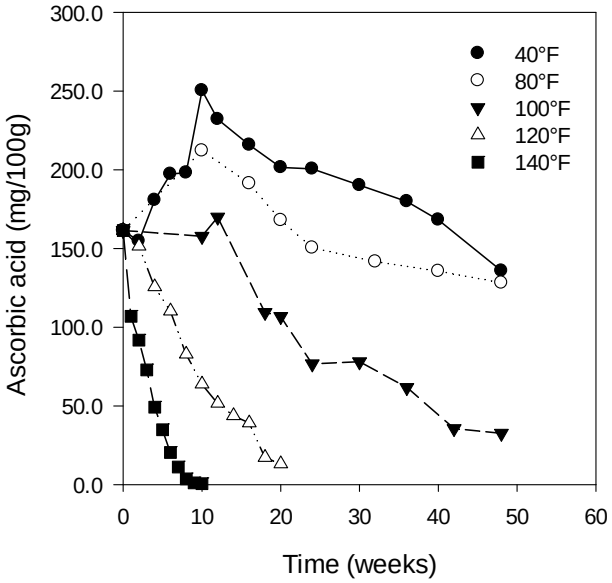


Figure 168. Changes in the ascorbic acid content of Mango Peach Applesauce during storage at 40, 80, 100, 120 and 140°F

4.3.5.3 Summary Of The Results For Mango Peach Applesauce

Below is a summary of the changes that occurred in the appearance (Table 37) and in the different physical (Table 38) and compositional attributes (Tables 39 and 40) measured in samples of Mango Peach Applesauce at the beginning and end of storage:

- Appearance: the higher the temperature, the darker the color of the samples.
- L* value: decreased for all temperatures except for samples stored at 40°F where there was a slight increase, most likely due to sample variation.
- Chroma: decreased for all temperatures (less vivid color).
- Hue: decreased for all temperatures (browning).
- Texture: decreased (more liquid) for all temperatures except for samples stored at 40°F for which there were no changes in texture.
- Moisture content: decreased in samples stored at 40 and 80°F and increased in samples stored at 100, 120 and 140°F.
- Water activity: decreased for all temperatures.
- pH: increased for all temperatures.
- Acidity: decreased for all temperatures.
- Soluble solids content: slightly decreased in samples stored at 40, 80 and 100°F, and increased in samples stored at 120 and 140°F.
- Ascorbic acid: decreased for all temperatures.
- Sucrose: decreased for all temperatures.
- Glucose: increased in samples stored at 80, 120 and 140°F, and decreased in samples stored at 40 and 100°F.
- Fructose: increased for all temperatures.
- Total sugars: decreased for all temperatures.

4.3.6 Pork Sausage In Cream Gravy

4.3.6.1 Physical Characteristics

Appearance and Color

Appearance of Pork Sausage in Cream Gravy (PS), unlike for other MRE foods used in this study, did not change considerably throughout storage, even for samples exposed to high temperatures (Figure 148). When color was instrumentally measured, there was even a slight increase in the L* value of the PS samples stored at 40, 80 and 100°F, meaning that they became lighter by the end of each respective storage period (Figure 170). The L* value of PS samples stored at 120°F was practically the same after 20 weeks, and it slightly decreased (darker color) in samples stored at 140°F. At the end of the storage period, chroma values were approximately the same as the initial values in PS samples stored at 40 and 80°F and increased (more vivid color) in samples stored at 100, 120 and 140°F (Figure 170). Hue angle values increased during storage regardless of the temperature (Figure 170). This increase in hue angles most likely resulted in a fading of the yellowish tone of the gravy, which became more whitish and thus the higher L* values measured by the end of the storage period. Even though there were some quantitative changes in the color of PS, those were difficult to perceive by the human eye. Note that differences between appearance and instrumental color measurements may be due to the fact that the samples were homogenized prior to color measurements (see Material and Methods section).

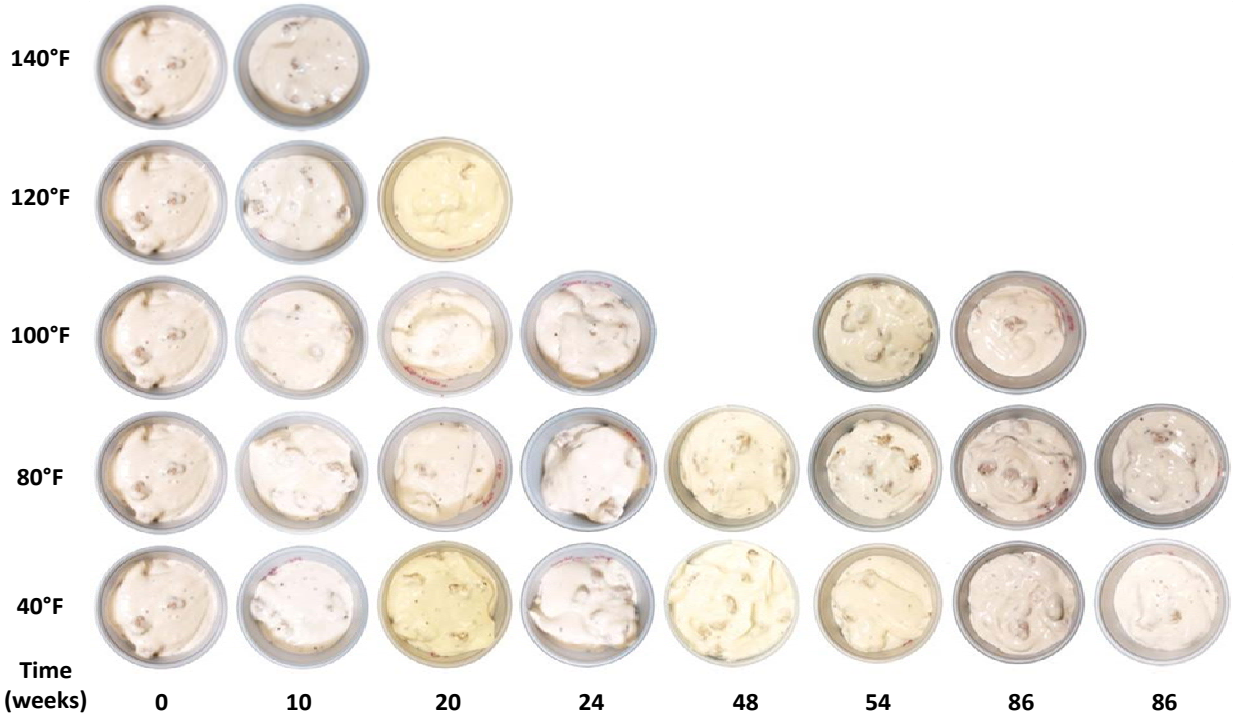


Figure 169. Changes in the appearance of Pork Sausage in Cream Gravy during storage at 40, 80, 100, 120 and 140°F

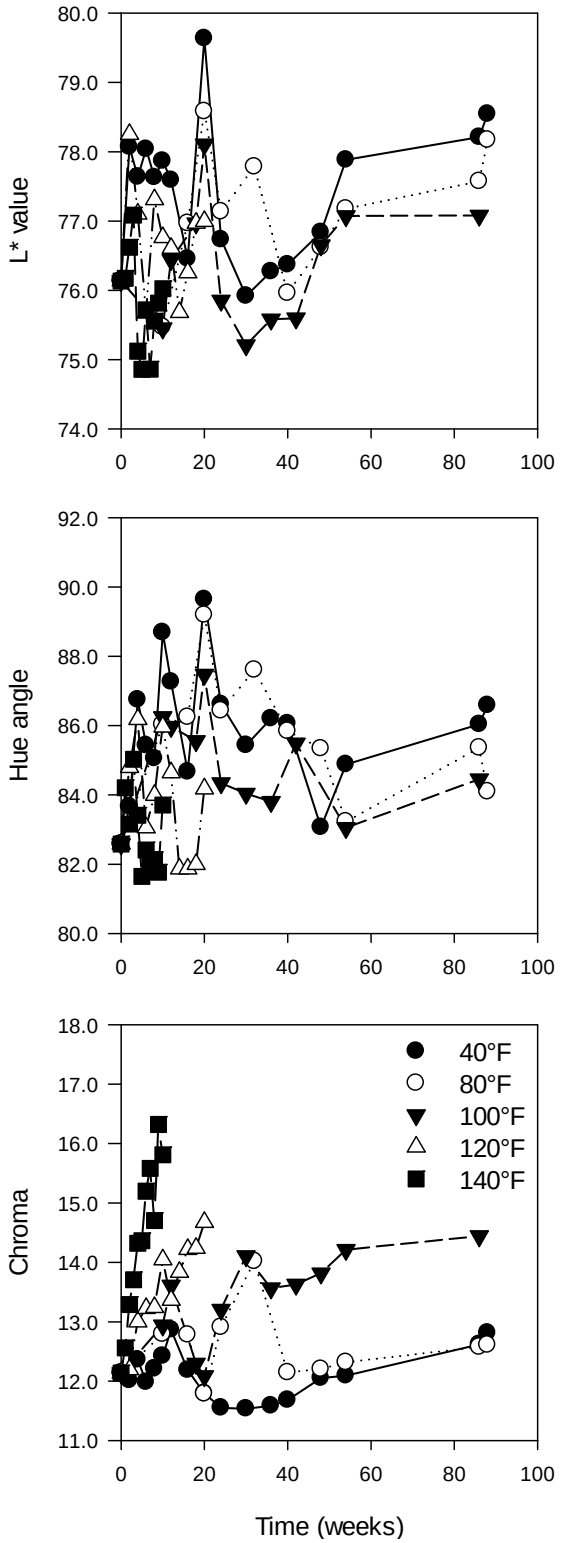


Figure 170. Changes in color attributes (L*, chroma and hue) of Pork Sausage in Cream Gravy during storage at 40, 80, 100, 120 and 140°F

Texture

The consistency of PS samples changed during storage, regardless of the temperature (Figure 171). Overall, the texture values increased for all temperatures except in PS samples stored at 140°F for 10 weeks, for which the texture decreased. The increase in firmness of samples stored at 120°F and below was most likely related to an increase in the consistency of the PS samples (the gravy became less creamy and thicker). On the other hand, the decrease in firmness in PS samples exposed to 140°F may have been caused by an increase in the fluidity of the gravy.

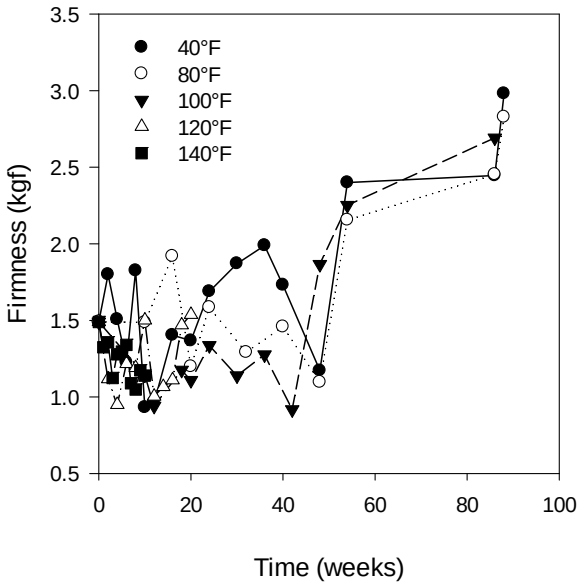


Figure 171. Changes in the texture of Pork Sausage in Cream Gravy during storage at 40, 80, 100, 120 and 140°F

4.3.6.2 Compositional Analysis

pH, Titratable Acidity and Soluble Solids Content

At the end of each respective storage period, the pH of PS was lower than the initial values, regardless of the temperature (Figure 172). In general, samples stored at lower temperatures had, at the end of the storage period, a lower pH than those stored at 120 and 140°F. Acidity increased during storage, but at the end of storage there was no difference between temperatures (Figure 172). The soluble solids content (SSC) of PS increased during storage for all temperatures except for samples stored at 140°F, for which there was no change compared to initial SSC values (Figure 172). The highest increase in SSC was observed in samples stored at 100°F, and the least increase was in samples stored at 120°F.

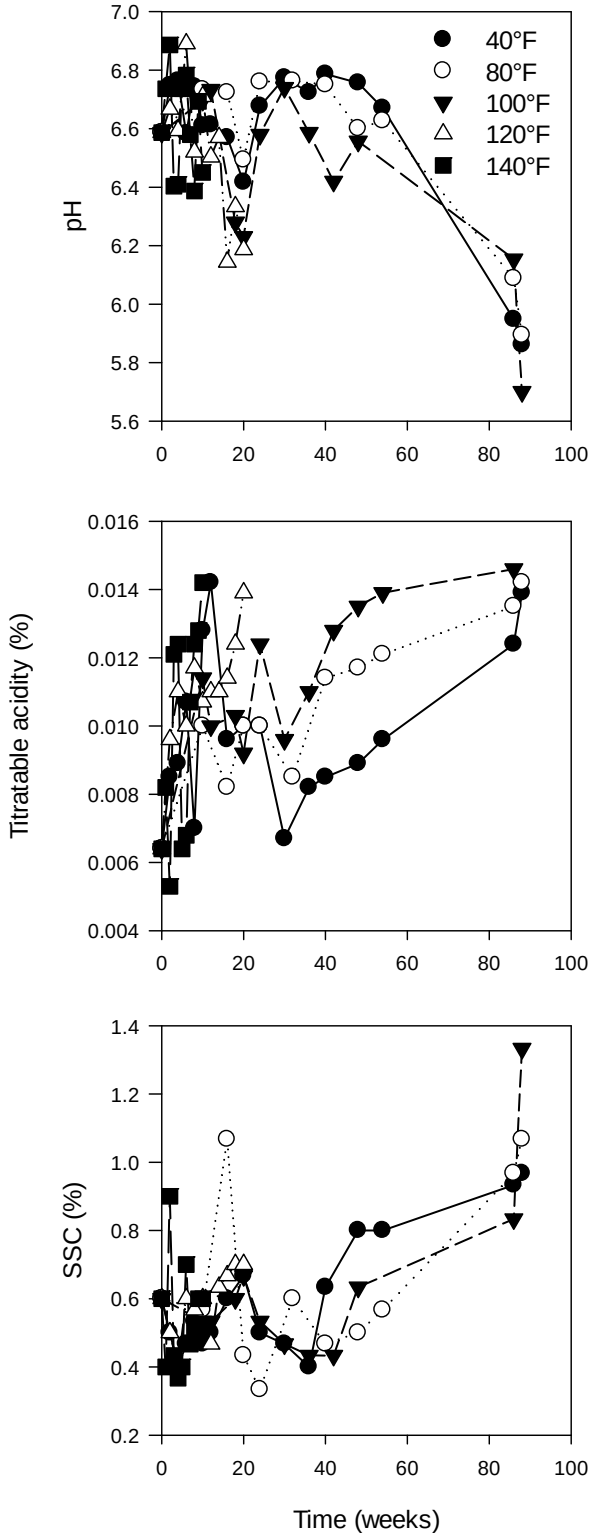


Figure 172. Changes in pH, titratable acidity and soluble solids content of Pork Sausage in Cream Gravy during storage at 40, 80, 100, 120 and 140°F

Water Activity and Moisture Content

Water activity of PS samples was slightly lower, but similar, in samples stored at 40, 80 and 100°F, and, compared to the initial values, did not change in PS samples stored at 120 and 140°F (Figure 173). Overall, the moisture content tended to increase during storage, particularly in samples stored at 120 and 140°F, and slightly decrease in samples stored at 100°F (Figure 173). These small changes in moisture content might have contributed to the changes in the consistency of the gravy.

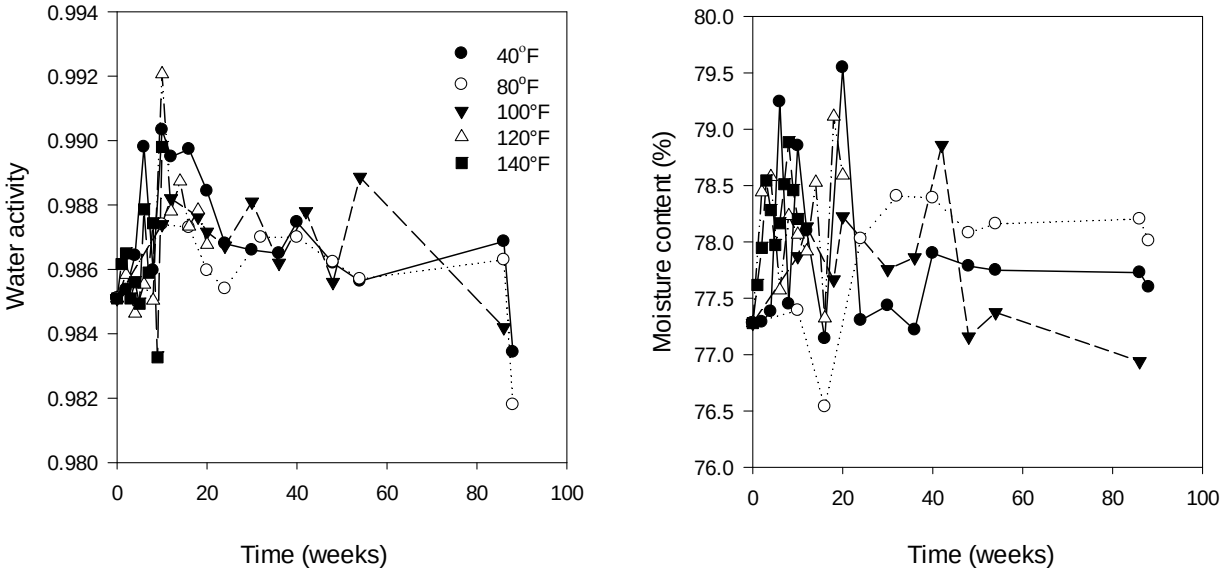


Figure 173. Changes in moisture content and water activity of Pork Sausage in Cream Gravy during storage at 40, 80, 100, 120 and 140°F

Lipid Oxidation

The peroxide value (PV) fluctuated throughout storage (Figure 174). Even though there was an increase in the PV of samples stored at 80 and 100°F, the values were still considerably low (8.8 and 9.7, respectively). The peroxide value decreased in PS samples stored at 40, 120 and 140°F.

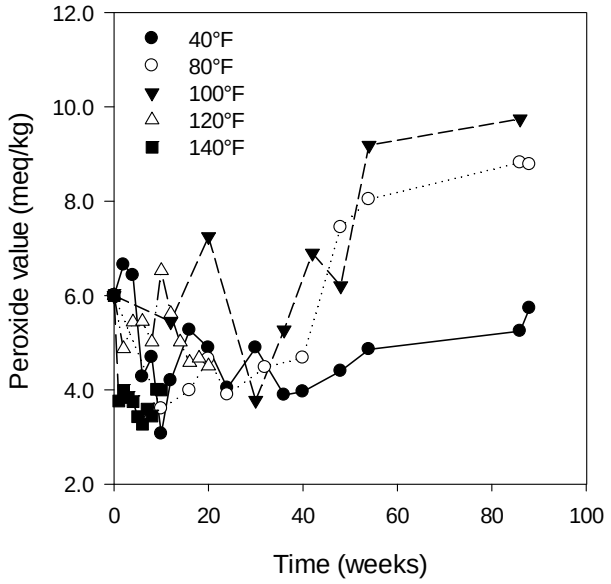


Figure 174. Changes in the peroxide value of Pork Sausage in Cream Gravy during storage at 40, 80, 100, 120 and 140°F

4.3.6.3 Summary Of The Results For Pork Sausage In Cream Gravy

Below is a summary of the changes that occurred in the appearance (Table 37) and in the different physical (Table 38) and compositional attributes (Tables 39 and 40) measured in samples of Pork Sausage in Cream Gravy at the beginning and end of storage:

- Appearance: there were no noticeable changes in appearance of the samples.
- L* value: increased (lighter color) in samples stored at 40, 80, 100 and 120°F, and was about the same in samples stored at 140°F.
- Chroma: increased for all temperatures (more vivid color).
- Hue: increased for all temperatures (less yellow).
- Texture: increased (less creamy) for all temperatures except for samples stored at 140°F, for which there was a decrease (less consistent).
- Moisture content: increased in all samples except for those stored at 100°F, for which there was a decrease.
- Water activity: decreased in samples stored at 40, 80 and 100°F, and was the same in samples stored at 120 and 140°F.
- pH: decreased for all temperatures.
- Acidity: increased for all temperatures.
- Soluble solids content: increased in samples stored at 40, 80, 100 and 120°F, and was the same in samples stored at 140°F.
- Peroxide value: decreased in samples stored at 40, 120 and 140°F, and increased in samples stored at 80 and 100°F.

4.3.7 Nut Raisin Mix

4.3.7.1 Physical Characteristics

Appearance and Color

The appearance of Nut Raisin Mix (NR) changed during storage with the nuts becoming darker as if they had been toasted, particularly when the samples were exposed at 140°F (Figure 175). When color was quantitatively measured, L* values decreased (darker color) regardless of the temperature (Figure 176). However, the greatest decrease in L* values (darker color) was observed in samples stored at 120 and 140°F, compared to those stored at lower temperatures. Chroma values also decreased regardless of the temperature (Figure 176); however, at the end of the storage period, NR samples stored at 140°F had the highest chroma values compared to chroma values of samples stored at lower temperatures. The higher chroma values (more vivid color) might have resulted in darkening of the nuts (became darker brown). Hue angle values decreased regardless of the storage temperature, meaning that the color became deeper (Figure 176). Note that differences between appearance and instrumental color measurements may be due to the fact that the samples were homogenized prior to color measurements (see Material and Methods section).

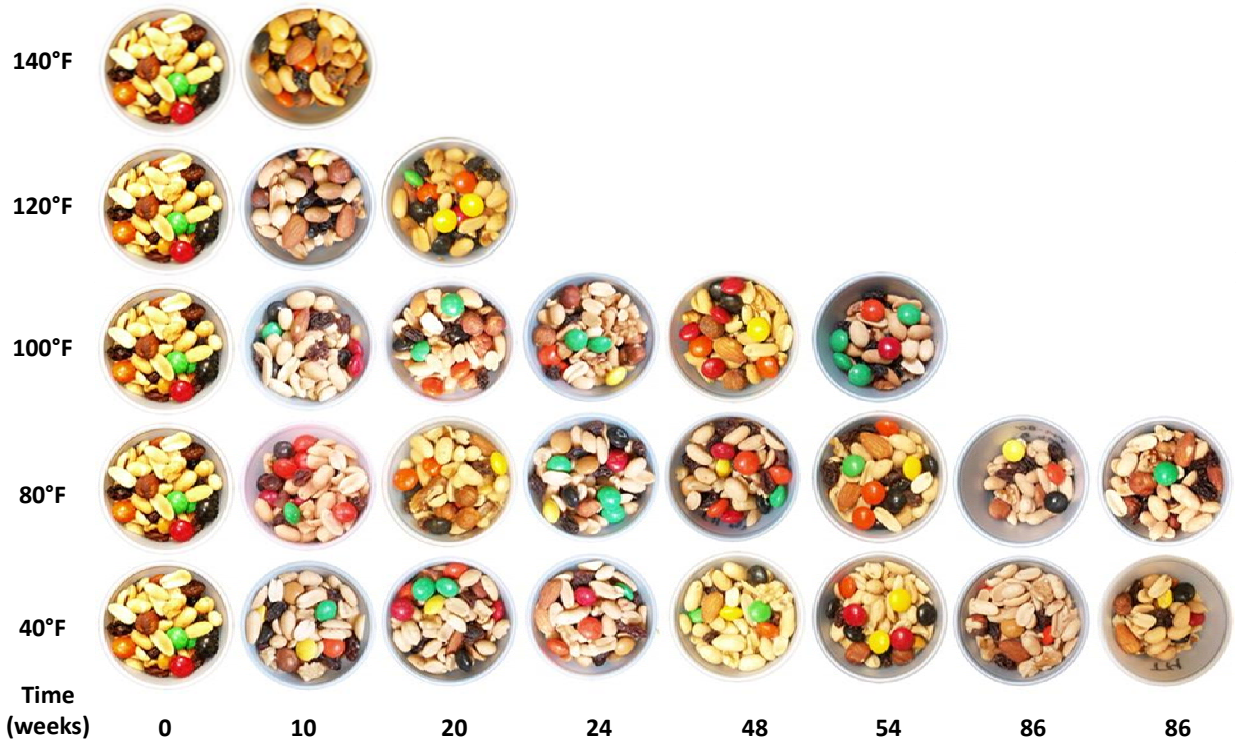


Figure 175. Changes in the appearance of Nut Raisin Mix during storage at 40, 80, 100, 120 and 140°F

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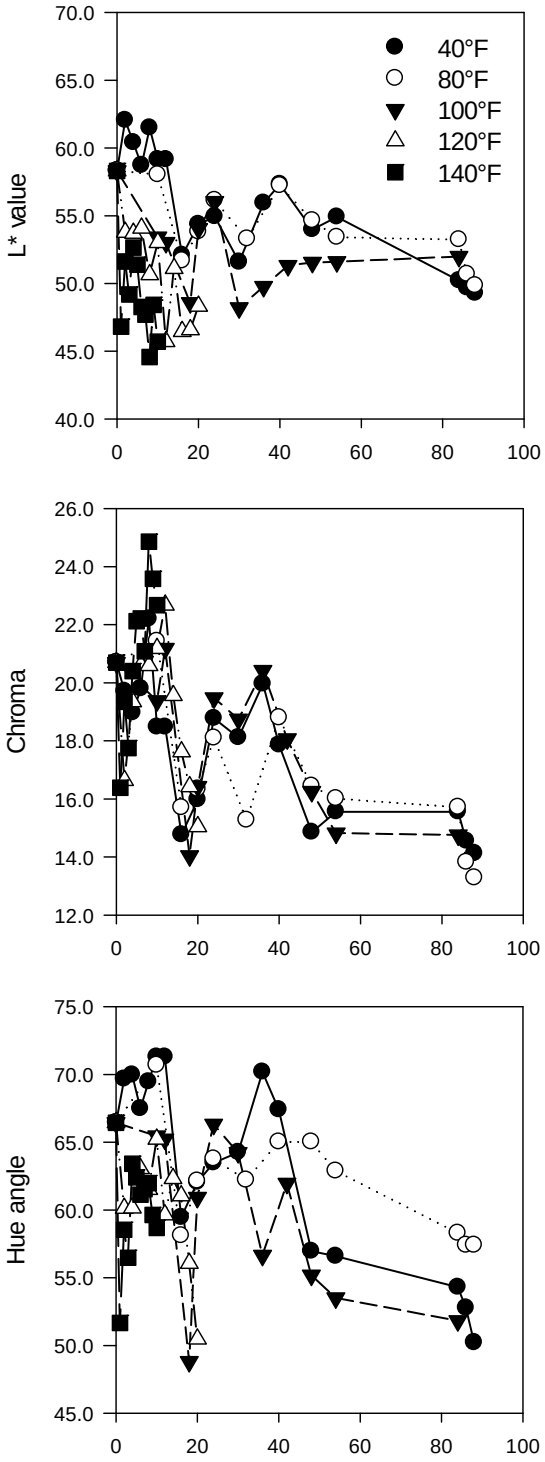


Figure 176. Changes in color attributes (L*, chroma and hue) of Nut Raisin Mix during storage at 40, 80, 100, 120 and 140°F

Texture

Texture of NR decreased during storage regardless of the temperature (Figure 177). At the end of each respective temperature, the force required to penetrate the nuts, raisins and chocolate pellets was less than it was initially, meaning that there was a decrease in the crispiness of the components. However, the greatest decrease in firmness (softening) was observed in samples stored at 40 and 80°F, compared to those stored at higher temperatures. One possible reason for this change in texture may be related to water migration from the raisins to the nuts, which rendered them less crispy and softer.

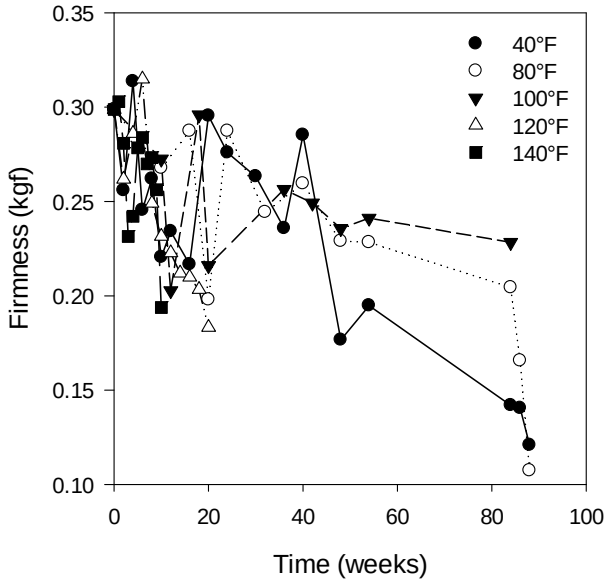


Figure 177. Changes in the texture of Nut Raisin Mix during storage at 40, 80, 100, 120 and 140°F

4.3.7.2 Compositional Analysis

pH, Titratable Acidity and Soluble Solids Content

Overall, the pH of NR decreased during storage regardless of the temperature (Figure 178). The decrease in pH was lowest in samples stored at 120 and 140°F, compared to those stored at lower temperatures. The acidity, on the other hand, increased for all temperatures, but the highest increase was measured in NR samples stored at 80 and 100°F, whereas the lowest increase was measured in samples stored at 140°F. The soluble solids content (SSC) decreased regardless of the temperature, but the highest decrease was measured in samples stored at 40°F (69.5%), whereas the lowest decrease was measured in samples stored at 140°F (7.9%). It is possible that a longer storage period, even if at refrigerated temperatures, may have a larger impact on the SSC than a shorter exposure to higher temperatures. Also the decrease in moisture content and water activity may have affected the percentage of soluble solids.

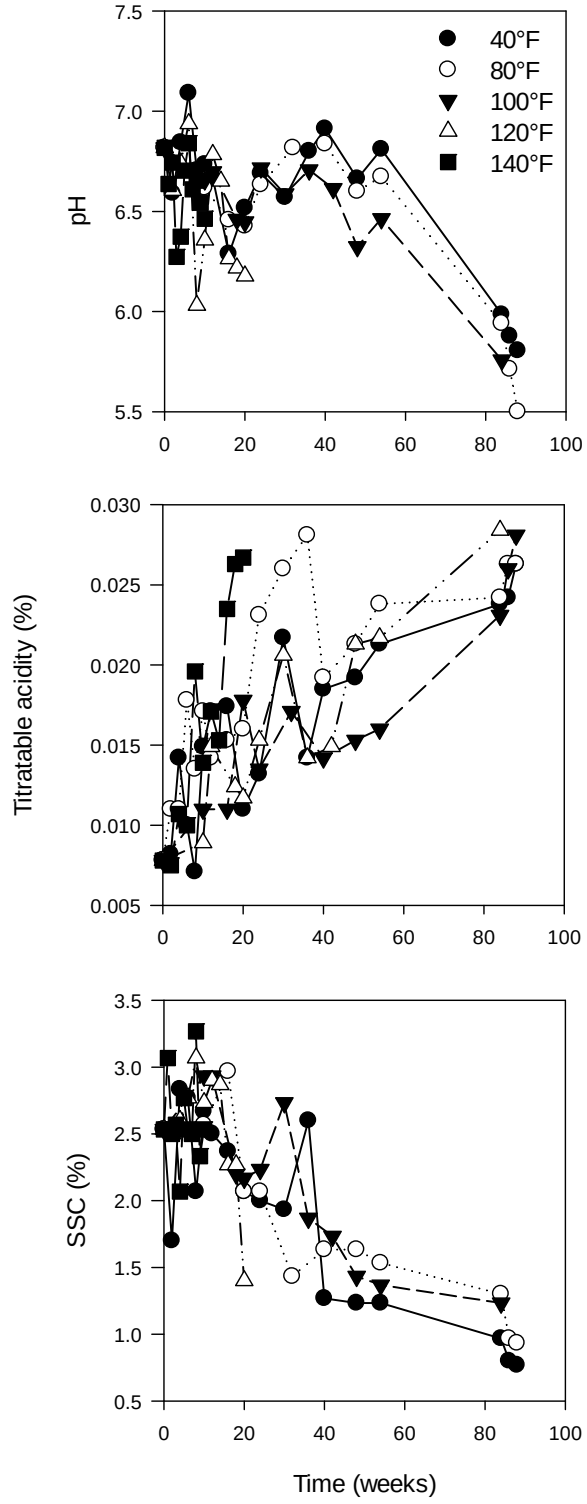


Figure 178. Changes in pH, titratable acidity and soluble solids content of Nut Raisin Mix during storage at 40, 80, 100, 120 and 140°F

Water Activity and Moisture Content

Water activity and moisture content decreased regardless of the storage temperature (Figure 179), but the decrease was more accentuated in samples stored at lower temperatures than at 140°F. This may have affected the soluble solids content as well as the acidity of the samples. Lower water activity values mean that there is less water available for a chemical reaction to occur, which may explain the fact that NR samples stored at lower temperatures had a higher total sugar content (particularly glucose and fructose) than those stored at higher temperatures (Figure 180).

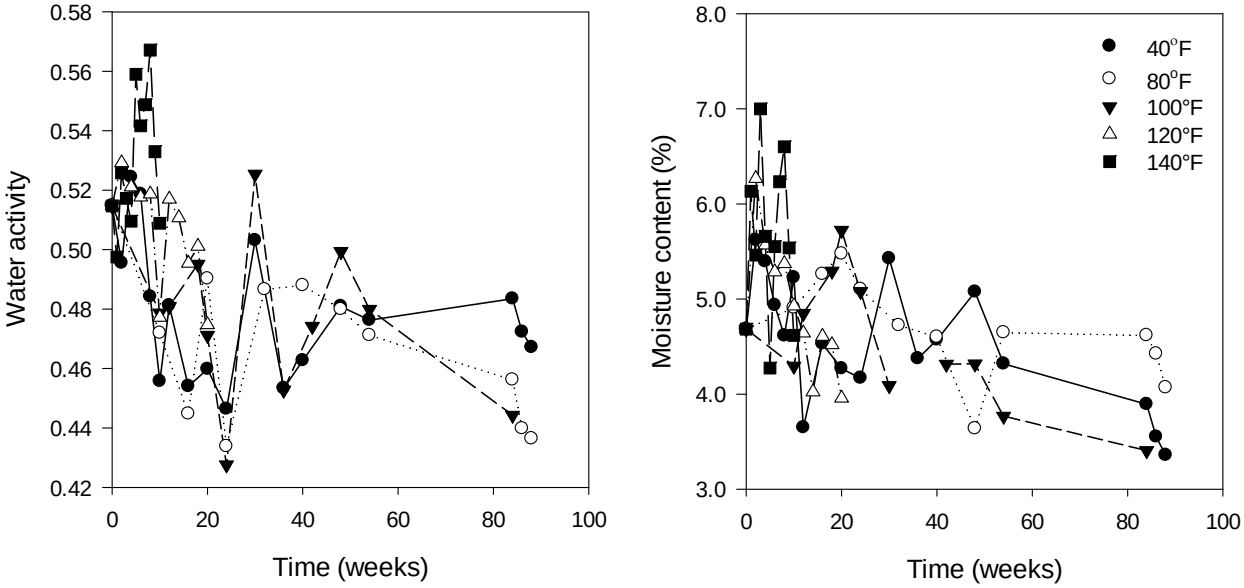


Figure 179. Changes in moisture content and water activity of Nut Raisin Mix during storage at 40, 80, 100, 120 and 140°F

Individual and Total Sugar Profiles

The sucrose, glucose, fructose and total sugars content decreased during storage regardless of the temperature (Figure 180). However, the decrease in glucose and fructose was higher in samples stored at 140°F than in those stored at 40°F. After 10 weeks at 140°F, glucose and fructose contents decreased by 74 and 78%, respectively, while after 88 weeks at 40°F, glucose and fructose contents were 37 and 66% lower than initial values, respectively. At the end of 88 weeks, NR samples stored at 80°F showed the highest levels of sucrose, glucose and fructose, compared to samples stored at other temperatures. Thus, it seems that refrigerated temperatures did not benefit sugar content retention in NR samples compared to storage at ambient temperatures.

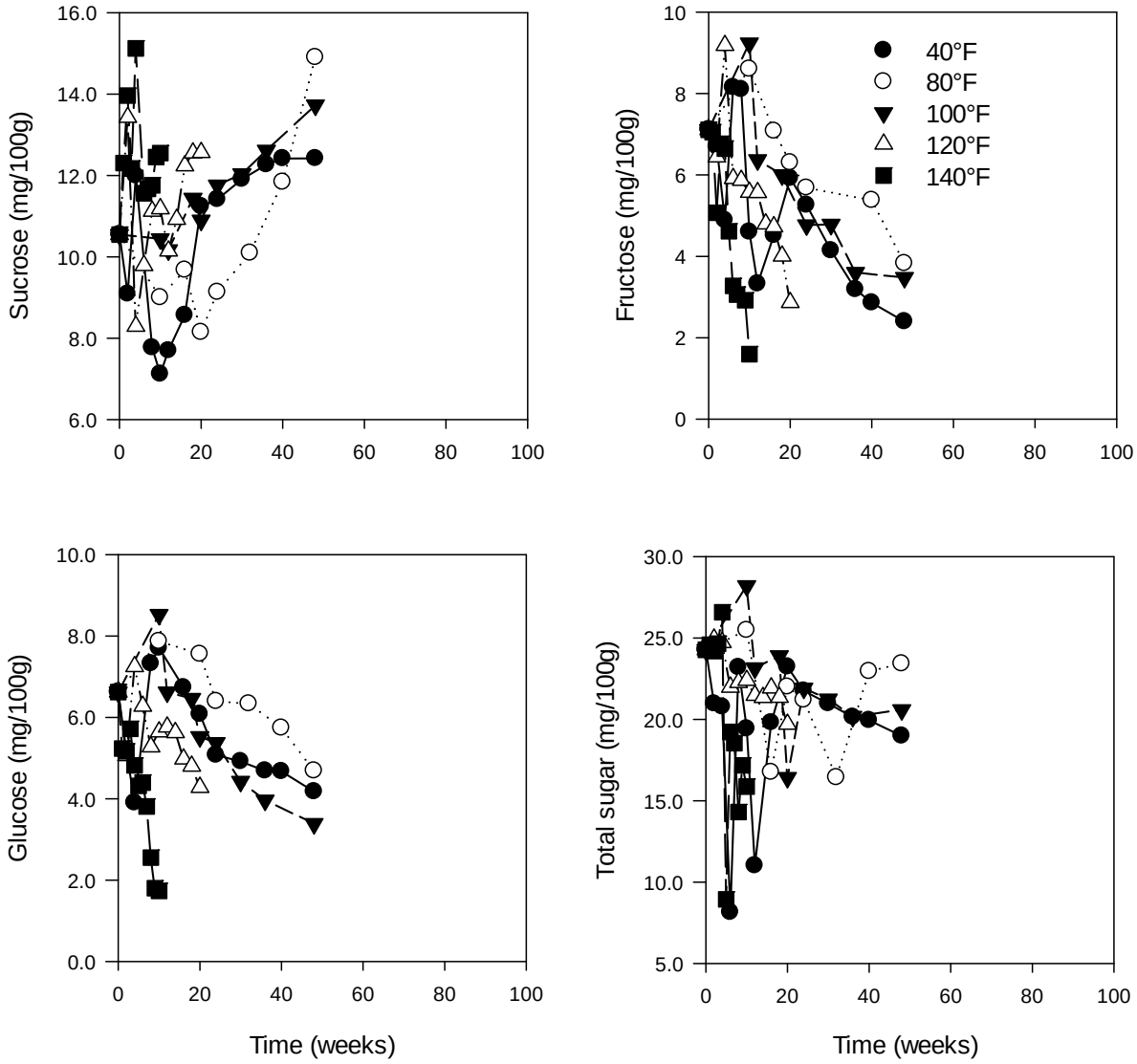


Figure 180. Changes in sugar profiles of Nut Raisin Mix during storage at 40, 80, 100, 120 and 140°F

Lipid Oxidation

Peroxide value (PV) increased during storage regardless of the temperature (Figure 181). After exposure to each respective temperature, the values were quite high, particularly in samples stored at temperatures above 40°F, due to the formation of peroxides or hydroperoxides. Thus, NR should be considered a food with potential to develop rancid off-flavor compounds, particularly when exposed to abuse temperatures (see sensory data).

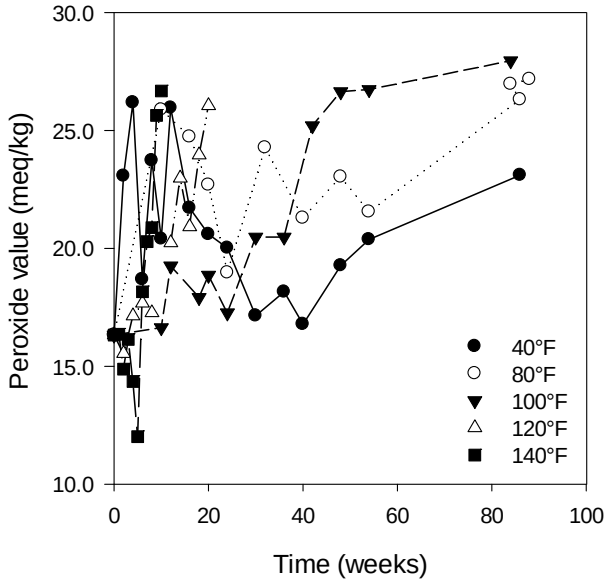


Figure 181. Changes in the peroxide value of Nut Raisin Mix during storage at 40, 80, 100, 120 and 140°F

4.3.7.3 Summary Of The Results For Nut Raisin Mix

Below is a summary of the changes that occurred in the appearance (Table 37) and in the different physical (Table 38) and compositional attributes (Tables 39 and 40) measured in samples of Nut Raisin Mix at the beginning and end of storage:

- Appearance: the higher the temperature, the darker the color of the samples.
- L* value: decreased (darker) for all temperatures.
- Chroma: decreased in samples stored at 40, 80, 100 and 120°F (less vivid), but increased in samples stored at 140°F (more vivid).
- Hue: decreased for all temperatures (more brownish).
- Texture: decreased for all temperature (chewier, less crunchy).
- Moisture content: decreased for all temperatures.
- Water activity: decreased in samples stored at 40, 80, 100 and 120°F, and was the same as initial values in samples stored at 140°F.
- pH: decreased for all temperatures.
- Acidity: increased for all temperatures.
- Soluble solids content: decreased for all temperatures.
- Peroxide value: increased for all temperatures.
- Sucrose: decreased for all temperatures.
- Glucose: decreased for all temperatures.
- Fructose: decreased for all temperatures.
- Total sugars: decreased for all temperatures.

Table 36. Initial and final appearance (after storage at 40, 80, 100, 120 and 140°F) of Beef Ravioli in Meat Sauce, Chipotle Snack Bread, Chunky Peanut Butter and Cheese Spread with Jalapenos

FSR Item	Temperature (°F)	Appearance		FSR Item	Temperature (°F)	Appearance	
		Initial	Final[a]			Initial	Final[a]
Beef Ravioli	40			Chunky Peanut Butter	40		
	80				80		
	100				100		
	120				120		
	140				140		
Chipotle Snack Bread	40			Cheese Spread	40		
	80				80		
	100				100		
	120				120		
	140				140		

[a]Final: 88 weeks at 40 or 80°F; 84 weeks at 100°F for Chipotle Snack Bread and 88 weeks at 100°F for Ravioli in Meat Sauce, Chunky Peanut Butter and Cheese Spread with Jalapenos; 20 weeks at 120°F; 10 weeks at 140°F.

Table 37. Initial and final appearance (after storage at 40, 80, 100, 120 and 140°F) of Mango Peach Applesauce, Pork Sausage in Gravy and Nut Raisin Mix

FSR Item	Temperature (°F)	Appearance		FSR Item	Temperature (°F)	Appearance	
		Initial	Final[a]			Initial	Final[a]
Mango Peach Applesauce	40			Nut Raisin Mix	40		
	80				80		
	100				100		
	120				120		
	140				140		
Pork Sausage in Gravy	40						
	80						
	100						
	120						
	140						

[a]Final: 88 weeks at 40 or 80°F; 84 weeks at 100°F for Nut Raisin Mix and 88 weeks at 100°F Mango Peach Applesauce and Pork Sausage in Gravy; 20 weeks at 120°F; 10 weeks at 140°F.

Table 38. Initial and final color and texture (after storage at 40, 80, 100, 120 and 140°F) of selected MRE items.

FSR Item	Temperature (°F)	L* value		Chroma		Hue		Texture (kgf)	
		Initial	Final[a]	Initial	Final[a]	Initial	Final[a]	Initial	Final[a]
Beef Ravioli	40	55.6	53.4	34.1	34.4	65.1	62.6	9.87	28.02
	80	55.6	52.7	34.1	33.5	65.1	63.5	9.87	6.92
	100	55.6	46.6	34.1	32.2	65.1	57.2	9.87	6.50
	120	55.6	48.7	34.1	31.6	65.1	59.7	9.87	7.81
	140	55.6	46.5	34.1	31.8	65.1	61.1	9.87	5.86
Chipotle Snack Bread	40	57.3	54.0	33.3	28.3	59.3	58.0	5.40	7.53
	80	57.3	51.1	33.3	29.7	59.3	58.1	5.40	6.54
	100	57.3	48.2	33.3	25.4	59.3	50.8	5.40	6.76
	120	57.3	48.3	33.3	23.7	59.3	45.2	5.40	5.54
	140	57.3	40.7	33.3	28.2	59.3	50.9	5.40	9.93
Chunky Peanut Butter	40	57.5	58.1	29.2	28.4	70.6	68.9	8964.05	7450.35
	80	57.5	57.1	29.2	27.3	70.6	69.3	8964.05	6644.50
	100	57.5	57.2	29.2	27.6	70.6	69.2	8964.05	5604.69
	120	57.5	56.3	29.2	29.6	70.6	71.7	8964.05	8290.63
	140	57.5	55.3	29.2	30.7	70.6	68.9	8964.05	8562.48
Cheese Spread	40	68.9	61.4	52.4	49.3	75.2	71.3	2724.36	3901.51
	80	68.9	65.8	52.4	46.6	75.2	73.1	2724.36	3268.77
	100	68.9	60.9	52.4	39.3	75.2	67.6	2724.36	6289.80
	120	68.9	59.9	52.4	40.1	75.2	71.0	2724.36	6578.11
	140	68.9	57.4	52.4	42.8	75.2	68.7	2724.36	10942.79
Mango Peach Sauce	40	38.7	39.7	13.6	11.2	93.3	86.7	0.08	0.08
	80	38.7	36.0	13.6	8.0	93.3	69.2	0.08	0.07
	100	38.7	29.2	13.6	8.8	93.3	22.5	0.08	0.05
	120	38.7	29.5	13.6	10.8	93.3	51.4	0.08	0.06
	140	38.7	24.6	13.6	10.3	93.3	24.2	0.08	0.05
Pork Sausage in Gravy	40	76.1	78.5	12.1	12.8	82.6	86.6	1.49	2.98
	80	76.1	78.2	12.1	12.6	82.6	84.1	1.49	2.83
	100	76.1	77.1	12.1	14.4	82.6	84.5	1.49	2.69
	120	76.1	77.0	12.1	14.7	82.6	84.2	1.49	1.54
	140	76.1	76.0	12.1	15.8	82.6	83.7	1.49	1.14
Nut Raisin Mix	40	58.3	49.3	20.7	14.1	66.4	50.2	0.30	0.12
	80	58.3	49.8	20.7	13.3	66.4	57.4	0.30	0.11
	100	58.3	52.0	20.7	14.8	66.4	51.8	0.30	0.23
	120	58.3	48.3	20.7	15.0	66.4	50.5	0.30	0.18
	140	58.3	45.7	20.7	22.7	66.4	58.7	0.30	0.19

[a]Final: 88 weeks at 40 or 80°F; 84 weeks at 100°F for Chipotle Snack Bread and Nut Raisin Mix and 88 weeks at 100°F for Ravioli in Meat Sauce, Chunky Peanut Butter, and Cheese Spread with Jalapenos; 20 weeks at 120°F; 10 weeks at 140°F.

Table 39. Initial and final chemical composition (after storage at 40, 80, 100, 120 and 140°F) of selected MRE items

FSR Item	Temperature (°F)	MC (%)		a_w		pH		Acidity (%)		SSC (%)		AA (mg/100g)		PV (meq/kg)	
		Initial	Final[a]	Initial	Final[a]	Initial	Final[a]	Initial	Final[a]	Initial	Final[a]	Initial	Final[a]	Initial	Final[a]
Beef Ravioli	40	71.84	73.50	0.99	0.99	6.43	5.17	0.010	0.030	1.27	0.70	*	*	8.72	2.64
	80	71.84	73.88	0.99	0.98	6.43	5.19	0.010	0.030	1.27	0.90	*	*	8.72	5.69
	100	71.84	73.65	0.99	0.99	6.43	5.07	0.010	0.030	1.27	0.37	*	*	8.72	11.09
	120	71.84	73.76	0.99	0.99	6.43	5.33	0.010	0.030	1.27	0.80	*	*	8.72	10.43
	140	71.84	74.05	0.99	0.98	6.43	5.85	0.010	0.030	1.27	0.80	*	*	8.72	6.63
Chipotle Snack Bread	40	20.56	17.67	0.80	0.78	6.65	5.59	0.011	0.025	2.53	1.00	7.49	0.92	12.89	9.35
	80	20.56	18.15	0.80	0.78	6.65	5.11	0.011	0.029	2.53	1.93	7.49	0.75	12.89	7.19
	100	20.56	18.86	0.80	0.79	6.65	4.98	0.011	0.037	2.53	2.13	7.49	0.42	12.89	9.03
	120	20.56	21.09	0.80	0.80	6.65	5.43	0.011	0.035	2.53	2.60	7.49	1.67	12.89	9.72
	140	20.56	21.94	0.80	0.79	6.65	5.42	0.011	0.042	2.53	2.50	7.49	1.33	12.89	6.21
Chunky Peanut Butter	40	1.06	0.80	0.40	0.40	7.07	6.17	0.010	0.020	1.80	1.57	146.86	74.85	15.37	1.70
	80	1.06	0.85	0.40	0.34	7.07	5.29	0.010	0.010	1.80	1.17	146.86	91.19	15.37	1.44
	100	1.06	0.72	0.40	0.38	7.07	5.05	0.010	0.020	1.80	1.10	146.86	78.83	15.37	4.96
	120	1.06	0.70	0.40	0.25	7.07	5.12	0.010	0.020	1.80	1.02	146.86	66.52	15.37	5.99
	140	1.06	1.01	0.40	0.31	7.07	6.87	0.010	0.010	1.80	1.43	146.86	37.89	15.37	3.47
Cheese Spread	40	40.54	38.32	0.94	0.93	6.65	5.62	0.030	0.080	2.30	1.80	*	*	13.71	5.09
	80	40.54	38.03	0.94	0.92	6.65	5.82	0.030	0.080	2.30	0.87	*	*	13.71	7.36
	100	40.54	39.70	0.94	0.94	6.65	5.90	0.030	0.080	2.30	0.73	*	*	13.71	10.13
	120	40.54	39.86	0.94	0.94	6.65	6.14	0.030	0.090	2.30	1.03	*	*	13.71	10.88
	140	40.54	39.90	0.94	0.94	6.65	6.24	0.030	0.090	2.30	1.03	*	*	13.71	16.59
Mango Peach Sauce	40	77.24	76.96	0.98	0.97	3.00	3.53	0.490	0.450	21.90	21.20	161.34	135.76	*	*
	80	77.24	76.67	0.98	0.97	3.00	3.51	0.490	0.480	21.90	21.17	161.34	128.15	*	*
	100	77.24	79.00	0.98	0.97	3.00	3.54	0.490	0.440	21.90	19.90	161.34	32.58	*	*
	120	77.24	78.68	0.98	0.97	3.00	3.57	0.490	0.420	21.90	22.20	161.34	13.00	*	*
	140	77.24	78.69	0.98	0.97	3.00	3.65	0.490	0.450	21.90	22.47	161.34	0.54	*	*
Pork Sausage in Gravy	40	77.28	77.60	0.99	0.98	6.59	5.86	0.006	0.014	0.60	0.97	*	*	6.00	5.73
	80	77.28	78.01	0.99	0.98	6.59	5.89	0.006	0.014	0.60	1.07	*	*	6.00	10.46
	100	77.28	76.94	0.99	0.98	6.59	5.70	0.006	0.015	0.60	1.33	*	*	6.00	6.21
	120	77.28	78.59	0.99	0.99	6.59	6.19	0.006	0.014	0.60	0.70	*	*	6.00	4.51
	140	77.28	78.20	0.99	0.99	6.59	6.45	0.006	0.014	0.60	0.60	*	*	6.00	4.00
Nut Raisin Mix	40	4.68	3.60	0.51	0.47	6.82	5.80	0.008	0.026	2.53	0.77	*	*	16.33	23.10
	80	4.68	4.07	0.51	0.44	6.82	5.50	0.008	0.028	2.53	0.93	*	*	16.33	27.17
	100	4.68	3.41	0.51	0.44	6.82	5.76	0.008	0.028	2.53	1.23	*	*	16.33	27.95
	120	4.68	3.96	0.51	0.47	6.82	6.18	0.008	0.027	2.53	1.40	*	*	16.33	26.04
	140	4.68	4.62	0.51	0.51	6.82	6.46	0.008	0.024	2.53	2.33	*	*	16.33	26.67

[a]Final: 88 weeks at 40 or 80°F; 84 weeks at 100°F for Chipotle Snack Bread and Nut Raisin Mix and 88 weeks at 100°F for Ravioli in Meat Sauce, Chunky Peanut Butter and Cheese Spread with Jalapenos; 20 weeks at 120°F; 10 weeks at 140°F.

MC = Moisture content; a = water activity; SSC = soluble solids content; AA = ascorbic acid (measurements were taken up to 48 weeks of storage); PV = peroxide value.

(*) Not measured.

(ND) Not detected.

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Table 40. Initial and final sugar and maltodextrin composition (after storage at 40, 80, 100, 120 and 140°F) of selected MRE items.

FSR Item	Temperature (°F)	Sucrose (g/100g)		Glucose (g/100g)		Fructose (g/100g)		Total sugars (g/100g)		Maltodextrine (g/100g)	
		Initial	Final[a]	Initial	Final[a]	Initial	Final[a]	Initial	Final[a]	Initial	Final[a]
Beef Ravioli	40	ND	ND	ND	ND	ND	ND	ND	ND	4.34	1.20
	80	ND	ND	ND	ND	ND	ND	ND	ND	4.34	1.21
	100	ND	ND	ND	ND	ND	ND	ND	ND	4.34	2.19
	120	ND	ND	ND	ND	ND	ND	ND	ND	4.34	2.23
	140	ND	ND	ND	ND	ND	ND	ND	ND	4.34	1.56
Chipotle Snack Bread	40	3.75	5.64	2.85	4.18	1.71	2.09	8.32	9.82	8.12	7.12
	80	3.75	5.82	2.85	4.28	1.71	2.43	8.32	12.52	8.12	7.69
	100	3.75	5.14	2.85	3.59	1.71	2.49	8.32	11.22	8.12	5.04
	120	3.75	3.66	2.85	2.53	1.71	3.21	8.32	9.40	8.12	5.09
	140	3.75	2.88	2.85	2.54	1.71	4.04	8.32	9.45	8.12	4.56
Chunky Peanut Butter	40	8.18	6.37	ND	ND	ND	ND	8.18	6.37	ND	ND
	80	8.18	6.17	ND	ND	ND	ND	8.18	6.17	ND	ND
	100	8.18	7.57	ND	ND	ND	ND	8.18	7.57	ND	ND
	120	8.18	7.17	ND	ND	ND	ND	8.18	7.17	ND	ND
	140	8.18	7.50	ND	ND	ND	ND	8.18	7.50	ND	ND
Cheese Spread	40	*	*	*	*	*	*	*	*	*	*
	80	*	*	*	*	*	*	*	*	*	*
	100	*	*	*	*	*	*	*	*	*	*
	120	*	*	*	*	*	*	*	*	*	*
	140	*	*	*	*	*	*	*	*	*	*
Mango Peach Sauce	40	7.07	4.66	4.92	4.48	7.14	7.89	19.13	17.03	ND	ND
	80	7.07	1.70	4.92	5.81	7.14	10.28	19.13	17.79	ND	ND
	100	7.07	ND	4.92	4.48	7.14	10.28	19.13	16.47	ND	ND
	120	7.07	ND	4.92	8.04	7.14	10.73	19.13	18.77	ND	ND
	140	7.07	ND	4.92	7.18	7.14	10.65	19.13	17.83	ND	ND
Pork Sausage in Gravy	40	*	*	*	*	*	*	*	*	*	*
	80	*	*	*	*	*	*	*	*	*	*
	100	*	*	*	*	*	*	*	*	*	*
	120	*	*	*	*	*	*	*	*	*	*
	140	*	*	*	*	*	*	*	*	*	*
Nut Raisin Mix	40	10.54	12.42	6.62	4.18	7.11	2.39	24.28	18.99	*	*
	80	10.54	14.9	6.62	4.69	7.11	3.83	24.28	23.41	*	*
	100	10.54	13.73	6.62	3.38	7.11	3.47	24.28	20.58	*	*
	120	10.54	12.56	6.62	4.28	7.11	2.86	24.28	19.7	*	*
	140	10.54	12.55	6.62	1.73	7.11	1.59	24.28	15.87	*	*

[a]Final: 48 weeks at 40, 80 and 100°F; 20 weeks at 120°F; 10 weeks at 140°F.

(*) Not measured.

(ND) Not detected.

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4.4 General Conclusions

Results obtain for the selected MRE food items (Beef Ravioli in Meat Sauce, Chipotle Snack Bread, Chunky Peanut Butter, Cheese Spread with Jalapenos, Mango Peach Applesauce, Pork Sausage in Cream Gravy and Nut Raisin Mix) were similar to those obtained for FSR food items (see Section 2) in terms of physical and chemical degradation during storage at refrigerated and non-refrigerated temperatures.

- In general, MRE food items developed a dark color when exposed to temperature above 80°F. Color changes in Chunky Peanut Butter and in Pork Sausage in Cream Gravy were, however, much subtler than those observed in the other items, even when exposed to high temperatures. The most striking changes in color were observed for Mango Peach Applesauce, which turned very dark at the end of the storage period, particularly samples stored at 120 and 140°F. The darker appearance was attributed to non-enzymatic browning reactions (Maillard reactions; amino acid + reducing sugar-glucose) that might have occurred during exposure to high temperatures.

- Changes in the texture were dependent on the temperature and on the MRE item. Beef Ravioli softened at high temperatures but became tougher when exposed to 40°F. Thus, in terms of texture, this item may not benefit from refrigerated storage. Chipotle Snack Bread hardened regardless of the temperature. Peanut Butter softened (became more spreadable), whereas Cheese Spread became less spreadable, particularly when exposed to high temperatures. Mango Peach Applesauce became more liquid as the temperature increased, but, under refrigeration conditions, there was practically no change in the consistency of the puree. Thus, this MRE food item may benefit from refrigerated conditions in terms of texture. Finally Nut Raisin Mix was chewier and less crunchy after storage.

- Changes in moisture content depended on the temperature and MRE item and may have contributed to the changes observed in the texture of the food. Thus, changes in texture were most likely related to the decrease (harder or less fluid) or increase (more fluid or softer) in moisture content observed throughout storage.

- Regarding changes in water activity of MRE samples, overall, water activity tended to decrease in MRE items stored below 100°F and to increase in samples stored at 120 and 140°F. Increases in water activity usually results in more free water available for chemical reactions to occur, such as a breakdown of some compounds, namely sugars and ascorbic acid.

- MRE samples, with the exception of Mango Peach Applesauce, tended to be more acid (lower pH/ higher acidity) as storage progressed. Overall, there was a decrease in the soluble solids content for all MRE items except in Mango Peach Applesauce, for which the soluble solids content increased. The soluble solids content of Chipotle Snack Bread

also increased in samples stored at high temperatures. The increase in soluble solids content may be due to the breakdown of more complex carbohydrates into simple sugars. The decrease in the soluble solids content may have resulted from the increase in moisture content observed in some food items or possibly from utilization of soluble compounds in chemical reactions that occurred within the complex food matrix.

- The total sugar content decreased in Mango Peach Applesauce and in Nut Raisin Mix samples stored at all temperatures, due to the decrease in sucrose, glucose and fructose. In Chipotle Snack Bread, sucrose, glucose and fructose tended to increase, most likely due to a decrease in maltodextrin. In Beef Ravioli, maltodextrin also tended to decrease (breaks down into glucose) during storage, regardless of the temperature.

- The ascorbic acid content was only measured in MRE items that had a significant content, and it decreased during storage regardless of the temperature. However, refrigerated temperatures helped reduce the degradation of ascorbic acid, particularly in Mango Peach Applesauce. In Chipotle Snack Bread and Chunky Peanut Butter, refrigeration seemed to have no advantage over storage at 80 or 100°F because the ascorbic acid content was higher at 80°F than at 40°F.

- The lipid oxidation values detected in most MRE items were quite low, considering the limits of acceptability (7-18 meq/kg), except in Nut Raisin Mix, for which peroxide values increased during storage to attain levels between 23 and 28 meq/kg. The low levels of peroxides in most of the MRE samples were possibly due to the low permeability of the packages to oxygen, which prevented the entrance of air and therefore the oxidation of fats, and, in the case of Peanut Butter, the high ascorbic acid levels measured in this product may have also helped to prevent fat oxidation. The high peroxide levels measured in Nut Raisin Mix suggests that this food may be prone to the development of rancid off-odors and off-taste, particularly when exposed to high temperatures.

5 Sensory Attributes Of FSR And MRE Items During Storage At Different Temperatures

5.1 Introduction

A major goal of this project was to develop a knowledge base for the changes in sensory food quality of selected shelf life limiting First Strike Rations (FSR) and Meal, Ready to Eat (MRE) menu items as a function of time and temperature in the DoD supply chain. In order to determine their shelf life, samples of FSR and MRE menu items were evaluated by a trained descriptive sensory panel. Sensory quality of ration components was determined for various storage intervals and temperature conditions in order to provide data for the development of computer shelf life models.

Samples of FSR and MRE menu items that had been stored at 80°F, 100°F, 120°F or 140°F were evaluated by a trained sensory panel to develop a knowledge base for the sensory changes in quality as a function of time and temperature in the DoD supply chain. Sensory quality data collected at various storage intervals and temperature conditions were provided to the project team developing the shelf life models.

5.2 Sensory Quality Of Selected FSR Items

5.2.1 Introduction

This part of the Phase II project was a continuation of storage research that was begun in Phase I for FSR menu items that had not reached the end of their shelf life by the end of Phase I.

The objectives in this part of the project were: 1) to study the effect of different storage temperatures: refrigerated (40°F), ambient (80°F) and extreme (100, 120 and 140°F) temperatures, which are temperatures within the range normally encountered in temperate and warm regions of the world (i.e., subtropical, tropical or arid areas), on the sensory quality of nine selected items from three FSR menus; and 2) to generate quantitative data to validate the sensory data used in the design of the shelf-life predicting model.

5.2.2 Materials And Methods

The same methods for sensory evaluation were used for work conducted under both Phase I and Phase II of the project

For the sensory evaluation of the selected FSR menu items, panelists were recruited based on their availability and ability to discriminate between stored and fresh processed foods. Sixteen panelists who qualified for participation were trained to become familiar with the FSR being studied as well as to determine the decline in their quality during storage. The training consisted of three sessions at which the panelists tasted 9 selected menu items that had been

stored under frozen or refrigerated conditions (control samples) or at 120°F for 2, 4, 5, 6, and 8 weeks. These samples were chosen to provide quality scores that encompassed the entire 1-9 scale used for this testing.

The samples were evaluated on a 1-9 scale based on how they compared to the controls stored under either frozen or refrigerated conditions. The choice of frozen vs. refrigerated temperature for control samples was based on communication with the researchers at NSRDEC. This scale was selected to closely follow the one being used at NSRDEC for similar purposes.

Figure 182 shows a segment of a typical ballot used during training. Paper ballots were preferred during training to encourage discussion and sharing of sensory experiences. Towards the end of the training phase, the panelists were allowed to work on and familiarize themselves with the computerized ballots (Figure 183).

TESTER: DATE:

PRODUCT: First Strike Rations

INSTRUCTIONS: Please indicate number for quality scores in the box and make comments in the remaining space.

REJECT			BORDERLINE		ACCEPT			
Extremely Poor	Very Poor	Poor	Below Fair / Above Poor	Fair	Below Good / Above Fair	Good	Very Good	Excellent
1	2	3	4	5	6	7	8	9

SAMPLE	APPEARANCE	ODOR	FLAVOR	TEXTURE	OVERALL QUALITY
Zapplesauce Reference					
Zapplesauce Sample					

Figure 182. Ballot used during training sessions.

Practice sessions followed in which three samples were presented for each product: (1) A control sample (stored under frozen or refrigerated conditions), (2) a sample that had clearly deteriorated to an unacceptable quality level, and (3) a sample in-between the “good” and the “bad” samples.

5.2.2.1 Reference Generation

In order to provide the panelists with examples of what constitutes an acceptable product and an unacceptable product throughout the course of the storage study, references were generated. Products were stored at 120°F for 10 weeks to make sure each of the menu items had deteriorated to a clearly unacceptable level of quality. Products were then moved to their control temperatures (frozen temperature or refrigerated). These references were the “bad references”. Products that were kept at their control temperatures were used as “good

references". The two references were provided to the panelists each time they evaluated a given product from the storage study.

5.2.2.2 Evaluation Of Stored Samples

During a sampling week, products were removed from high temperature storage and evaluated over the course of 3 days to minimize sensory fatigue. The panelists rated the quality of appearance, odor, flavor, texture and overall quality of three samples along with the good and bad references and as such tasted 9 products in total each day. The panelists were required to take a 3 minute break in between tasting each product category by use of a computerized ballot that would not advance to the next screen before the countdown finished. Water was provided to cleanse their palates. The panelists were only told the name of the products they were evaluating and had no knowledge of the storage temperature or the storage time being studied. Figure 183 is a view of the computerized ballot. This screen would be followed by another on which the panelist commented on the samples. Figure 184 shows one of the two groups of panelists evaluating the products.

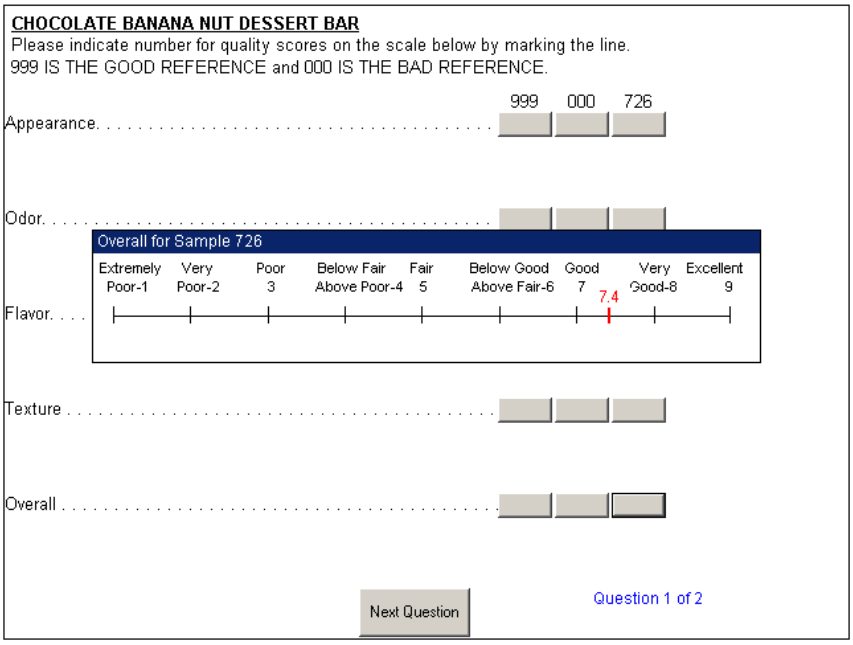


Figure 183. A screen shot of a typical ballot used for the evaluation of stored FSR

Sampling frequency at each temperature was determined based on estimates of total storage time making sure each product would be tested four or five times before deterioration. Point of deterioration was defined as the first point in time after which the mean overall (and any other attribute) quality score was below 4.0 twice in two consecutive sampling times. Although this quality rating for a failing product is lower than what is used at NSRDEC, the panelists were trained to have a uniform and consistent understanding of what constitutes a failing product.



Figure 184. A group of trained panelists evaluating First Strike Rations

5.2.3 Results

5.2.3.1 FSR Storage/Shelf Life Testing

Following up on the longest storage study of Phase I, FSR stored at 80°F were evaluated by the sensory panelists. Out of the 9 products tested, Beef Snack, BBQ was the first to be rejected after 96 weeks of storage (based on a cut-off rating score of 4 for overall quality). Only the five menu items (Zapplesauce, Filled French Toast, Bacon Cheddar Sandwich, Italian Style Sandwich and Honey BBQ sandwich) that were being used for the validation of the shelf life model were paneled once more, at 113 weeks. Honey BBQ Beef Sandwich and Zapplesauce were rejected at this time and Italian Style Sandwich was rated right at the cut-off (4.0). Table 41 summarizes the results of FSR long term storage at 80°F.

Table 41. Overall quality scores for FSR in the later stages of storage at 80°F

FSR Item	Last overall quality score recorded
Zapplesauce	3.9 (113 weeks)
Bacon Cheddar Sandwich	5.2 (113 weeks)
Italian Style Sandwich	4.0 (113 weeks)
Filled French Toast	5.1 (113 weeks)
Honey Barbecued Beef Sandwich	3.2 (113 weeks)
Beef Snack BBQ	3.7 (96 weeks)
Wheat Snack Bread	5.3 (96 weeks)
Tortilla	5.8 (96 weeks)

5.3 FSR Model Validation

The experiment for FSR model validation was conducted following the experimental setup shown in Figure 185. The sequence of the time temperature conditions were based on what might be considered as a common scenario for rations moving in the supply chain (see below). The sandwiches (Bacon Cheddar, Italian Style and Honey BBQ Beef) and applesauce (Zapplesauce) were chosen among the 9 FSR items for the validation study based on the following considerations:

a) Shorter shelf-life: Based on Table 18 in the Phase I Final Report (p.170), Zapplesauce, Bacon Cheddar Sandwich and Italian Style Sandwich expired after 30, 6 and 2 weeks of storage at 100°F, 120°F and 140°, respectively. Honey BBQ Beef Sandwich expired after 24, 6 and 3 weeks of storage at 100°F, 120°F and 140°F, respectively. The shortest durations to expiration for any of the 9 FSR items studied were 24 weeks at 100°F, 6 weeks at 120°F, and 2 weeks at 140°F. The 4 selected FSR items were those that expired the fastest at 2 of the 3 temperatures studied to completion (80°F storage was still underway and the results were not available for this consideration).

b) One primary item from each of the 3 FSR menus (Bacon Cheddar Sandwich-Menu 1, Italian Style Sandwich-Menu 2 and Honey BBQ Beef Sandwich-Menu3) and one secondary item common to all menus (Zapplesauce).

Selection of exposure times and temperatures for FSR model validation are described as follows:

For the FSR shelf life validation study, four discrete temperature points (85°F, 95°F, 130°F and 100°F) were selected for the FSR packages to be stored prior to periodic taste panels. Below you can find the explanations and reasoning behind choosing these temperatures for each step of the validation study. We had two goals to accomplish with the evaluation study: 1) thoroughly compare shelf life model accuracy with real taste panels to make sure the model is

precise in not only estimating the current quality of the product but also the remaining shelf life, and 2) be as realistic as possible in terms of the temperatures and shipping/storage durations encountered in real life distributions.

a) For the storage temperature we selected 85°F. This is a typical assumed value for a temperature controlled warehouse. Since one of our temperature points for the shelf life study is 80°F, we wanted to pick a different value to make sure the estimation algorithm works for any temperature point which can be encountered in a real life operation.

b) The duration for storage was 2 weeks since the FSRs are typically made-to-order so their storage time is limited compared to MREs and would be representative of the actual use case.

c) For shipping temperature, we selected 95°F based on a prior shipping daily temperature study performed by NSRDEC. In this study, the average shipping time was around 4 weeks and the mean of average daily minimum and maximum temperatures recorded in the data were close to 95°F.

d) For the storage at destination (imitating a warehouse in the desert for instance) we had two separate evaluation paths.

- For the first part of evaluation were stored the FSR at 130°F for 2 weeks followed by 3 weeks at the same temperature so that we would be able to observe a measurable and significant change in the quality of FSR items. We then compared the shelf life model output to the actual taste panel output to first see if the results were consistent. The reason for picking 130°F is that it is a relatively high temperature and was not one of the four temperature points we used for the original shelf life study. Hence, we could test if the model was accurate beyond just the original 80°F, 100°F, 120°F and 140°F experimental temperature points.

- The second part of this evaluation dealt with estimating the "remaining" shelf life. In order to accomplish this we kept the products at 100°F for an initial 15 weeks followed by an additional 15 weeks. The model predicted an estimated shelf life assuming that the average temperature of the product was going to be 100°F for the remainder of the storage. We then performed taste panels to see if the estimated shelf life coincided with the true shelf life of the product which has been defined by the overall quality of one of the items falling below 4.0 quality index value. Once again, the reason for choosing 100°F was to make sure the model is accurate at all temperature points that may be encountered in a real life operation.

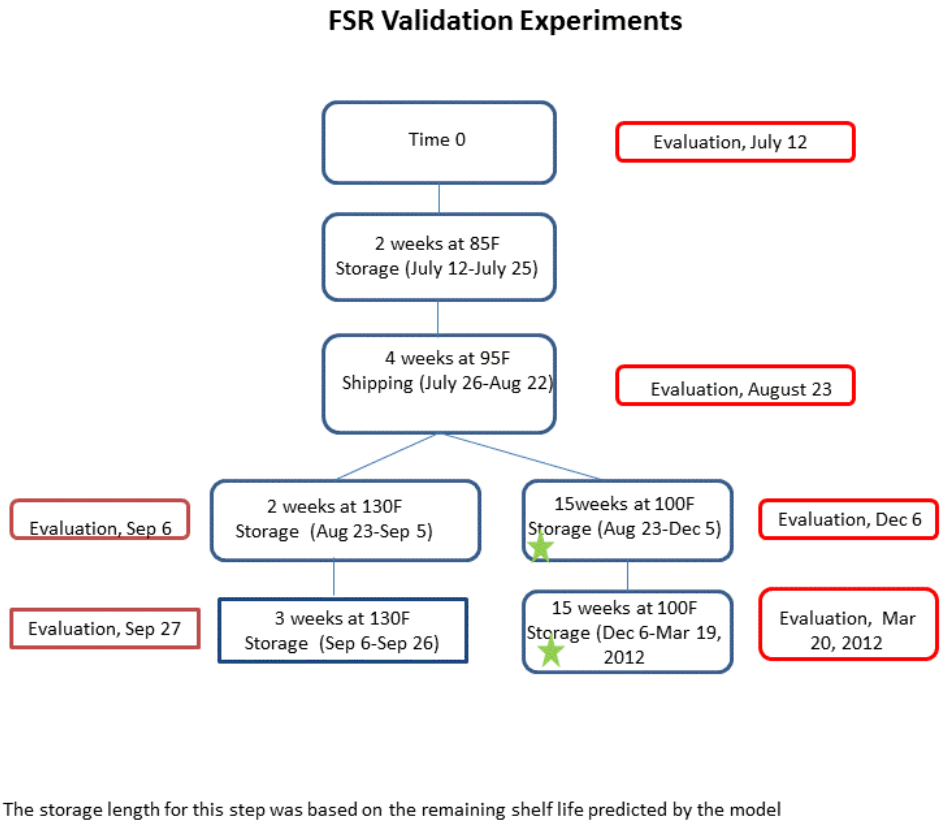
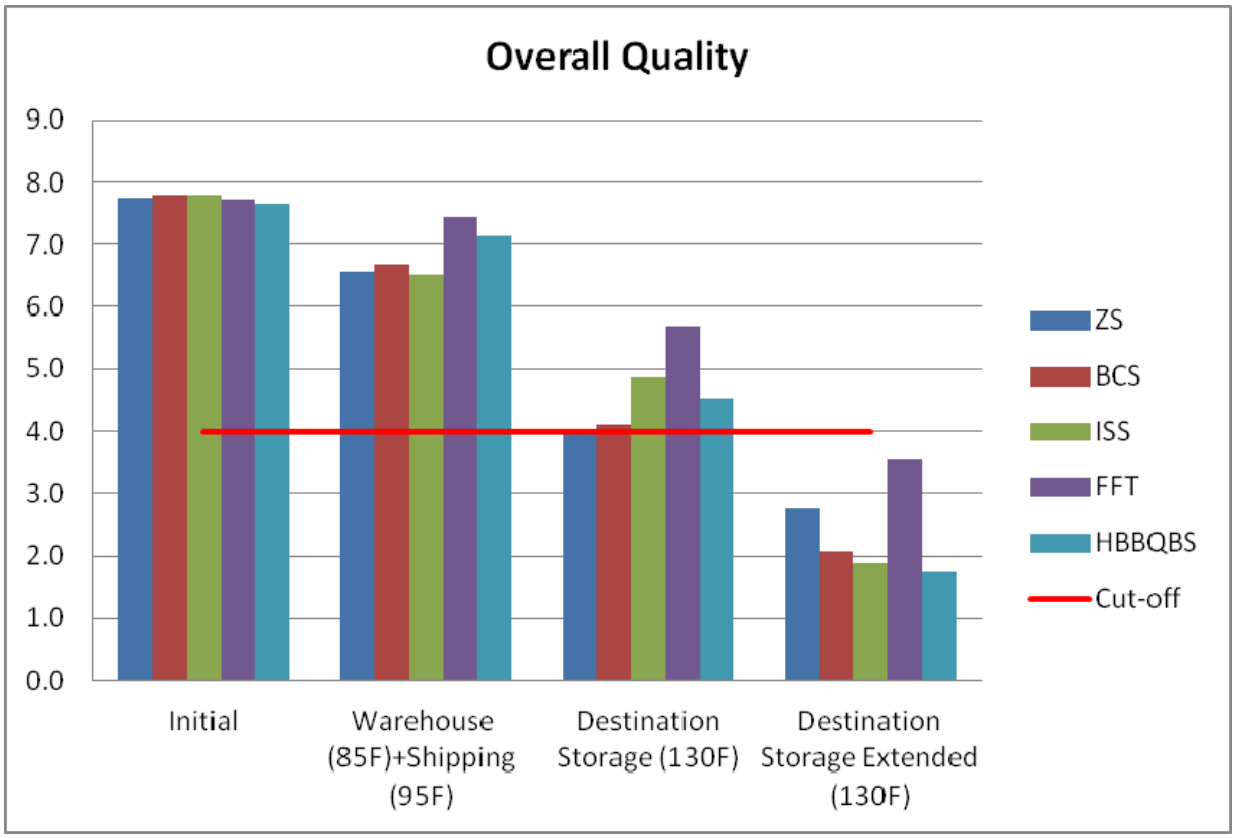


Figure 185. Design for the storage study of FSR samples (Zapplesauce, Bacon Cheddar Sandwich, Italian Style Sandwich, Filled French Toast, Honey Barbecued Beef Sandwich) for model validation

Panelists who have been familiar with the FSRs from the Phase I of this study evaluated the samples at intervals indicated in Figure 185. Their ratings for appearance, odor, flavor, texture, and overall quality were recorded. As in Phase I, a drop in the average rating for overall quality to below 4.0 indicated an unacceptable product. Accordingly, conditions simulating warehouse storage and overseas shipping of the products did not result in a loss of quality below acceptable levels for any of the five FSRs tested. After two weeks of storage at 130°F (simulating temperature at destination), the overall quality score for Zapplesauce and Bacon Cheddar Sandwich dropped to just above the rejection point (Figure 186). The other 3 rations (Italian Style Sandwich, Filled French Toast and Honey Barbecued Beef Sandwich) also showed a decline in their quality falling short of rejection. The scores assigned by the panel were well correlated with the shelf life algorithm output. Based on the remaining shelf life predicted by the algorithm, the storage at 130°F was extended by an additional 3 week period at the end of which all five of the stored products were rejected by the panelists.

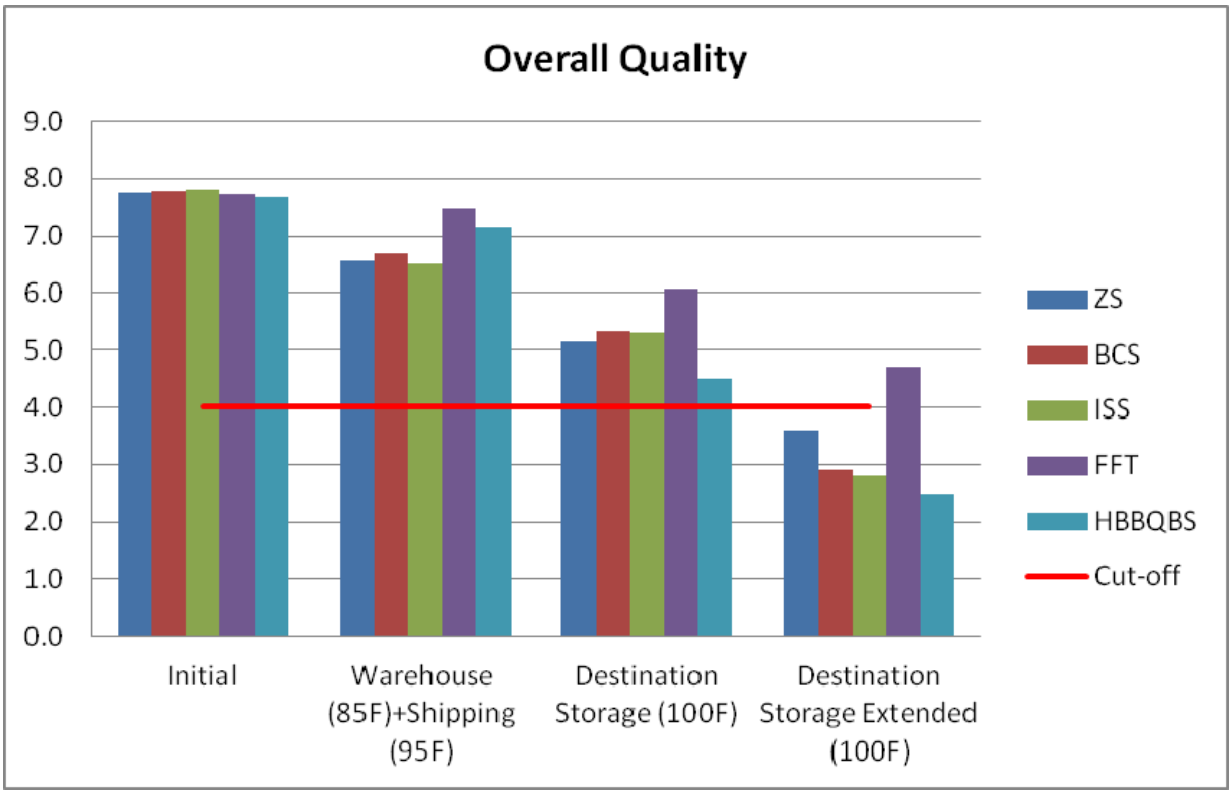
An alternative set of conditions were also used following the warehouse storage and shipping stages, as described earlier. Here, the storage temperature at the destination was set at 100°F with the main purpose of validating how well the model predicted the remaining shelf life. The

rations were evaluated by the panel at the end of 15 weeks. The number of days left before the end of shelf life was estimated by the algorithm for each of the five products. Based on the estimates, 100°F storage was extended for 15 additional weeks to see if all the products would expire like the model predicted. Four of the five expired by the end of this extension. Only Filled French Toast was rated above the 4.0 cut-off (Figure 187). Looking for possible reasons to explain this discrepancy, the packages of Filled French Toast used for Phase I and the validation experiments in Phase II were compared. Nutrition Facts table revealed that the product used for validation experiments had more than twice as much total fat. Both saturated fat and trans fat were also higher in the sample that lasted longer than predicted. Batch-to-batch variation may have contributed to this discrepancy between the panel and model quality scores.



Note: The scores are the averages obtained at the end of the segment indicated on the x-axis.

Figure 186. Change in the overall quality of FSR samples (Zapplesauce, Bacon Cheddar Sandwich, Italian Style Sandwich, Filled French Toast, Honey Barbecued Beef Sandwich) under conditions simulating products' transfer in the supply chain



Note: The scores are the averages obtained at the end of the segment indicated on the x-axis.

Figure 187. Change in the overall quality of FSR samples (Zapplesauce, Bacon Cheddar Sandwich, Italian Style Sandwich, Filled French Toast, Honey Barbecued Beef Sandwich) as rated by the panelists

5.4 Sensory Quality Of Selected MRE Items

5.4.1 Materials And Methods

The sensory team began the study with the generation of "bad references" for the future tests of storage stability of the seven selected MRE items (beef ravioli in meat sauce (BRM), pork sausage in cream gravy (PSG), jalapeno cheese spread (CS3), wheat chipotle snack bread (SBF), applesauce with mango and peach puree (AMP), chunky peanut butter (PBC), and nut raisin mix with M&Ms (NMM)). For this purpose, MRE items stored at 120°F were evaluated by the panelists every 2 weeks. A total of 16 panelists were trained to detect a range of possible deteriorative changes in MRE items at various levels of quality. A control sample (named the "good reference") was also presented to the panelists each time they evaluated the sensory quality of an abused sample.

Each training session consisted of individual product evaluation followed by group discussion for each product. Monographs (M2B, M2S1, M4Y1, M5M, M6J, M6L, M8K) describing item characteristics and possible deteriorative changes in the MRE were used to guide the panelists. The storage temperature used to accelerate the degradation of the MRE samples was raised to 140°F 9 weeks into the bad reference generation stage. Samples rejected by the panelists based

on a cut-off rating score of 4 for overall quality were named “bad references” and were placed at 40°F where the good references were also being kept. Although the quality rating for a failing product is lower than what is used at NSRDEC, the panelists were trained to have a uniform and consistent understanding of what constitutes a failing product. They also have had experience using the scale with a cut-off of 4.0 in Phase I.

Once the generation of bad references was completed, storage at the experimental temperatures of 80, 100, 120 and 140°F started. The frequency of sampling for each of these experiments is shown in Table 42. On each day of testing, the panelists received the sample and the two references (good and bad) and evaluated the quality attributes (appearance, odor, flavor, texture and overall quality) of the stored sample. Computer generated ballots using sensory software (Compusense) were used to collect the data throughout the testing phase (Figure 188). The number of MRE items served on a day was no more than 3 to prevent sensory fatigue. The computerized ballot required the panelists take a 3-minute-break in between MRE items.

Table 42. Sampling frequency at experimental temperatures

Storage Temperature (°F)	Sampling Frequency
80	Every 8 weeks
100	Every 6 weeks
120	Every 2 weeks
140	Every week

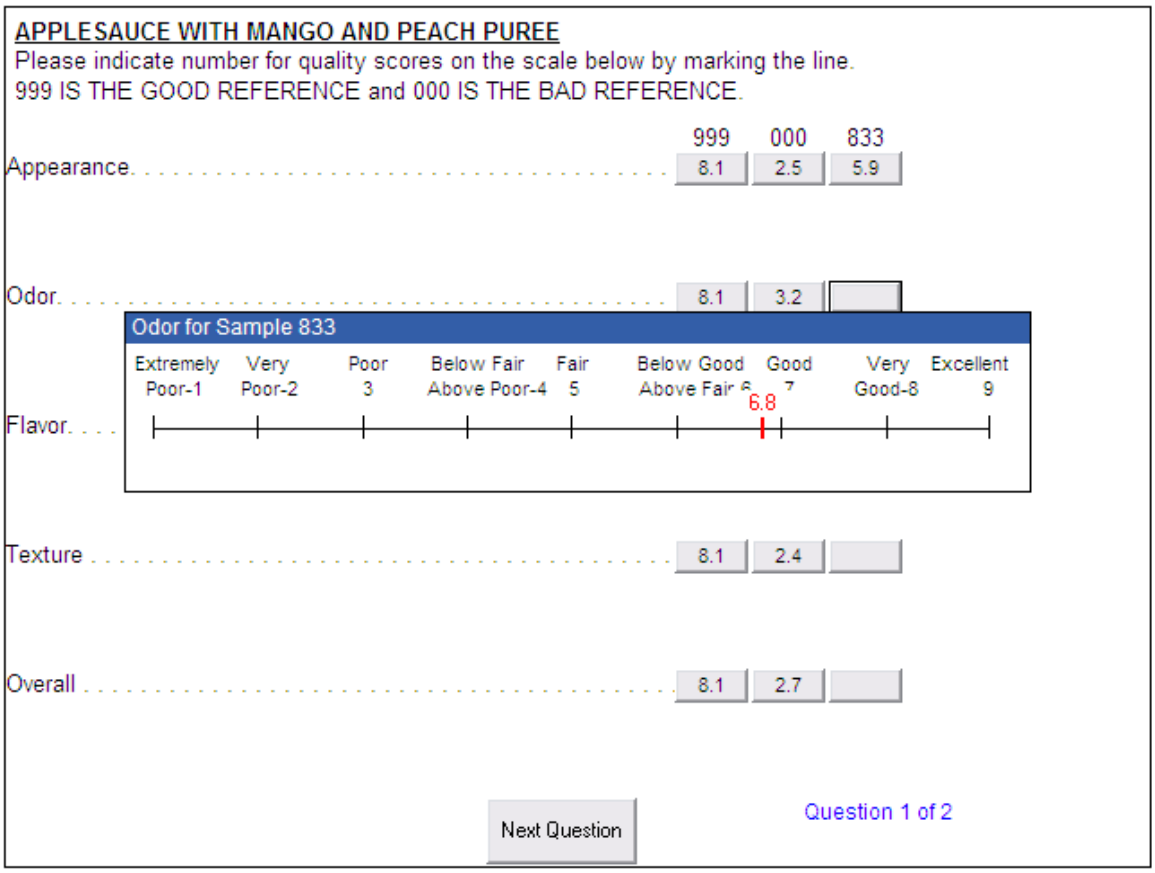


Figure 188. Computerized ballot used for evaluation of MRE throughout the testing phase

5.4.2 Results

5.4.2.1 140°F Storage

Seven MRE products (Applesauce with Mango and Peach Puree, Beef Ravioli in Meat Sauce, Wheat Chipotle Snack Bread, Nut Raisin Mix with M&Ms, Jalapeno Cheese Spread, Chunky Peanut Butter, Pork Sausage in Gravy) were sampled from the 140°F storage temperature every week. The mean quality scores were calculated and are summarized in Figures 189 to 195.

Jalapeno Cheese Spread was the first MRE item to drop below the cut-off of 4.0 (3 weeks). Applesauce with Mango and Peach Puree, Nut Raisin Mix with Pan Coated Disks, Chipotle Wheat Snack Bread, Beef Ravioli in Meat Sauce and Pork Sausage in Gravy followed, each one a week after another. Chunky Peanut Butter, however took 19 weeks at 140°F to drop below the rejection cut-off.

The cheese spread was reported to have a darkened color, less jalapeno odor, old cheese flavor and rubbery texture at 3 weeks. The applesauce was rejected with dark color, musty smell, sour and caramelized taste and runny consistency. Nut raisin mix had darkened nuts and dry raisins, with pan coated disks that would easily break under light finger pressure. When the panelists

rejected the Chipotle Wheat Snack Bread, they referred to its darkened appearance, very dry, crumbly texture, burnt smell and perfumy flavor. The changes detrimental to the quality of beef ravioli were listed as darkened sauce with oiling off, rancid meat flavor, and grassy tomato flavor. Pork Sausage in Gravy was rejected at 8 weeks because of the darkened, sour and metallic tasting gravy and dried pork. Peanut butter lasted 19 weeks at 140°F until it had oiling-off and the peanut particles were no longer crunchy.

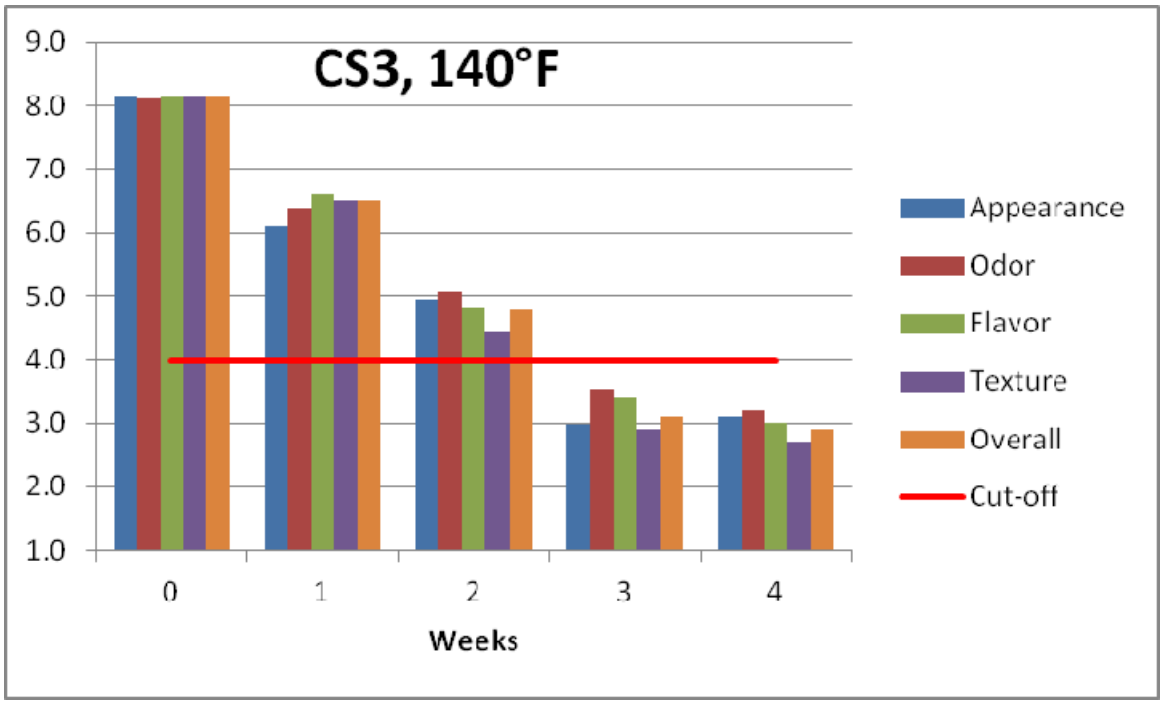


Figure 189. Changes in the quality attributes of Jalapeno Cheese Spread stored at 140°F

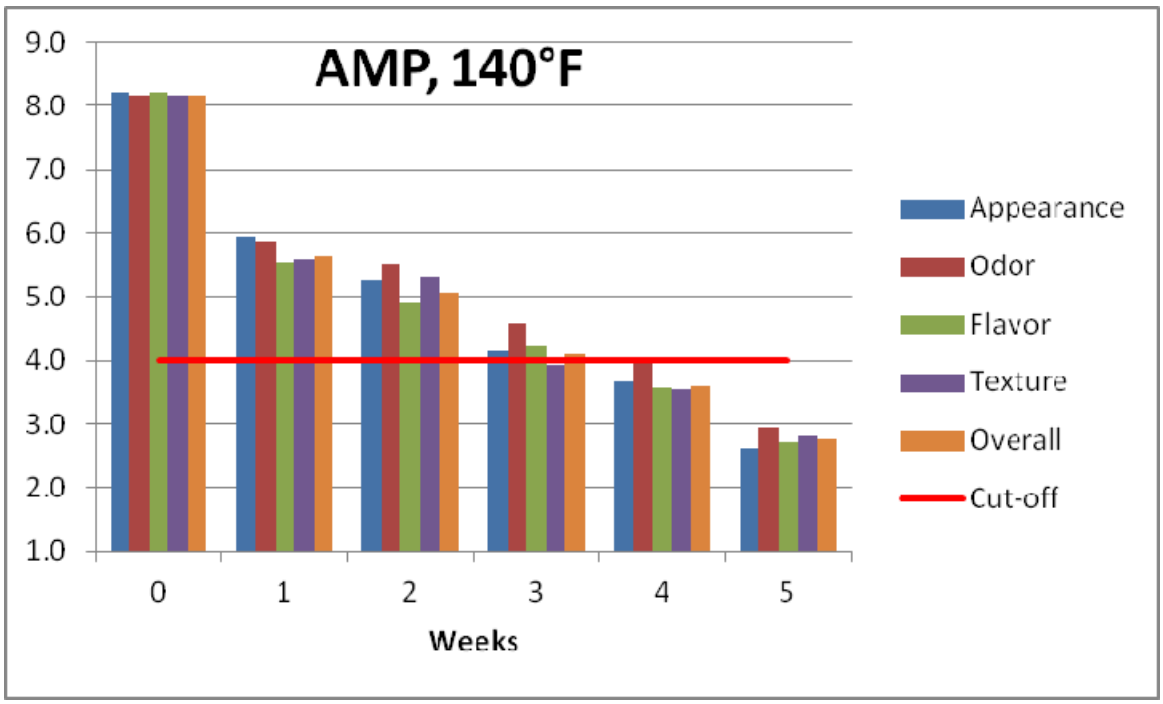


Figure 190. Changes in the quality attributes of Applesauce with Mango and Peach Puree stored at 140°F

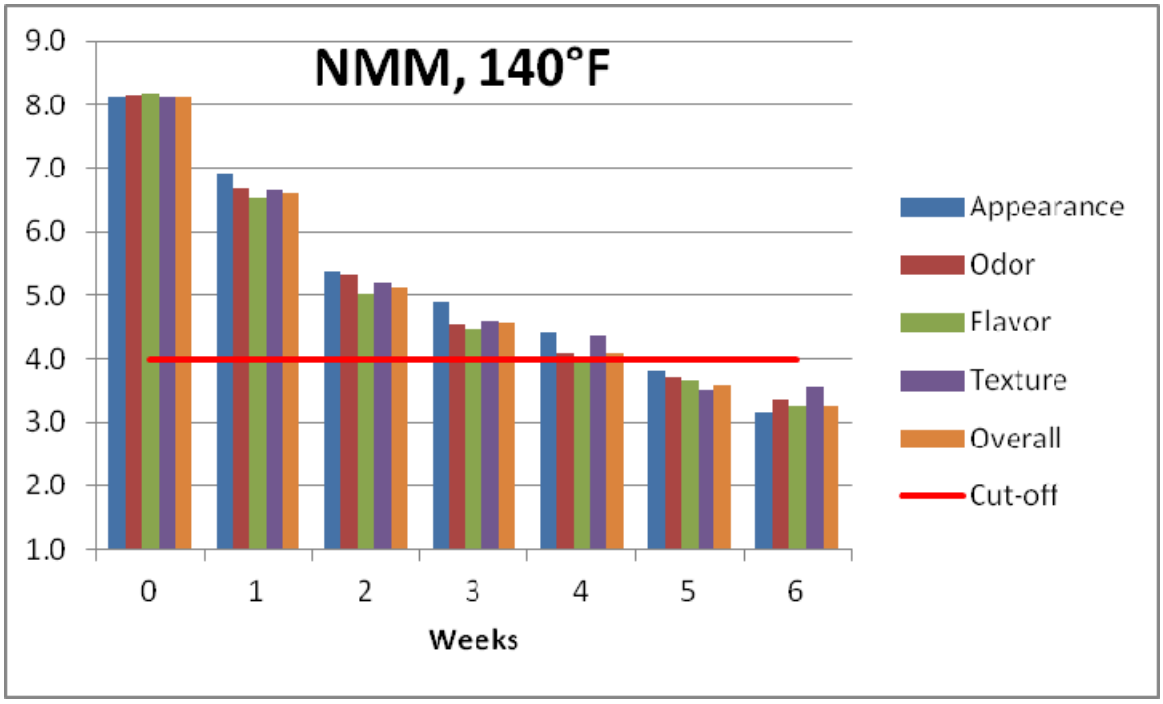


Figure 191. Changes in the quality attributes of Nut Raisin Mix with Pan Coated Disks (M&M) stored at 140°F

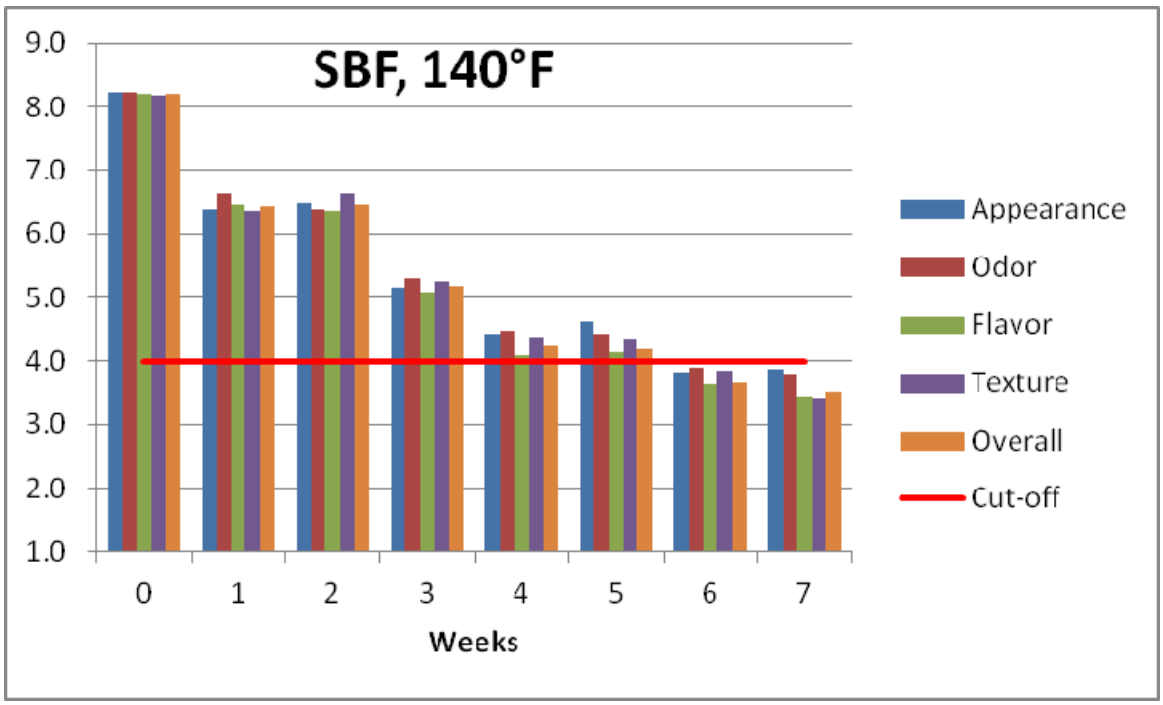


Figure 192. Changes in the quality attributes of Chipotle Wheat Snack Bread stored at 140°F.

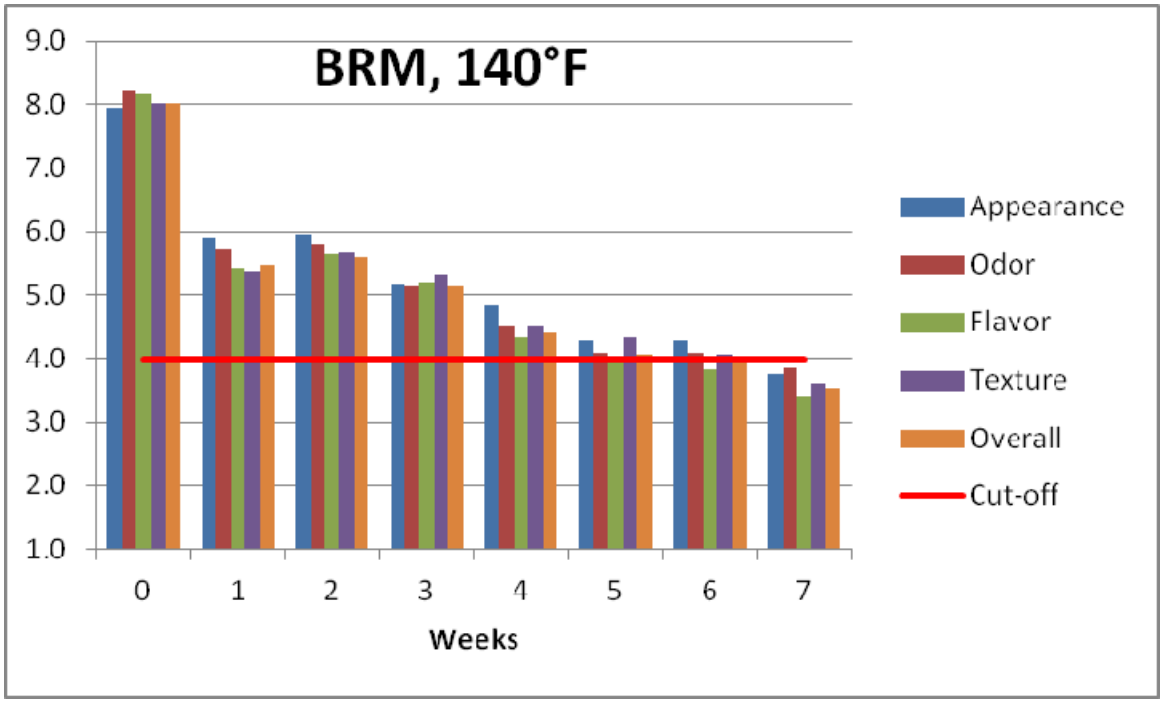


Figure 193. Changes in the quality attributes of Beef Ravioli in Meat Sauce stored at 140°F

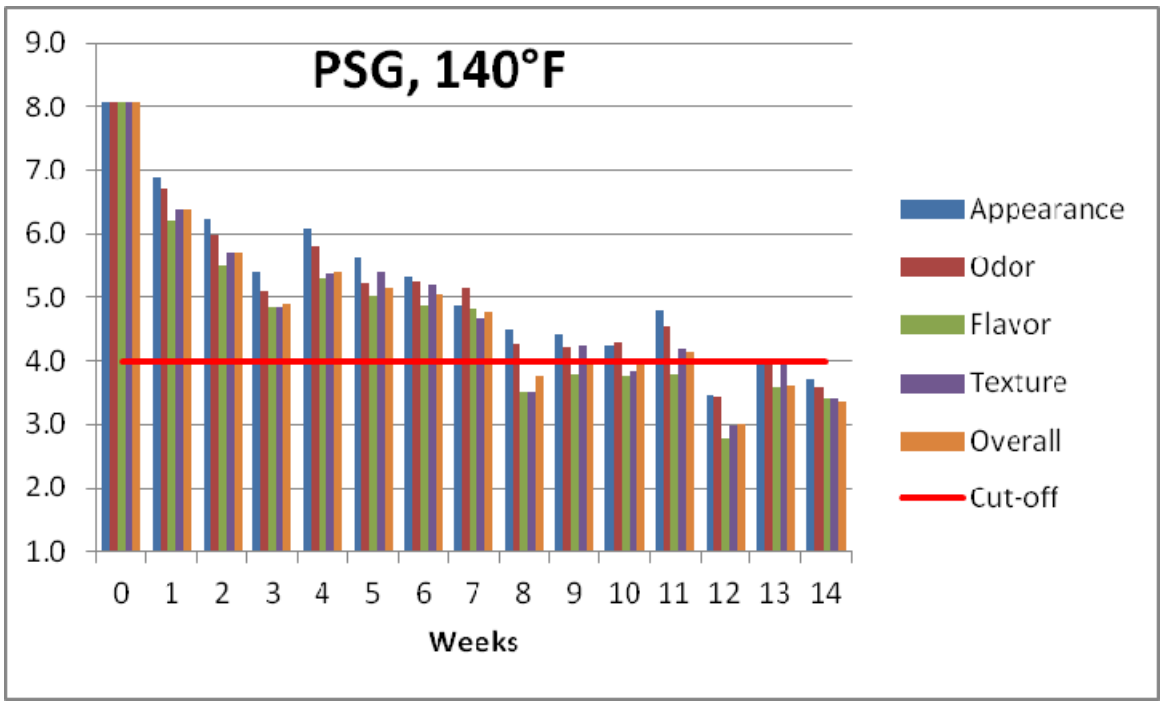


Figure 194. Changes in the quality attributes of Pork Sausage in Gravy stored at 140°F

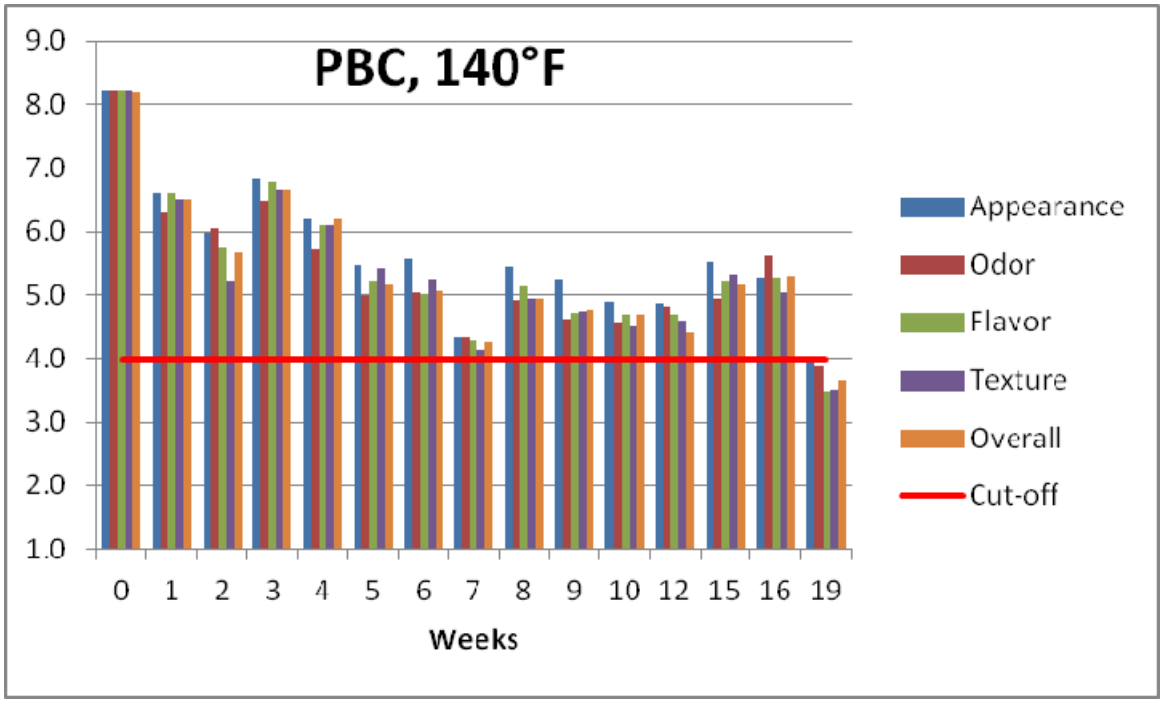


Figure 195. Changes in the quality attributes of Chunky Peanut Butter stored at 140°F

5.4.2.2 120°F Storage

MRE items were sampled from the 120°F storage temperature every 2 weeks. The mean quality scores were calculated and are summarized in Figures 196 to 202. All items expired in the same order as for the 140°F storage: Cheese spread at 8 weeks followed by applesauce at 12 weeks, nut raisin mix, chipotle wheat bread and beef ravioli in the middle (at 18, 20 and 20 weeks) and pork sausage significantly later at 32 weeks. Peanut butter was kept at 120°F for much longer and sampled periodically until samples ran out at 45 weeks. The mean overall quality was recorded at 4.9 at this time (not rejected).

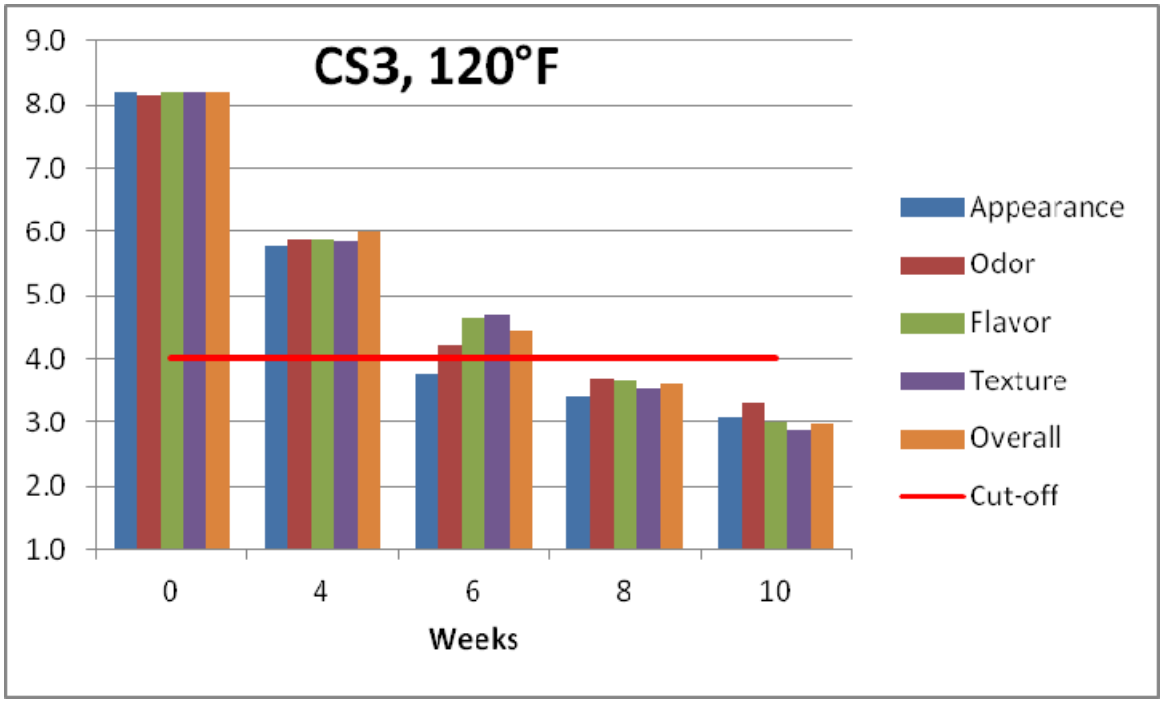


Figure 196. Changes in the quality attributes of Jalapeno Cheese Spread stored at 120°F

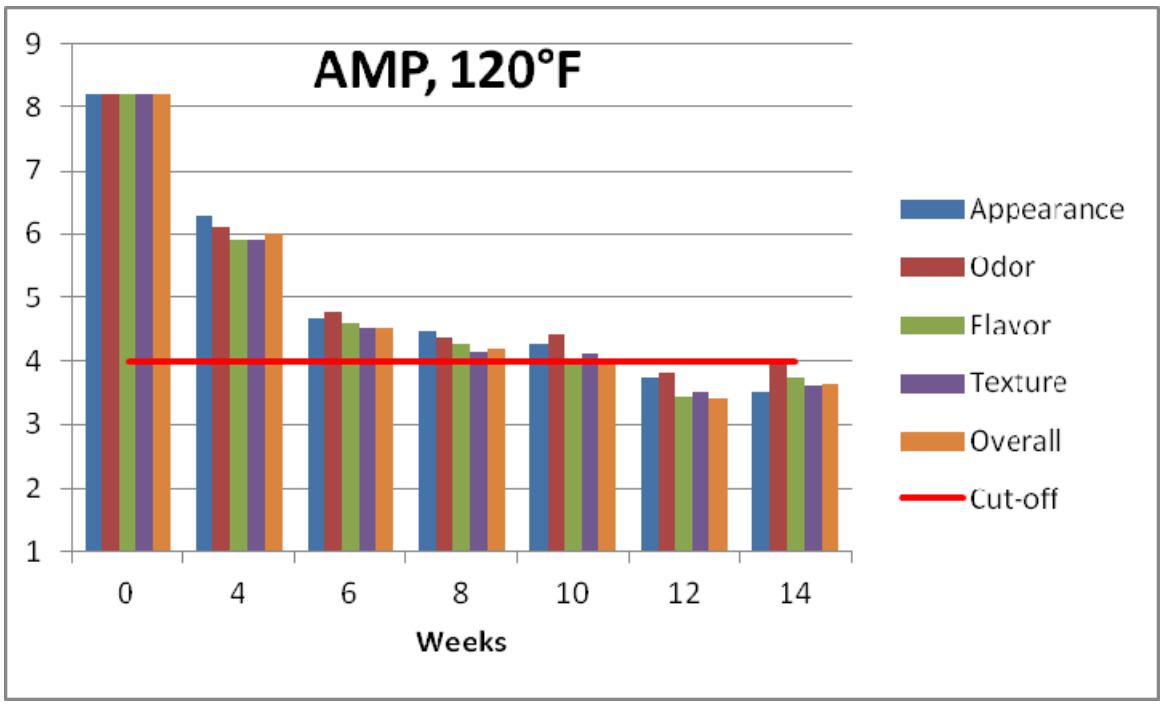


Figure 197. Changes in the quality attributes of Applesauce with Mango and Peach Puree stored at 120°F

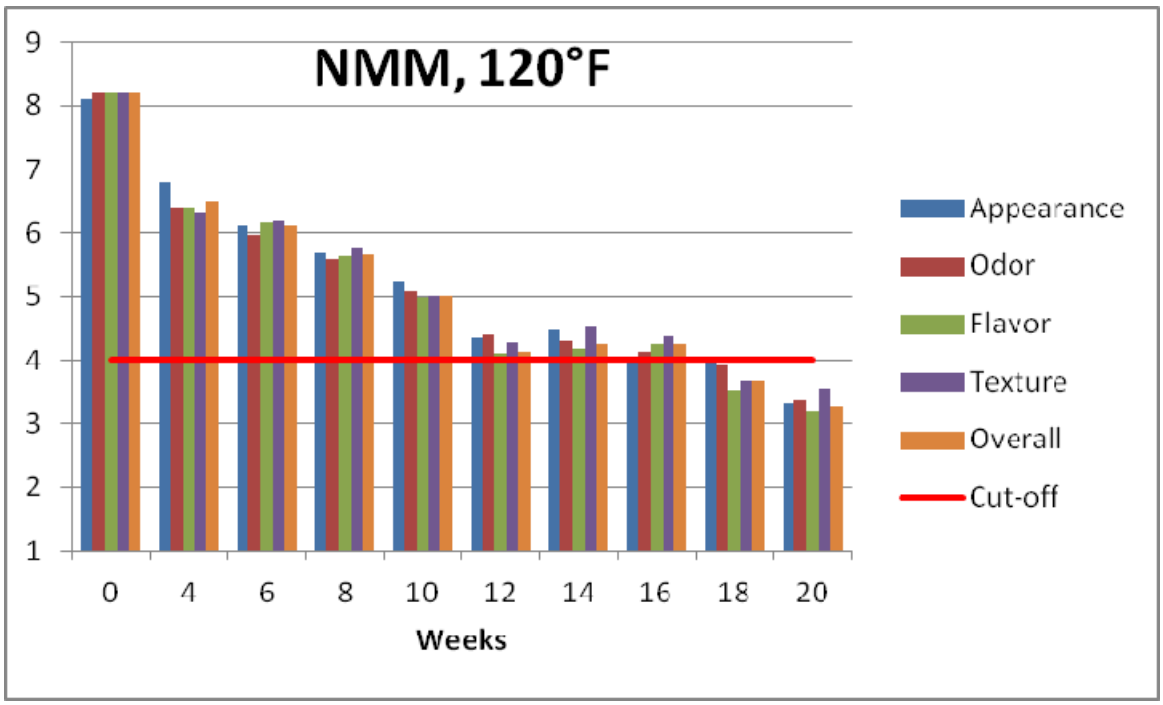


Figure 198. Changes in the quality attributes of Nut Raisin Mix with Pan Coated Disks (M&M) stored at 120°F

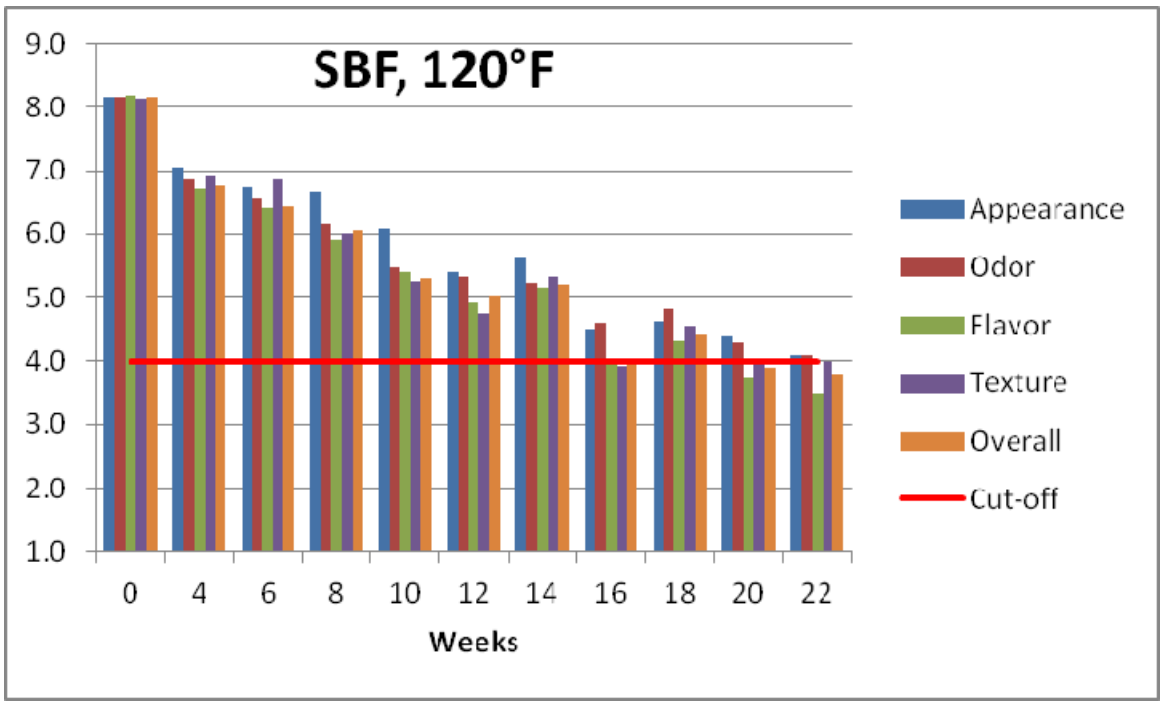


Figure 199. Changes in the quality attributes of Chipotle Wheat Snack Bread stored at 120°F

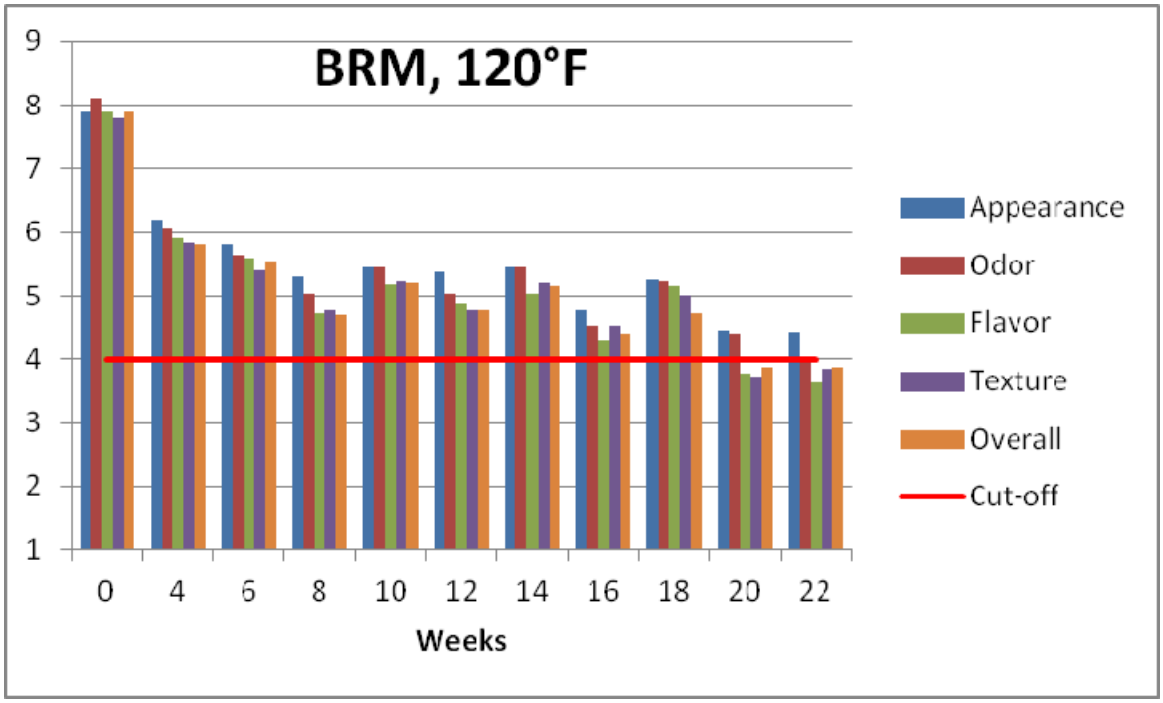


Figure 200. Changes in the quality attributes of Beef Ravioli in Meat Sauce stored at 120°F

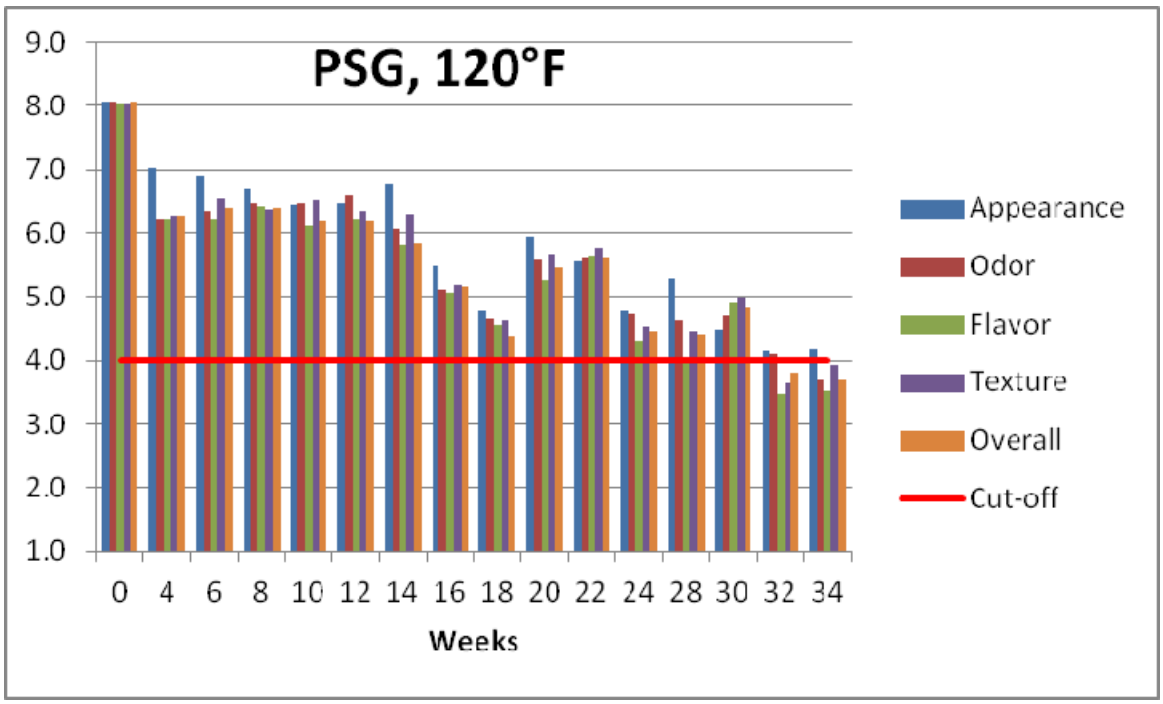


Figure 201. Changes in the quality attributes of Pork Sausage in Gravy stored at 120°F

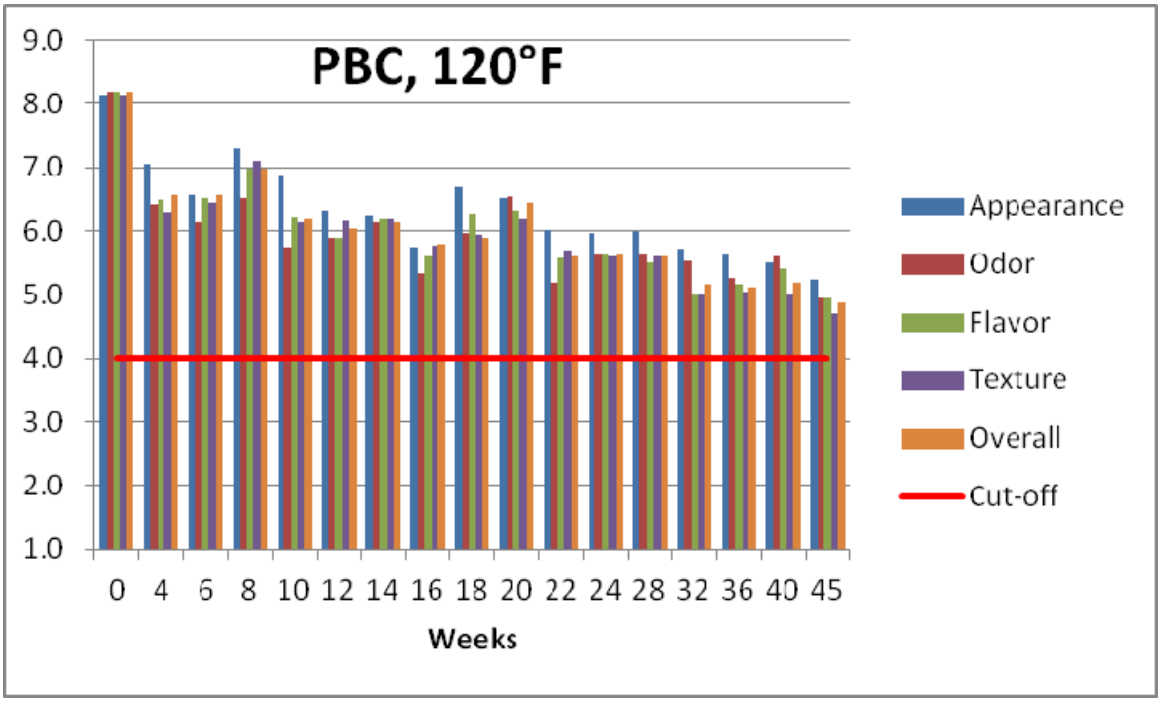


Figure 202. Changes in the quality attributes of Chunky Peanut Butter stored at 120°F

5.4.2.3 100°F Storage

The changes to the sensory properties of the MRE were much slower at this temperature. Cheese spread, which expired after 3 weeks of storage at 140°F and 8 weeks at 120°F, lasted 36 weeks at 100°F. Applesauce lasted 42 weeks at 100°F, compared to 4 weeks at 140°F and 12 weeks at 120°F. Nut raisin mix could not be evaluated past 76 weeks when its overall quality was rated at 4.2 (samples ran out beyond 12 sampling points). Chipotle wheat snack bread expired at 82 weeks, at which time the panel was dismissed (no more funds available). The mean quality scores were plotted for all sampling points before this point in time (Figures 203 to 209). Beef ravioli, pork sausage and peanut butter were kept at the storage chamber longer and were evaluated once more by two laboratory members who had been involved with the sensory evaluation of MRE since the beginning of this study. The sensory quality scores thus obtained were shared with the Objective 1 team in case they provided further insight into the data set collected from the panel. Based on the latter observations, beef ravioli and pork sausage were beyond the rejection cut-off of 4.0. Peanut butter, on the hand was still acceptable after 94 weeks at 100°F. Although on a much spread-out schedule, the 7 MRE menu items were observed to expire in the same order as they did at the higher temperatures (120 and 140°F).

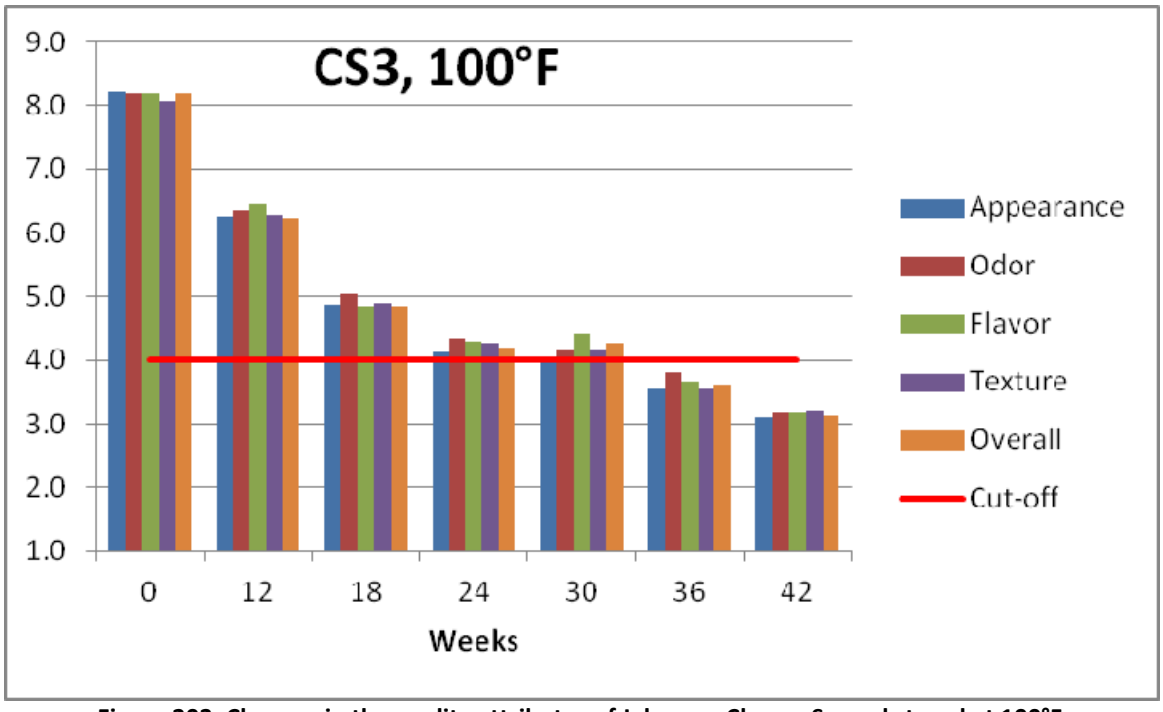


Figure 203. Changes in the quality attributes of Jalapeno Cheese Spread stored at 100°F

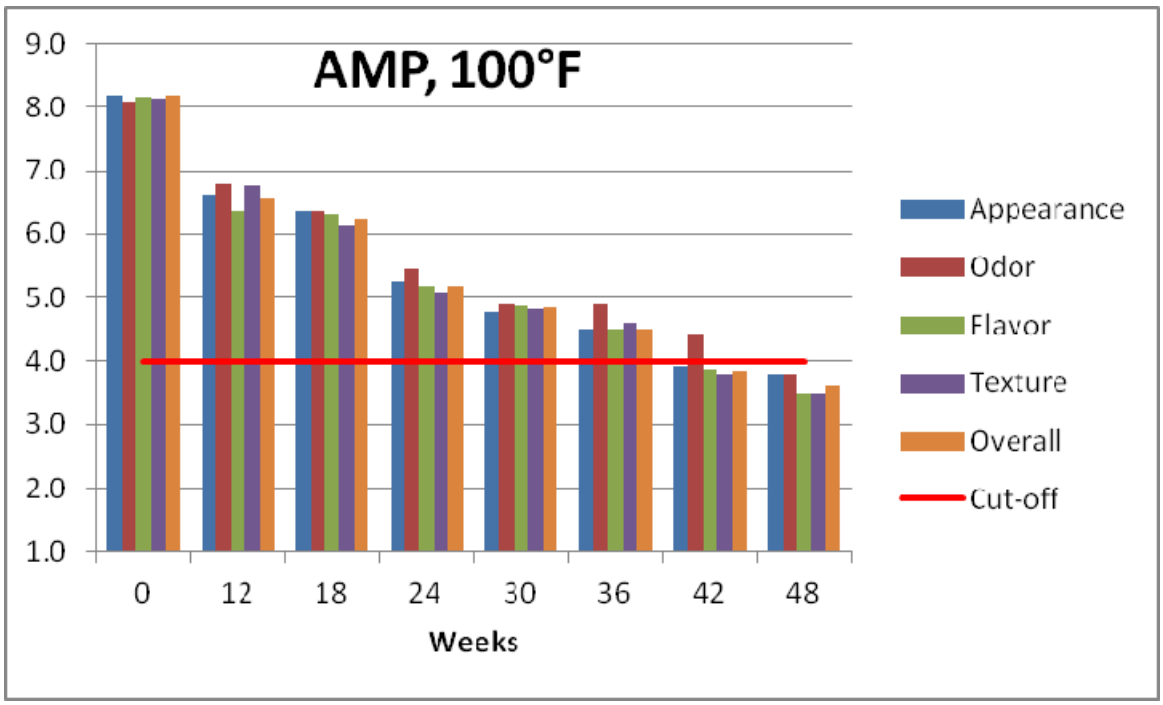


Figure 204. Changes in the quality attributes of Applesauce with Mango and Peach Puree stored at 100°F

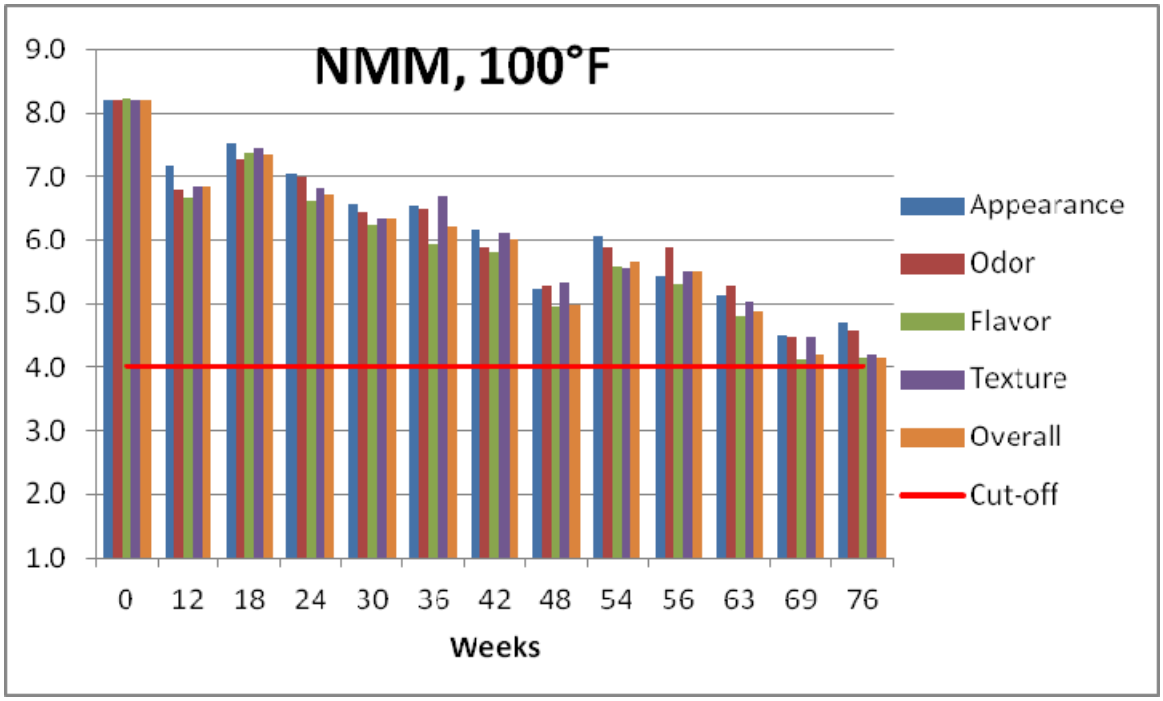


Figure 205. Changes in the quality attributes of Nut Raisin Mix with Pan Coated Disks (M&M) stored at 100°F

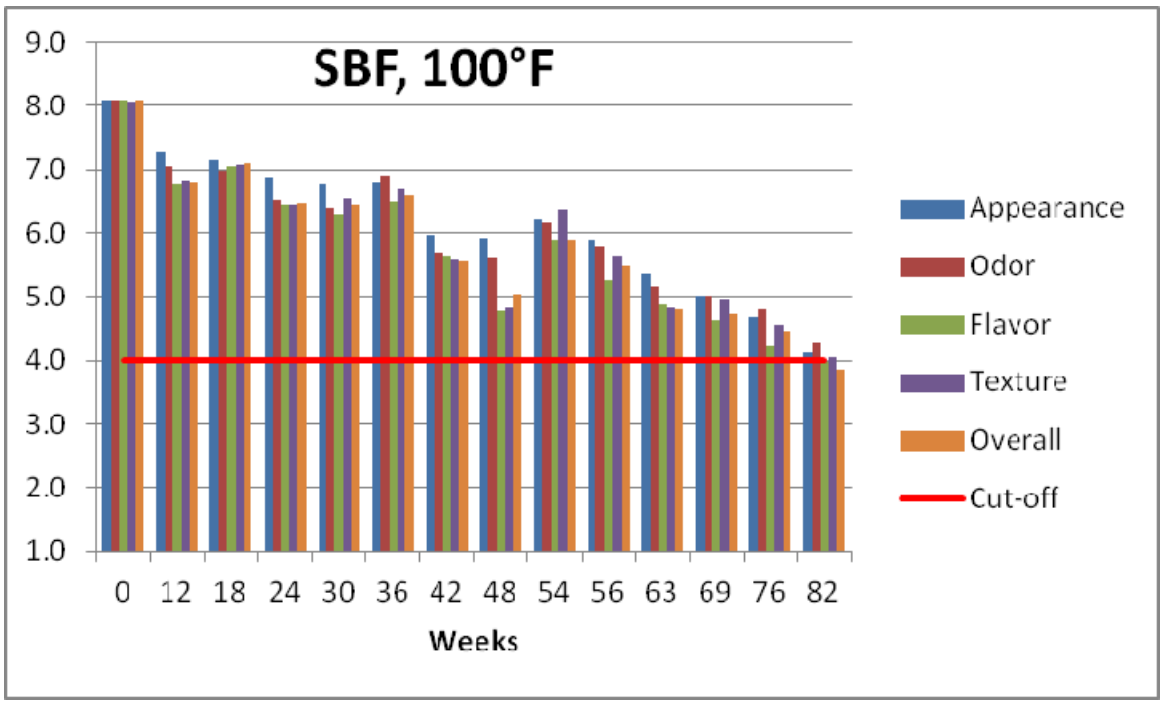


Figure 206. Changes in the quality attributes of Chipotle Wheat Snack Bread stored at 100°F

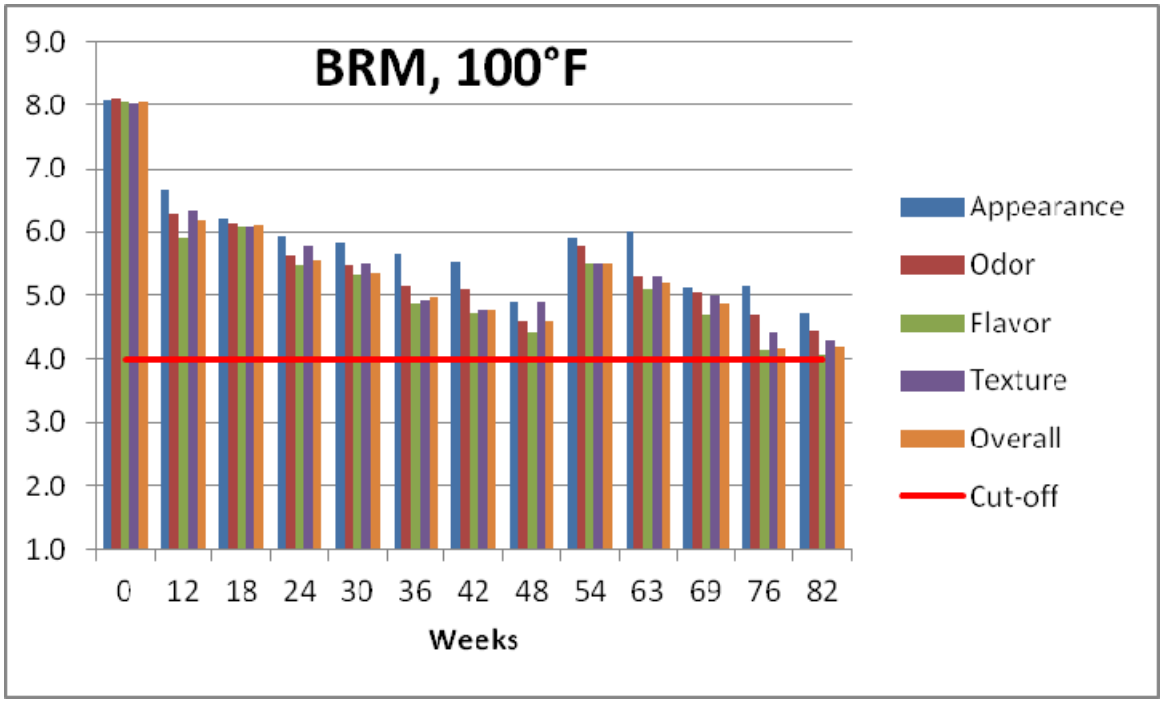


Figure 207. Changes in the quality attributes of Beef Ravioli in Meat Sauce stored at 100°F

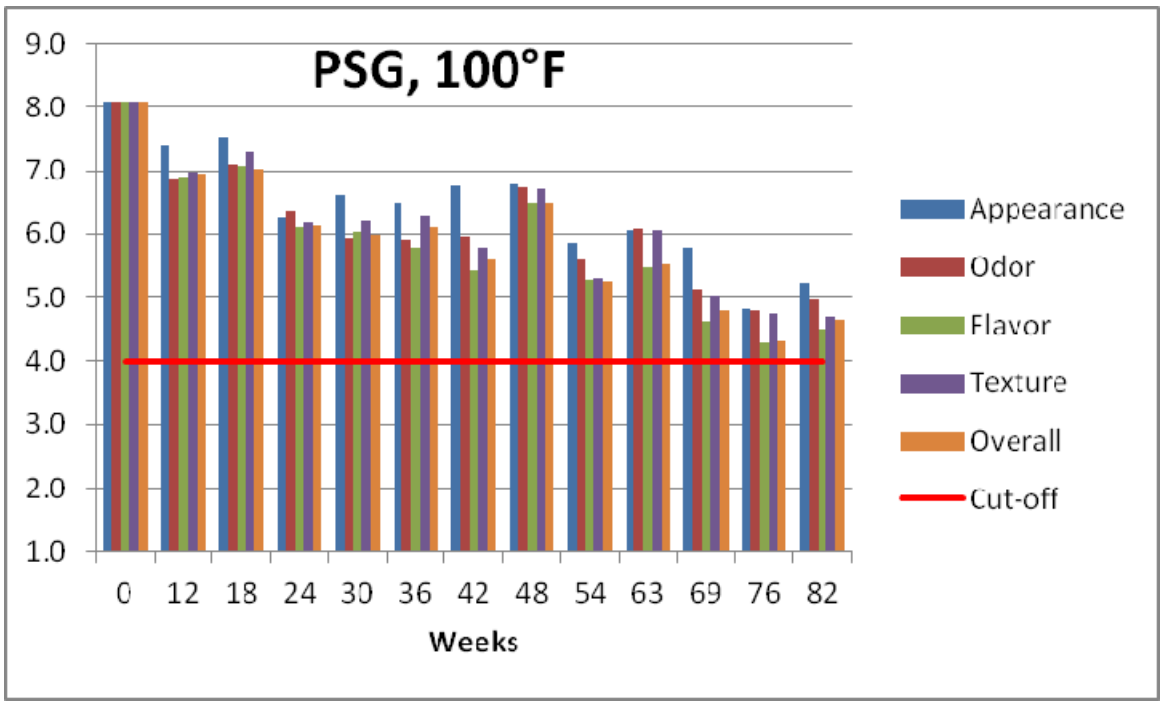


Figure 208. Changes in the quality attributes of Pork Sausage in Gravy stored at 100°F

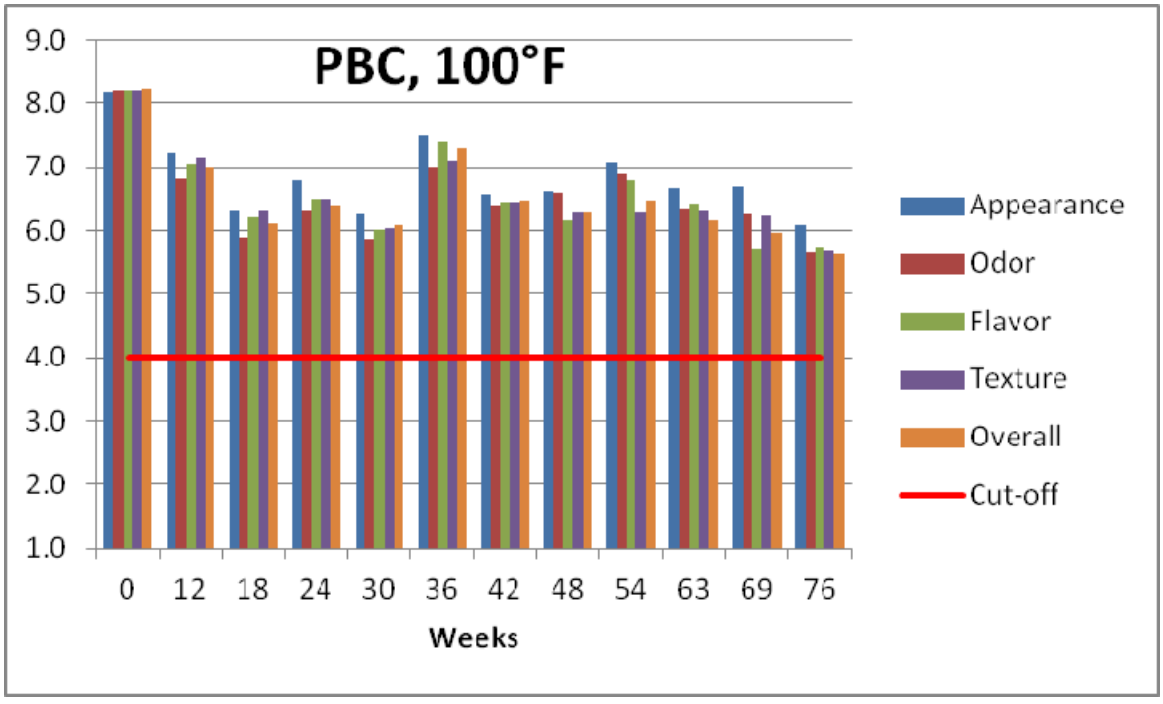


Figure 209. Changes in the quality attributes of Chunky Peanut Butter stored at 100°F

5.4.2.4 80°F Storage

The MRE were developed with a 3-year shelf life requirement at 80°F. Seven MRE items kept at this temperature were evaluated periodically by the sensory panel until 67 weeks. The mean overall quality scores recorded at 67 weeks are shown in the 80°F column of Table 43. The weeks to rejection at this temperature are not reported because none of the MREs was rejected the last time they were evaluated by the panel. All scores were in the acceptable range, as expected. MRE stored at this temperature were evaluated once more after the panel was dismissed, at 88 weeks of storage. Based on the evaluation by the same two judges (lab members) mentioned earlier in the 100°F results section above, cheese spread and applesauce were just above the rejection cut-off and the others were all well above this quality level.

Table 43. Number of weeks to rejection or last quality score recorded and number of weeks of storage for MRE samples

Products	140°F	120°F	100°F	80°F[1]
Jalapeno Cheese Spread	3	8	36	6.3
Applesauce with Mango and Peach Puree	4	12	42	5.7
Nut Raisin Mix with Pan Coated Disks	5	18	4.2 (76 weeks)	6.9
Chipotle Wheat Snack Bread	6	20	82	6.6
Beef Ravioli in Meat Sauce	7	20	94	6.2
Pork Sausage in Gravy	8	32	94	6.0
Chunky Peanut Butter	19	4.9 (45 weeks)	5.0 (94 weeks)	6.8

[1] Listed are the mean overall quality scores at 67 weeks of storage at 80°F.

5.4.3 Summary

The results of the sensory quality evaluations are summarized in terms of number of weeks to product deterioration at each storage temperature (Table 43). Product deterioration was defined as a mean overall quality score below 4.0. Although appearance, odor, flavor and texture attributes were rated in addition to the overall quality rating, the latter scores adequately described deterioration as was the case in Phase I of this study. This was mainly because the panelists would reflect any unacceptable attribute rating into the overall quality score.

6 Strategies To Better Maintain FFV Quality And Reduce Losses During Transportation In Mixed Loads Overseas

6.1 Introduction

Broccoli, Romaine lettuce and vine ripe tomatoes were identified as fresh fruits and vegetables (FFV) product that experience higher than average outturn problems in mixed load marine container shipments from the U.S. west coast to U.S. military bases in various Pacific locations such as Japan, South Korea, Taiwan and Guam. The transit times for these shipments varies from 10 to 16 days on the water; adding 2 or 3 days in port at departure and destination means that these products are in the mixed load containers from about 15 to 21 days. Examination of Shipping Instructions provided by our NSRDEC point of contact indicated that the broccoli and Romaine lettuce are carried at a proper set point temperature of 33°F. However, vine ripe tomatoes are carried at 45°F, which we know from research in our laboratory and others (Bai et al., 2011; Maul et al., 2000) is too low for development of good flavor and aroma. Furthermore, we determined that broccoli and Romaine lettuce are sometimes shipped in containers with ethylene-producing products (plums and kiwifruit), which could lead to accelerated senescence and deterioration.

The selected FFV products were stored in controlled environment chambers with conditions simulating existing DoD shipping conditions (time, temperature, ethylene exposure) for existing supply chains *versus* controlled atmospheres (CA) and/or modified atmosphere packaging (MAP) with and without ethylene scrubbing. The CA combinations tested were chosen based on previous reported research results and POC communication of CA or MAP atmospheres that have already been used by DoD or are currently under development for DoD use. We also evaluated the potential for using MAP to allow handling of partially ripened tomatoes at higher temperatures that are more compatible with desirable flavor and aroma development.

Development of MAP solutions for the target FFV was accomplished in two steps, with the first involving storage of the products in CA with and without ethylene scrubbing to define the optimum parameters for shipping in terms of product quality maintenance. Using this information, we identified the parameters for candidate MAP systems that duplicate the optimum parameters and worked with two MAP companies (Stepac and Apio) to acquire sample packaging that we used in our research.

Based on the results of our initial storage research in air and CA, we determined that the shipping times required to transport broccoli and Romaine lettuce by sea within the Pacific region do not exceed their shelf life, nor do ethylene levels likely to occur in mixed loads result in reduced shelf life for these products. These observations imply that outturn problems with these products are likely related to their age (i.e., freshness) at the time of container loading. Thus, we subsequently focused our research on how to determine the physiological condition and remaining shelf life of broccoli and Romaine lettuce at the time at which marine containers are loaded with mixed load products.

6.2 Determining Design Parameters For MAP To Be Used With FFV In The DoD Supply Chain

6.2.1 Broccoli And Romaine Lettuce Shelf Life In Simulated Marine Shipments

To initiate our investigation of potential causes of broccoli and Romaine lettuce outturn problems, we conducted two experiments in which broccoli and Romaine lettuce heads that had been harvested at typical commercial maturity 1 day prior to the start of the experiments, being held overnight at 33°F. The products were stored in normal air at 33°F as in current DoD practice, for up to 30 days for broccoli and 20 days for Romaine lettuce. The product appearance was subjectively evaluated periodically during the storage and the color, respiration rate, ethylene production, and weight loss were measured.

Both the broccoli and Romaine lettuce were judged to be of acceptable quality at the end of those storage periods. Pictures showing the broccoli after 0, 10, 20, and 30 days in air storage at 33°F show that there was little or no change in appearance when the product was handled continuously at the proper temperature (Figure 210).

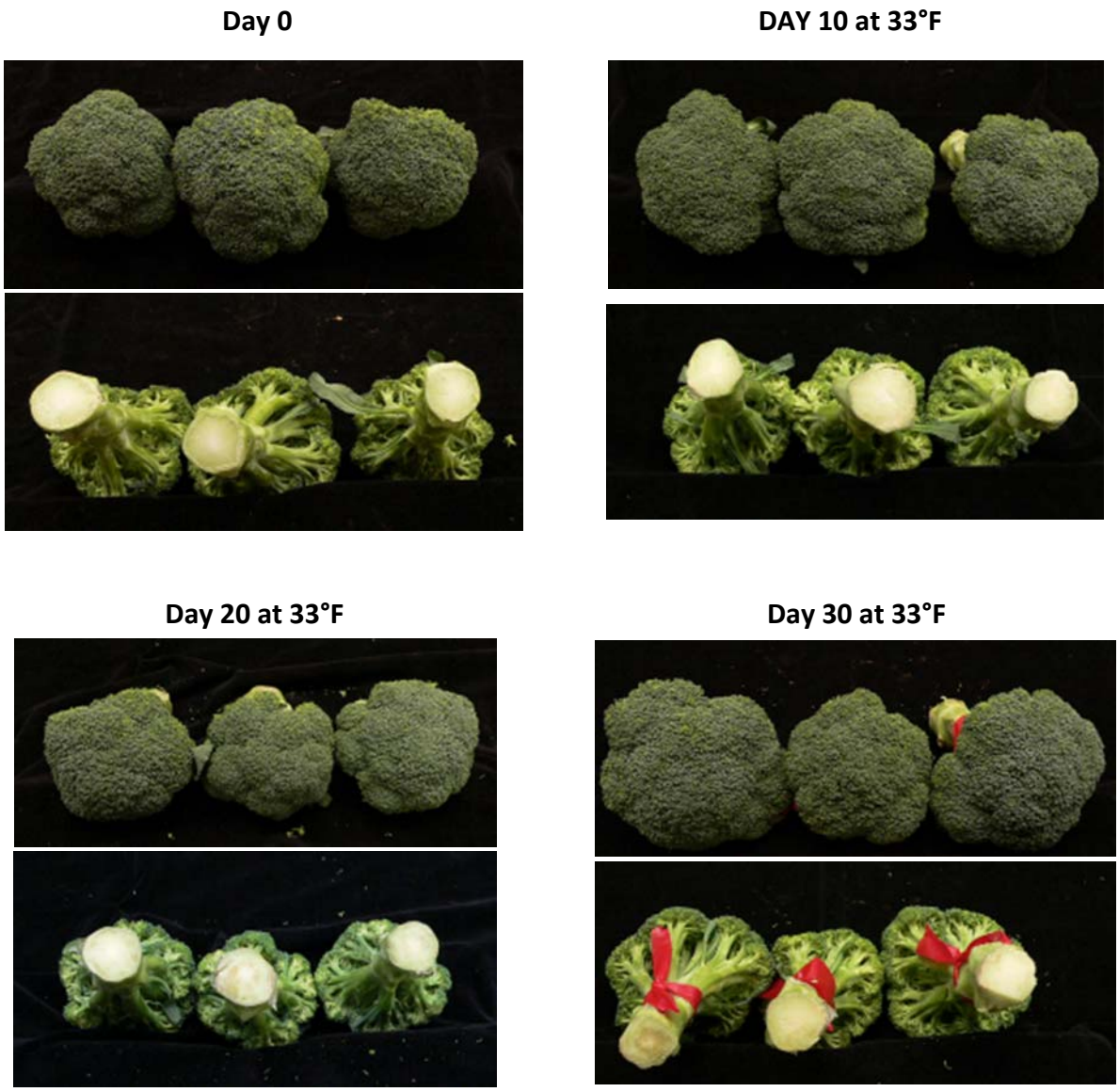


Figure 210. Appearance of broccoli during storage at 33°F for 30 days

Pictures showing the lettuce after 0, 10, and 20 days in air storage at 33°F show that there was also little or no change in appearance when the product was handled continuously at the proper temperature (Figure 211).



Figure 211. Appearance of Romaine lettuce during storage at 33°F for 30 days

Based on the results of this experiment as well as experiments that revealed lack of ethylene effects during storage on freshly harvested broccoli and Romaine lettuce, we modified our experimental approach to identify indices of physiological age in broccoli and Romaine lettuce that could be used to predict the remaining shelf life of those products.

6.2.2 Broccoli And Romaine Lettuce Indices Of Physiological Age

In order to identify potential indices of physiological age in broccoli and Romaine lettuce that could be used to predict the remaining shelf life of those products we subsequently procured from a local grocery store samples of both products that had been harvested 10 days previously (10DAH; unknown handling conditions) and we subjectively evaluated the appearance and measured the following parameters periodically during storage for 5 days more (15DAH) at 33°F plus 2 days at 68°F: color, weight loss, chlorophyll a and total chlorophyll content, chlorophyll fluorescence, vitamin C content, protein content. We also used chemical reagents to subjectively evaluate the browning potential of the tissue on freshly cut butt ends of the heads in terms of phenolic content and polyphenoloxidase (PPO) activity (Kader and Chordas, 1984). This experiment was conducted two times.

Broccoli and lettuce appearance changed little during the storage period (Figs. 191 and 192) and this observation was supported by the small color changes that were measured (Figs. 193 and 194).

10 Days After Harvest (Initial)



15 Days After Harvest (33°F for 5 days)



17 Days After Harvest (33°F for 5 days plus 68°F for 2 days)



Figure 212. Appearance of broccoli during storage at 33°F for 5 days plus 68°F for 2 days beginning 10 days after harvest

10 Days After Harvest (Initial)



15 Days After Harvest (33°F for 5 days)



17 Days After Harvest (33°F for 5 days plus 68°F for 2 days)



Figure 213. Appearance of Romaine lettuce during storage at 33°F for 5 days plus 68°F for 2 days beginning 10 days after harvest

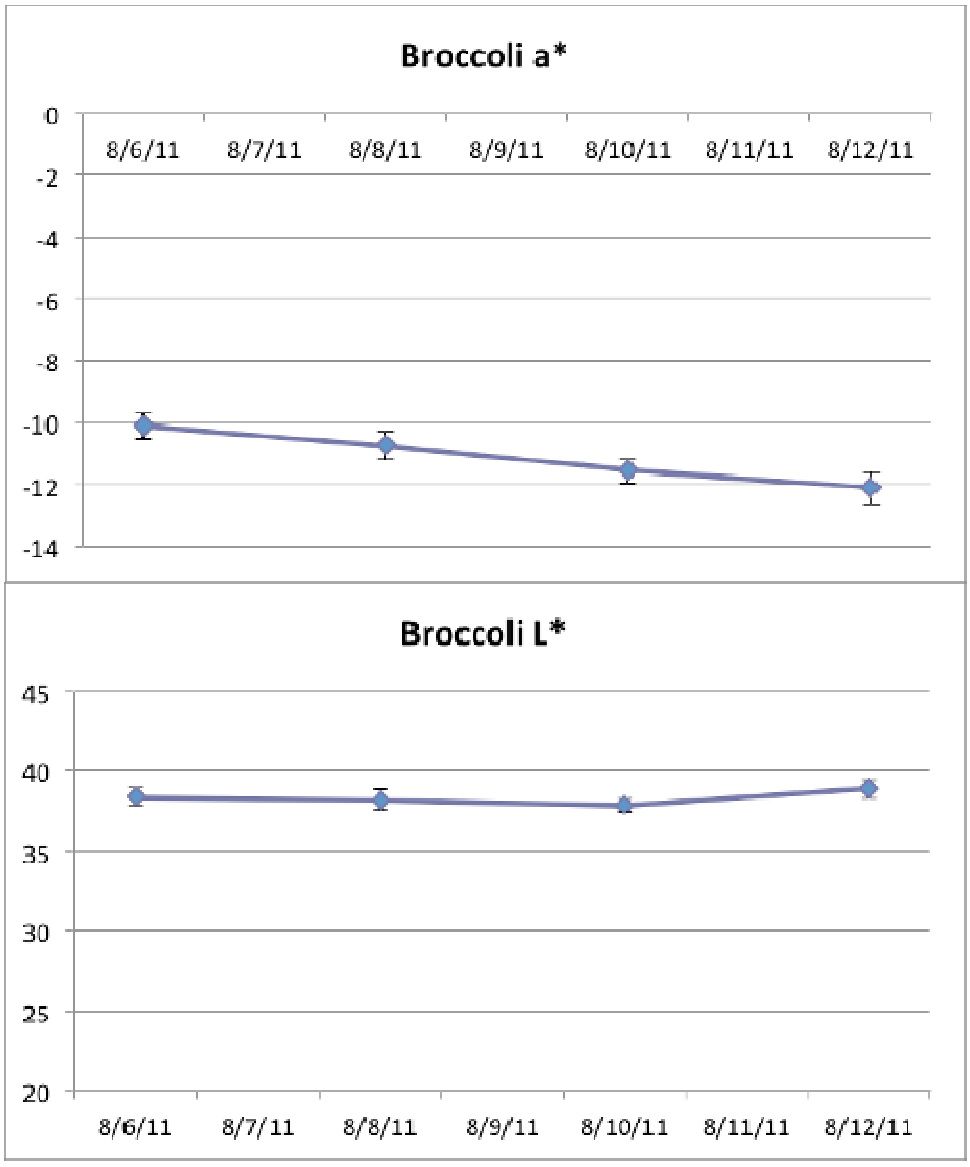


Figure 214. Color (a* and L* values) of broccoli during storage at 33°F for 7 days beginning 10 days after harvest. Error bars are equal to the standard error for each day.

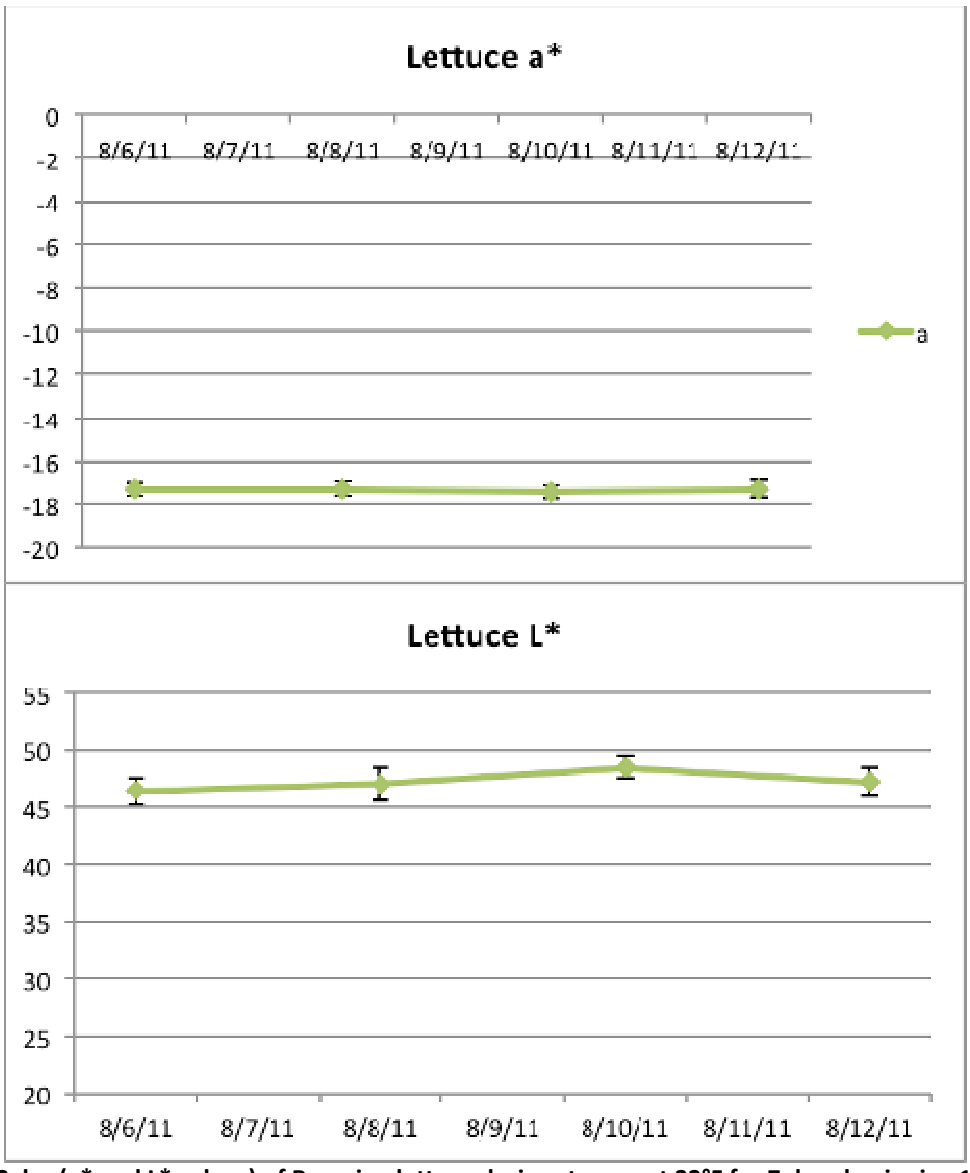


Figure 215. Color (a* and L* values) of Romaine lettuce during storage at 33°F for 7 days beginning 10 days after harvest. Error bars are equal to the standard error for each day.

Weight loss during the storage period was 10% or slightly less in broccoli and Romaine lettuce (Figs. 195 and 196).

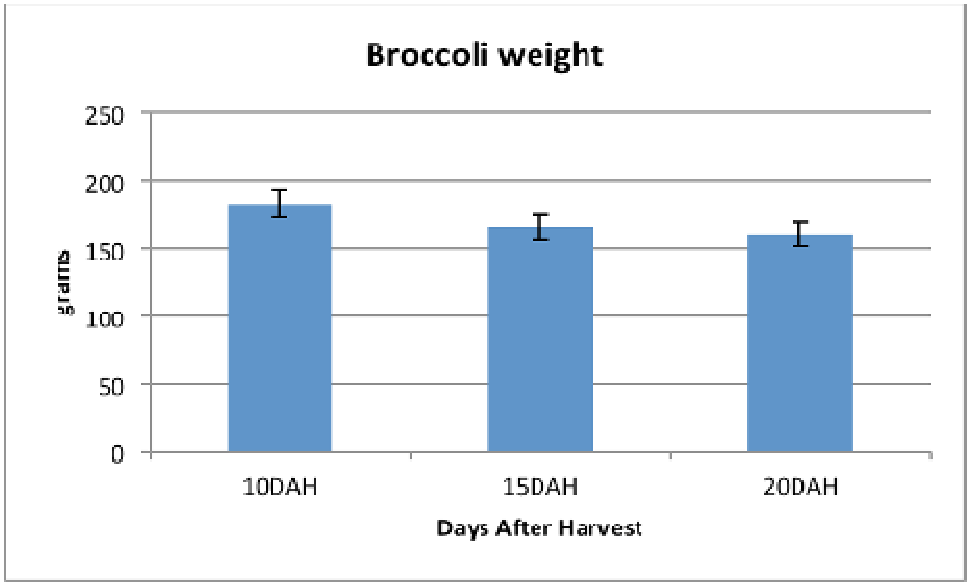


Figure 216. Weight of broccoli during storage at 33°F for 10 days beginning 10 days after harvest. Error bars are equal to the standard error for each day

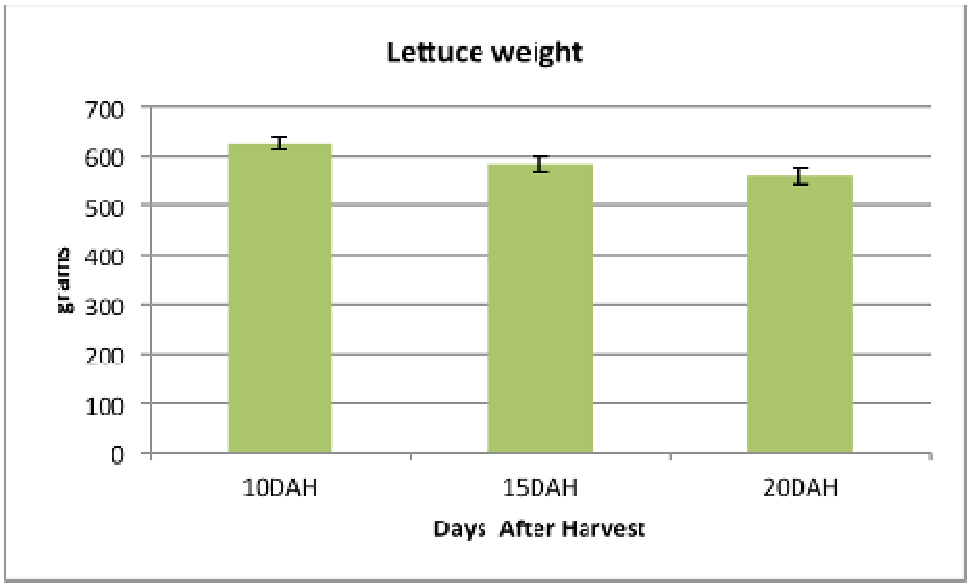


Figure 217. Weight of Romaine lettuce during storage at 33°F for 10 days beginning 10 days after harvest. Error bars are equal to the standard error for each day

Having observed that the butt ends of broccoli and Romaine lettuce heads become increasingly darker after harvest, we adapted a method that had been previously used to evaluate the browning potential of peaches and other stonefruit to determine the potential usefulness of this measurement for judging the physiological age of broccoli and Romaine lettuce. The method uses reagents that change color when they react with polyphenoloxidase (PPO) enzyme in one test and with phenolic compounds in the second test.

For broccoli and Romaine lettuce the color reactions were nonexistent to slight (Figs. 197 and 198) indicating very low PPO activity and very low phenolic content, neither of which change appreciably during the postharvest period.

PPO activity 8/6/2011

Before the reagents **After the reagents**



Phenolic compounds 8/6/2011

Before the reagents **After the reagents**



PPO activity 8/10/2011

Before the reagents **After the reagents**



Figure 218. Browning potential on the cut surface of broccoli during storage at 33°F for 5 days beginning 10 days after harvest. Error bars are equal to the standard error for each day

PPO activity 8/6/2011
Before the reagents



After the reagents



Phenolic compounds 8/6/2011
Before the reagents



After the reagents



PPO activity 8/8/2011
Before the reagents



After the reagents



Phenolic compounds 8/8/2011
Before the reagents



After the reagents



UNCLASSIFIED

PPO activity 8/10/2011
Before the reagents



After the reagents



Figure 219. Browning potential on the cut surface of broccoli during storage at 33°F for 5 days beginning 10 days after harvest. Error bars are equal to the standard error for each day

The vitamin C content in broccoli did not change significantly during the 5-day storage period at 33°F (Figure 220). However, vitamin C content declined about 40% in Romaine lettuce under the same conditions (Figure 221). The latter result suggested to us that vitamin C content might have some potential as an indicator of Romaine lettuce physiological age.

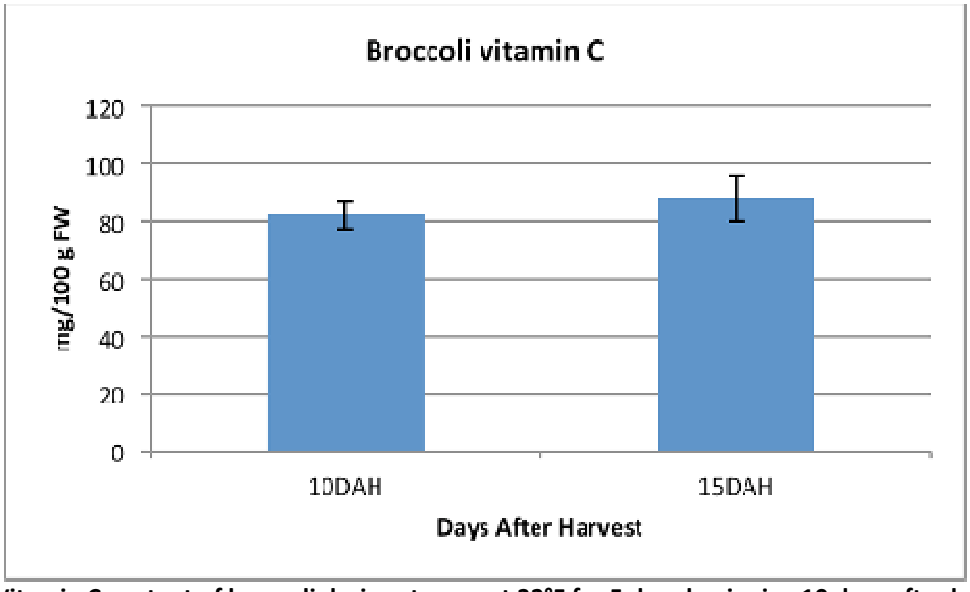


Figure 220. Vitamin C content of broccoli during storage at 33°F for 5 days beginning 10 days after harvest. Error bars are equal to the standard error for each day

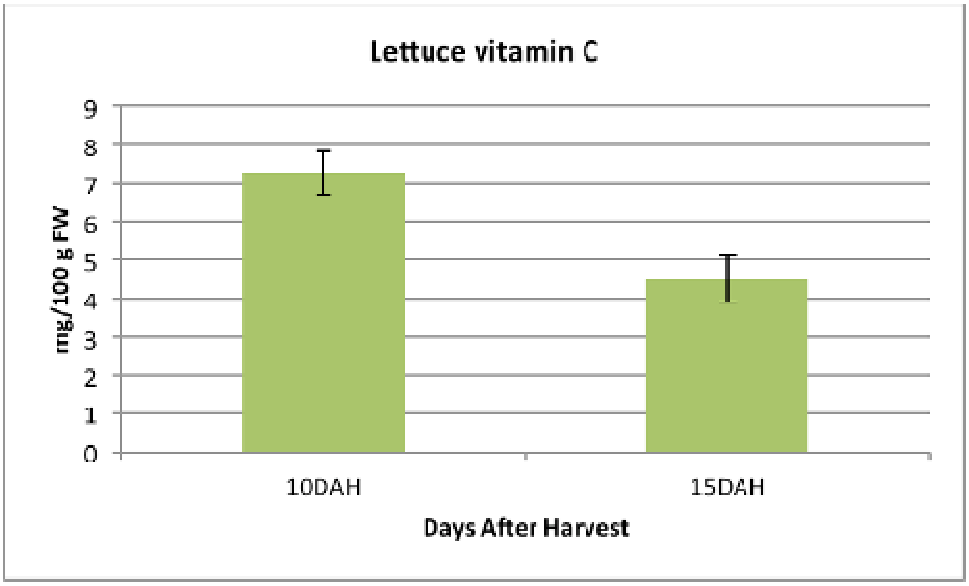


Figure 221. Vitamin C content of Romaine lettuce during storage at 33°F for 5 days beginning 10 days after harvest. Error bars are equal to the standard error for each day

Neither chlorophyll a nor total chlorophyll levels changed much in broccoli during the 5-day storage period at 33°F (Figure 222). However, chlorophyll a and total chlorophyll declined by about one-third in Romaine lettuce under the same conditions (Figure 223). The latter result suggested to us that chlorophyll content might have some potential as an indicator of Romaine lettuce physiological age. When chlorophyll fluorescence was measured in broccoli and Romaine lettuce, no differences were found (data not shown). Since chlorophyll fluorescence is an indicator of physiological stress, the implication was that these products did not experience stress during the postharvest storage.

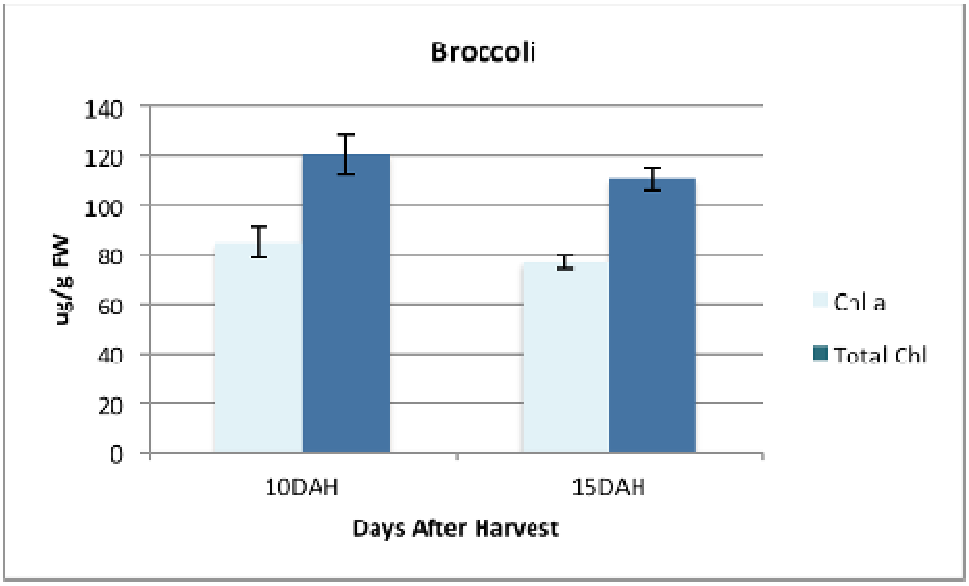


Figure 222. Chlorophyll a and total chlorophyll content of broccoli during storage at 33°F for 5 days beginning 10 days after harvest. Error bars are equal to the standard error for each day

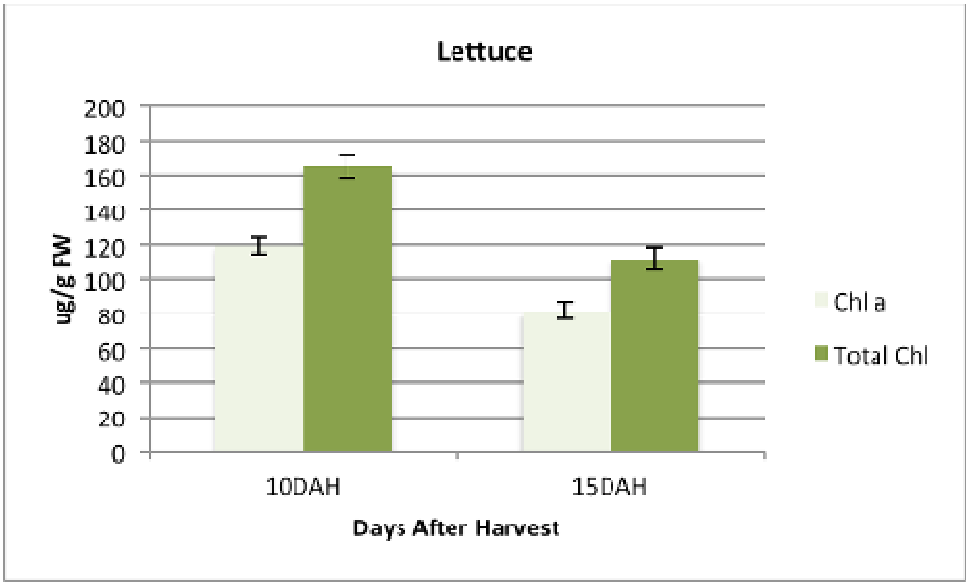


Figure 223. Chlorophyll a and total chlorophyll content of Romaine lettuce during storage at 33°F for 5 days beginning 10 days after harvest. Error bars are equal to the standard error for each day

Protein degradation is a feature of plant senescence so we hypothesized that protein content would decline during the postharvest period. Protein content actually appeared to increase slightly in broccoli during the 5-day storage period at 33°F (Figure 224) although that slight increase may not be meaningful in terms of broccoli physiology. In contrast, the protein content of Romaine lettuce declined by about 15% (Figure 225).

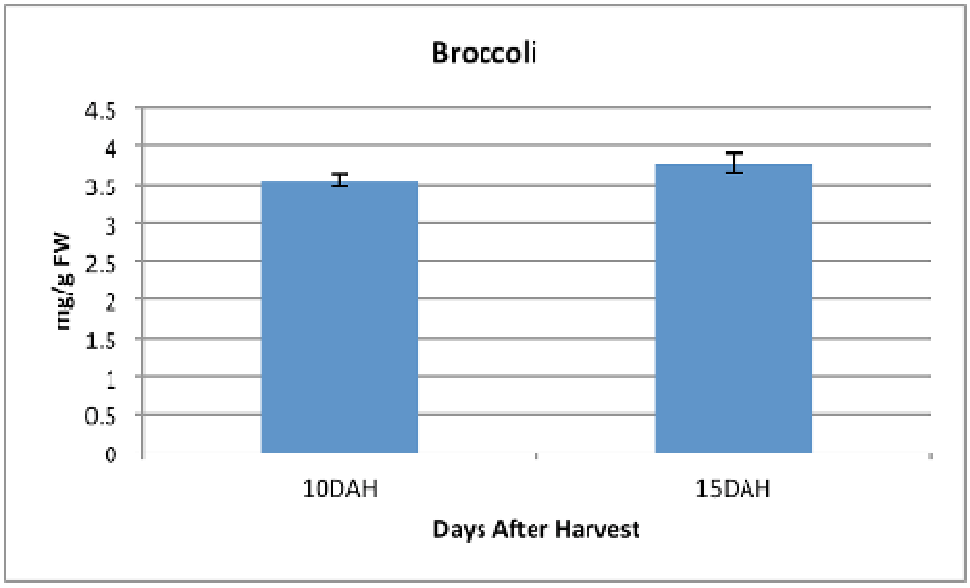


Figure 224. Total protein content of broccoli during storage at 33°F for 5 days beginning 10 days after harvest. Error bars are equal to the standard error for each day

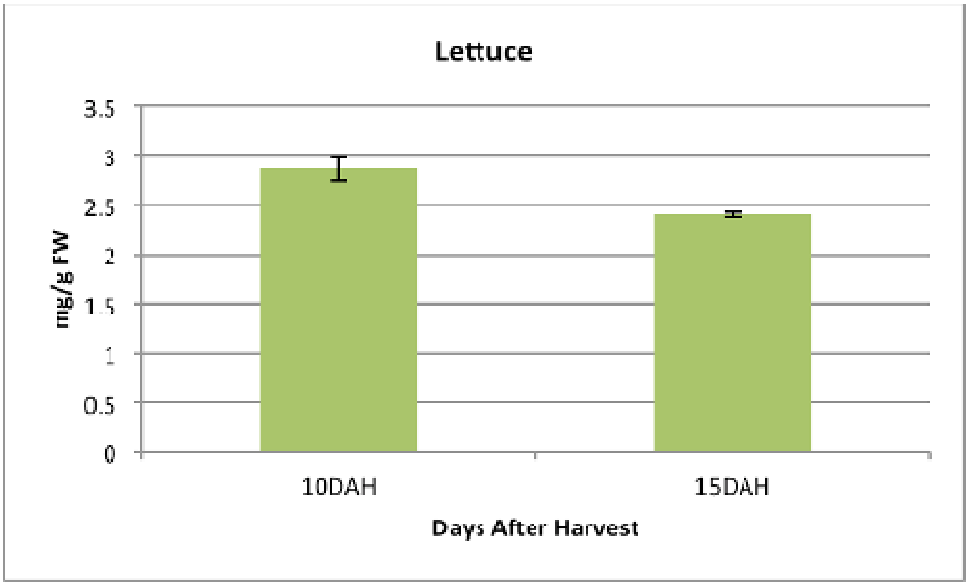


Figure 225. Total protein content of Romaine lettuce during storage at 33°F for 5 days beginning 10 days after harvest. Error bars are equal to the standard error for each day

6.2.3 Vine Ripe Tomato Response To Chilling And Non-Chilling Temperatures

Two preliminary experiments were conducted with vine ripe tomatoes at the pink (USDA stage 4) ripeness stage to determine if negative quality changes result from exposure to the 45°F shipping temperature being used for this crop in mixed load ocean shipments. Our previous research and that of others has recently shown that the putative "optimum" postharvest temperatures for handling tomatoes, which are based on avoidance of visible chilling injury symptoms (abnormal color and texture development, pitting and decay), actually cause inhibition of flavor development in the fruit. Tasti-Lee tomatoes stored at 45°F were compared to fruit stored at 55, 59 and 64°F for 3 weeks. As expected, there were no differences in visual quality of the tomatoes at the different temperatures. However, total aroma volatiles were reduced at 45°F in agreement with previous reports for other tomato varieties (Bai et al., 2011; Maul et al., 2000).

6.2.4 Controlled Atmosphere Storage Of Romaine Lettuce

Romaine lettuce that had been harvested at typical commercial maturity 1 day prior to the start of the experiments was held overnight in air at 33°F and then stored in air and in two CA treatment conditions - CA1: 2% O_2 plus 5% CO_2 and CA2: 2% O_2 plus 2% CO_2. The lettuce was stored for 20 days at 33°F to simulate a marine container transport period, followed by a retail shelf life simulation period of 1 day in air at 68°F. This experiment was conducted two times. After the visual quality evaluation it was concluded that the Romaine lettuce in CA2 had better visual quality than the air control (Figure 226). However, CA1 with 5% CO2 caused injury to the lettuce midribs ('brown stain') after 20 days, so that CA treatment was not used when the experiment was repeated.

DAY 0



DAY 10 CA1 (2% O_2 plus 5% CO_2)



DAY 10 CA2 (2% O_2 plus 2% CO_2)



DAY 10 AIR



DAY 20 CA1 (2% O_2 plus 5% CO_2)



DAY 20 CA2 (2% O_2 plus 2% CO_2)



AIR 20 DAYS



Figure 226. Appearance of Romaine lettuce during storage in air or CA at 33°F for 20 days plus 1 day in air at 68°F

The color indices of the green leaf blades of Romaine lettuce did not change during storage (Figure 227) while chlorophyll content fluctuated (Figure 228 and 229). Green plant tissues contain excess chlorophyll in terms of the appearance of green color, such that a large amount of chlorophyll must be degraded before a visual change becomes apparent.

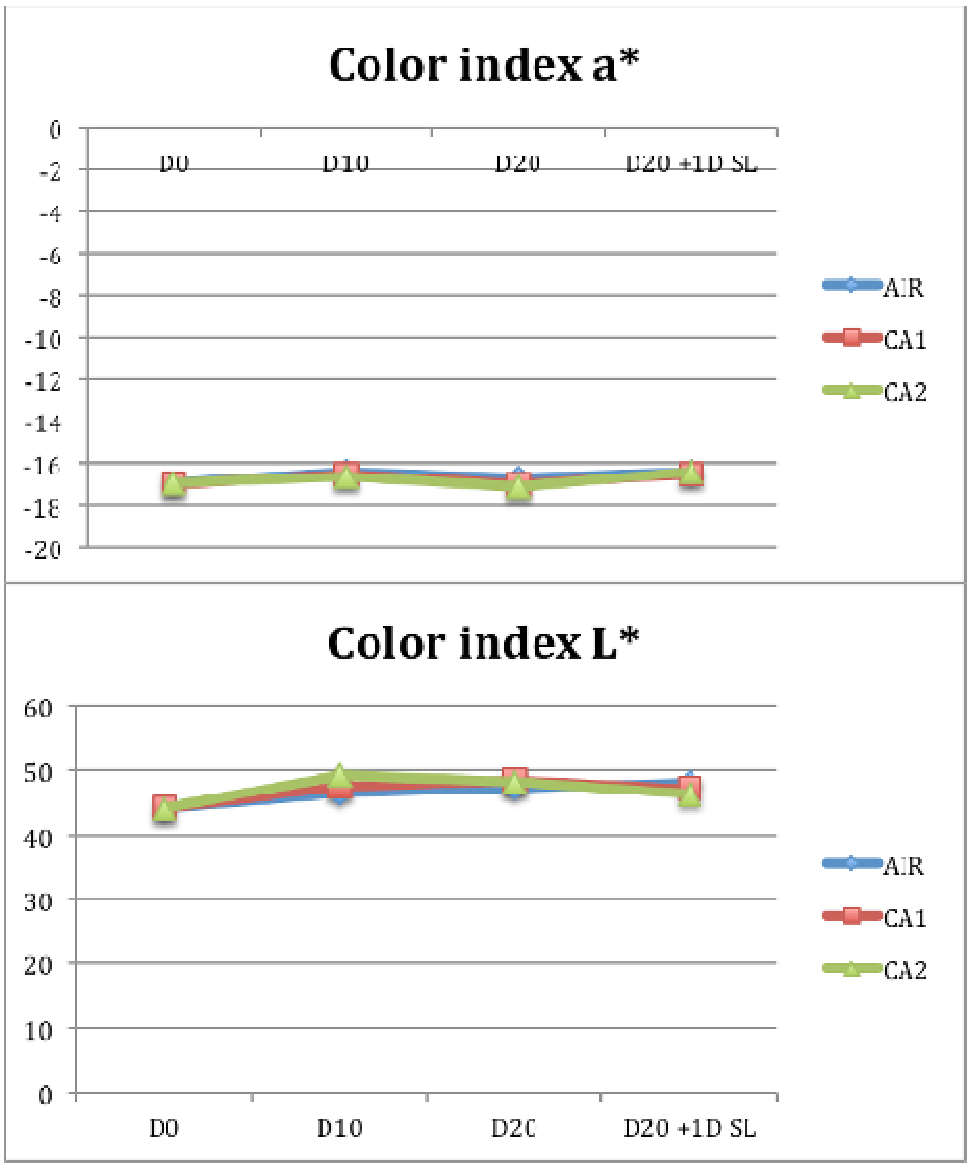


Figure 227. Color (a* and L*) of Romaine lettuce during storage in air or CA at 33°F for 20 days plus 1 day in air at 68°F

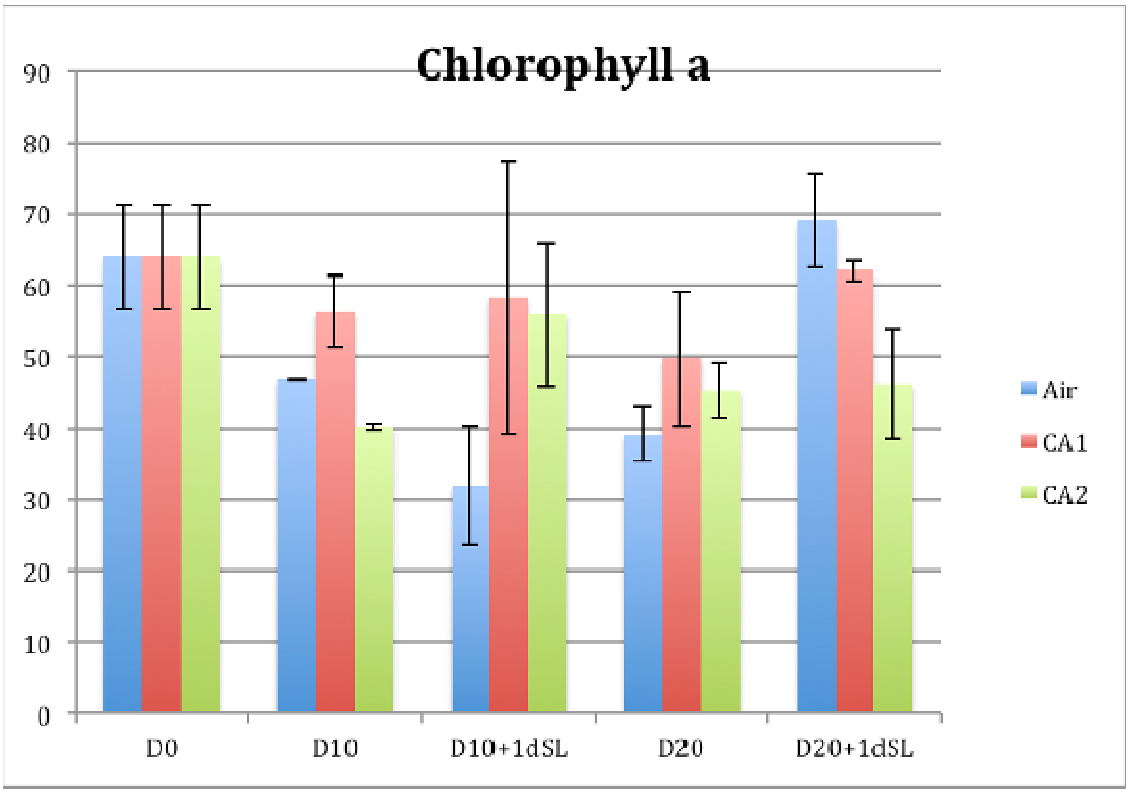


Figure 228. Chlorophyll a content of Romaine lettuce during storage in air or CA at 33°F for 20 days plus 1 day in air at 68°F

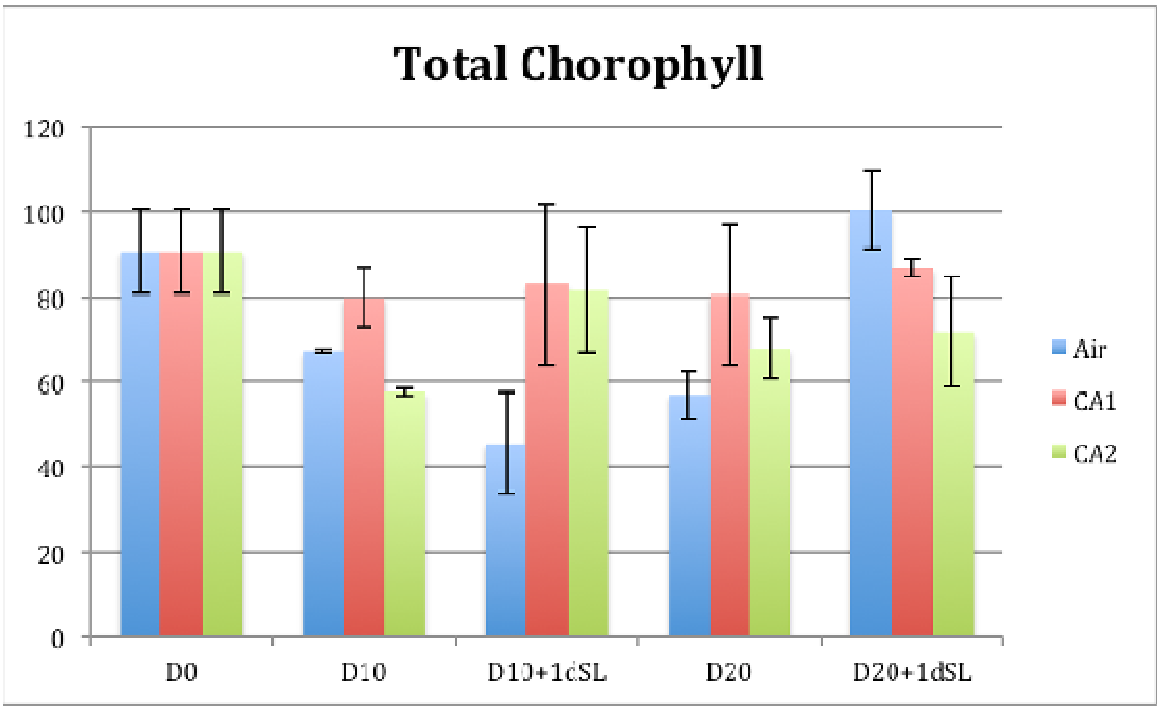


Figure 229. Total chlorophyll content of Romaine lettuce during storage in air or CA at 33°F for 20 days plus 1 day in air at 68°F

The apparent respiration rate of Romaine lettuce was higher in CA than in air during storage, which was probably an indication of physiological stress from the elevated carbon dioxide in the CA (Figure 230). However, respiration was lower in the heads from CA storage than air storage once they were transferred to air. The small effect of CA on respiration rate reflects the lack of any remarkable differences in appearance among heads from the different treatments. In contrast, ethylene production was lower in CA than in air after 20 days of storage (Figure 231). However, upon transfer to air, the ethylene production by the heads from CA1 with 5% carbon dioxide, rose markedly, reflecting the injury that the tissue had experienced.

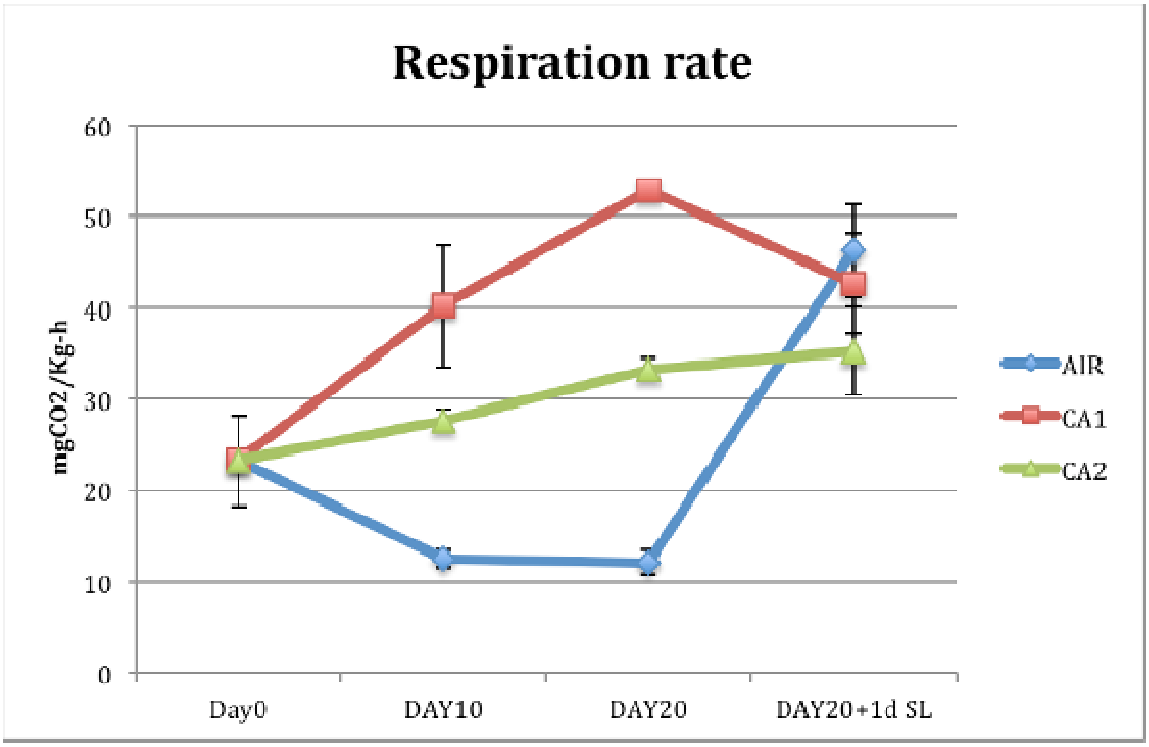


Figure 230. Respiration rate of Romaine lettuce during storage in air or CA at 33°F for 20 days plus 1 day in air at 68°F

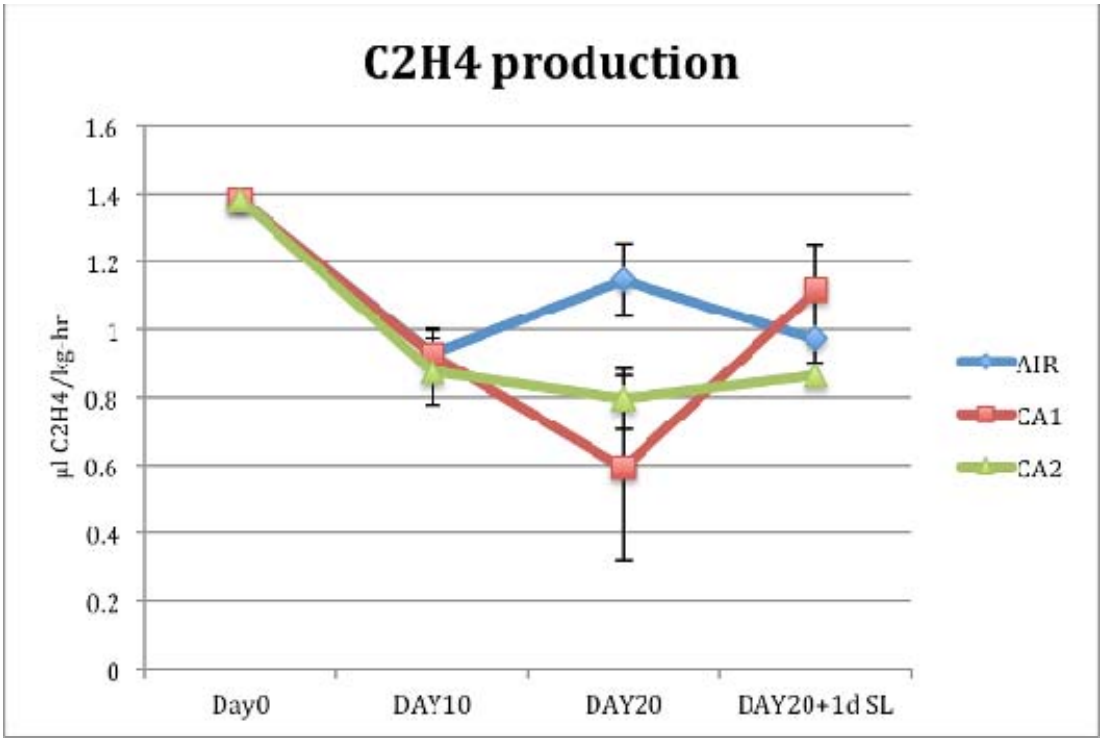


Figure 231. Ethylene production by Romaine lettuce during storage in air or CA at 33°F for 20 days plus 1 day in air at 68°F

As proteins are degraded during plant senescence, the amount of free amino acids increases. A beneficial effect of CA in reducing the increase in free amino acid levels was seen most clearly during the 1-day shelf period after both 10 days and 20 days of storage (Figure 232).

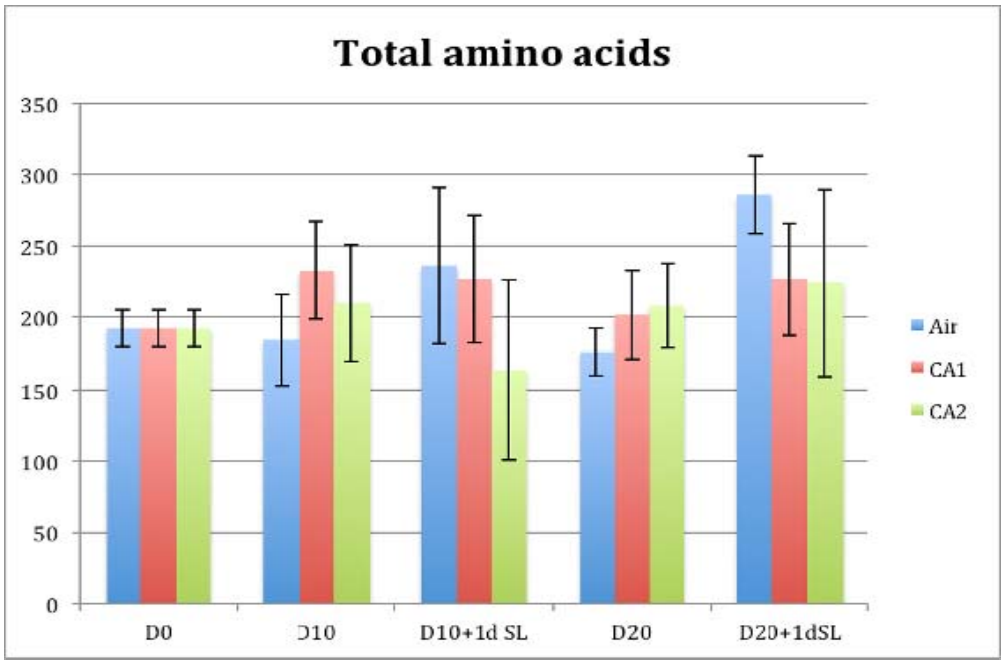


Figure 232. Total amino acid content of Romaine lettuce during storage in air or CA at 33°F for 20 days plus 1 day in air at 68°F

There was indication after 10 days of storage that CA may have caused increased loss of sugars in the Romaine lettuce, but by 20 days of storage there was no difference between air-stored and CA-stored lettuce (Figure 233).

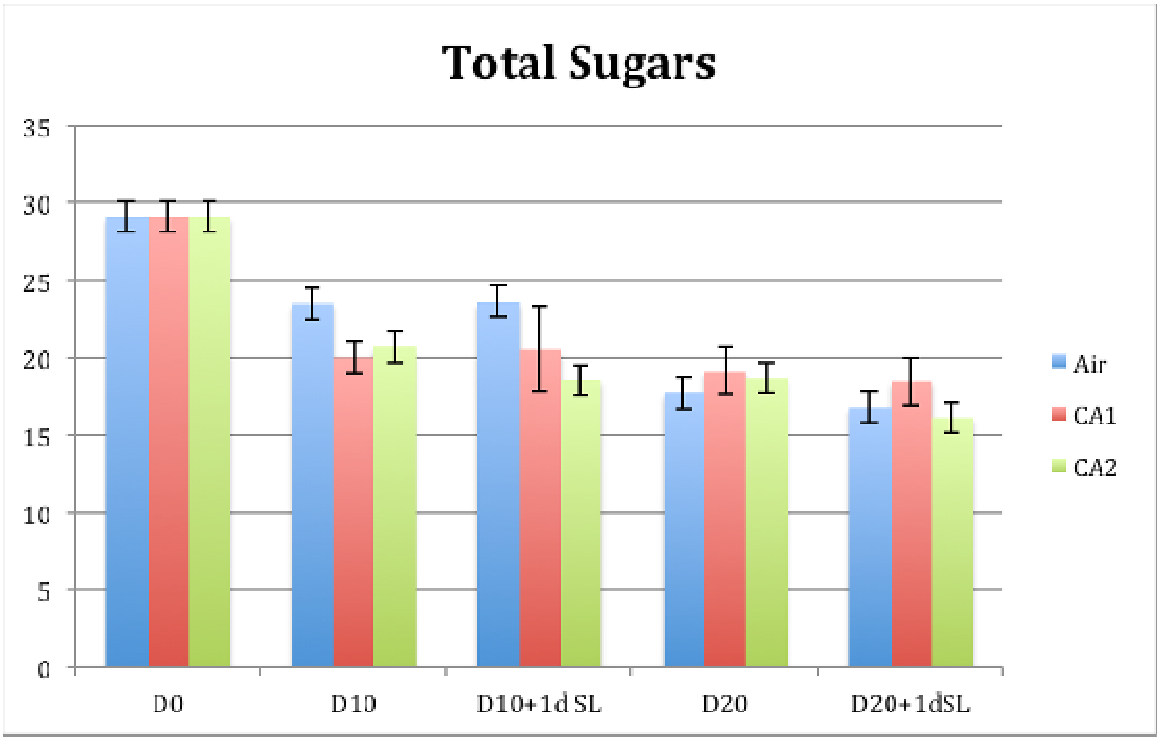


Figure 233. Total sugar content of Romaine lettuce during storage in air or CA at 33°F for 20 days plus 1 day in air at 68°F

6.2.5 Controlled Atmosphere Storage Of Broccoli At Different Physiological Ages

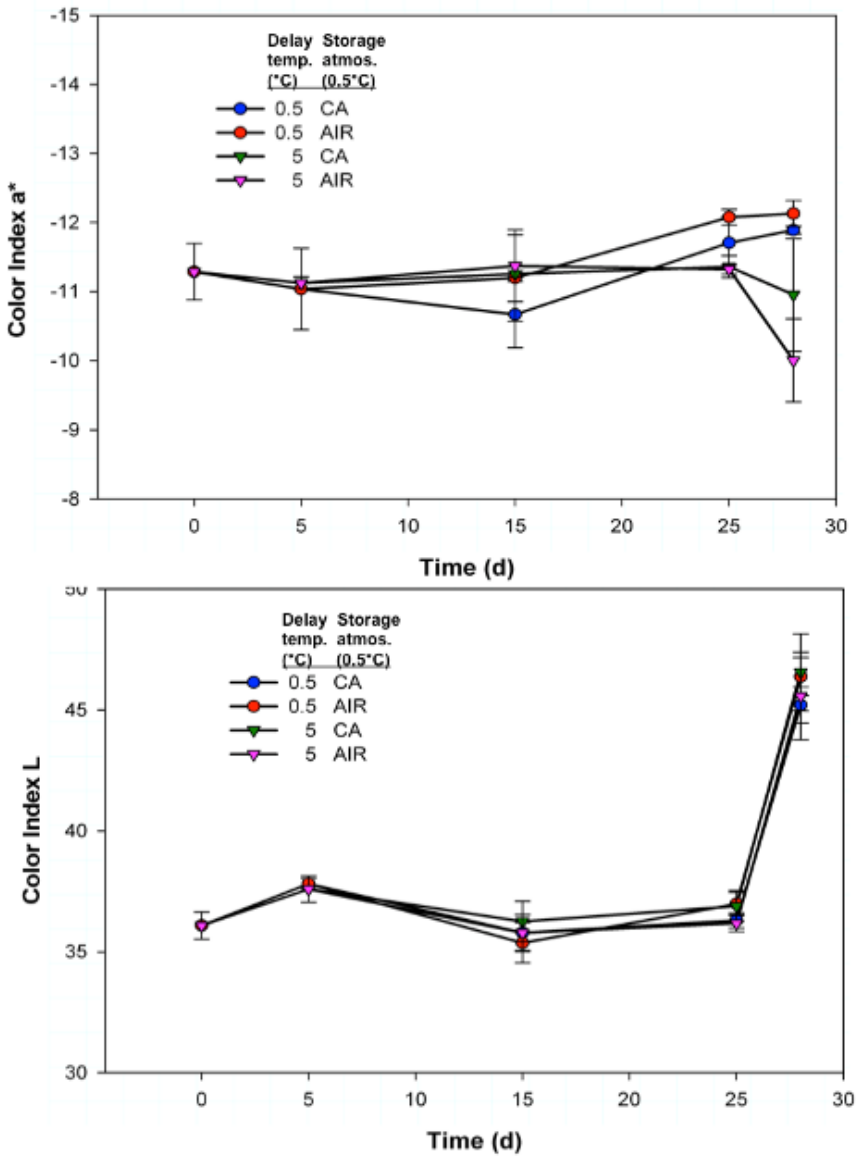
Based on our initial shelf life experiments (Section 6.2.1) CA experiments were designed utilizing broccoli that received different "pre-storage" treatments intended to obtain product samples that were at different "freshness stages" prior to the start of either air or CA storage that simulated marine shipments. This was accomplished by pre-storing the products at either 33°F or 41°F for 0, 5 or 10 days before they were placed into either air or controlled atmosphere at 33°F for a 20-day storage that simulated a marine container transport period, followed by a retail shelf life simulation period of 3 days in air at 68°F (Table 44).

Table 44. Storage treatments

Pre-storage treatment	Air or CA storage period	Retail shelf life period	Total postharvest time
None	20 days at 33°F	3 days at 68°F	23 days
5 days at 33°F	20 days at 33°F	3 days at 68°F	28 days
10 days at 33°F	20 days at 33°F	3 days at 68°F	33 days
5 days at 41°F	20 days at 33°F	3 days at 68°F	28 days
10 days at 41°F	20 days at 33°F	3 days at 68°F	33 days

The broccoli was harvested at typical commercial maturity 1 day prior to the start of the experiments and was held overnight in air at 33°F prior to the start of the experiment. The CA for broccoli was 1% O_2 plus 10% CO_2. Color changes, weight loss, chlorophyll fluorescence, vitamin C, chlorophyll a and b and total chlorophyll, total sugars, total amino acids, total phenolics, total protein, and overall visual quality were evaluated after 10 and 20 days of storage at 33°F and after 20 days of storage at 33°F plus 3 days shelf life in air at 68°F. This experiment was conducted two times.

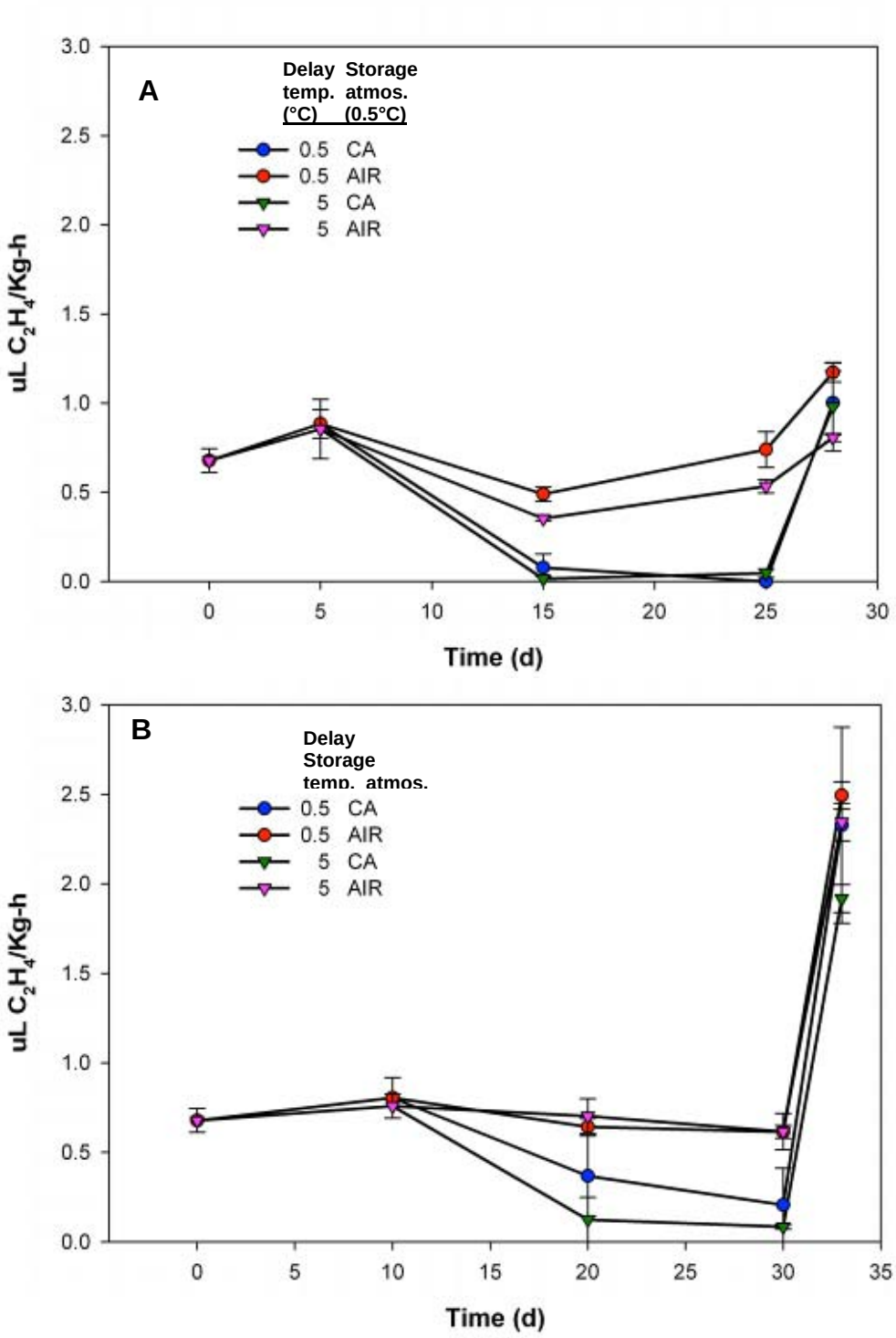
CA had little or no effect on the color measurements of broccoli, only slightly improving the a* value retention during shelf for the 5-day delay at 41°F (Figure 234).



Note: Means ± SE of 3 replications. Results for no delay and 10 days delay were similar (data not shown).

Figure 234. Color index (a* and L*) for broccoli stored in air or CA at 33°F for 20 days plus 3 days shelf life in air at 68°F after 5 days delay in air at 33°F or 41°F

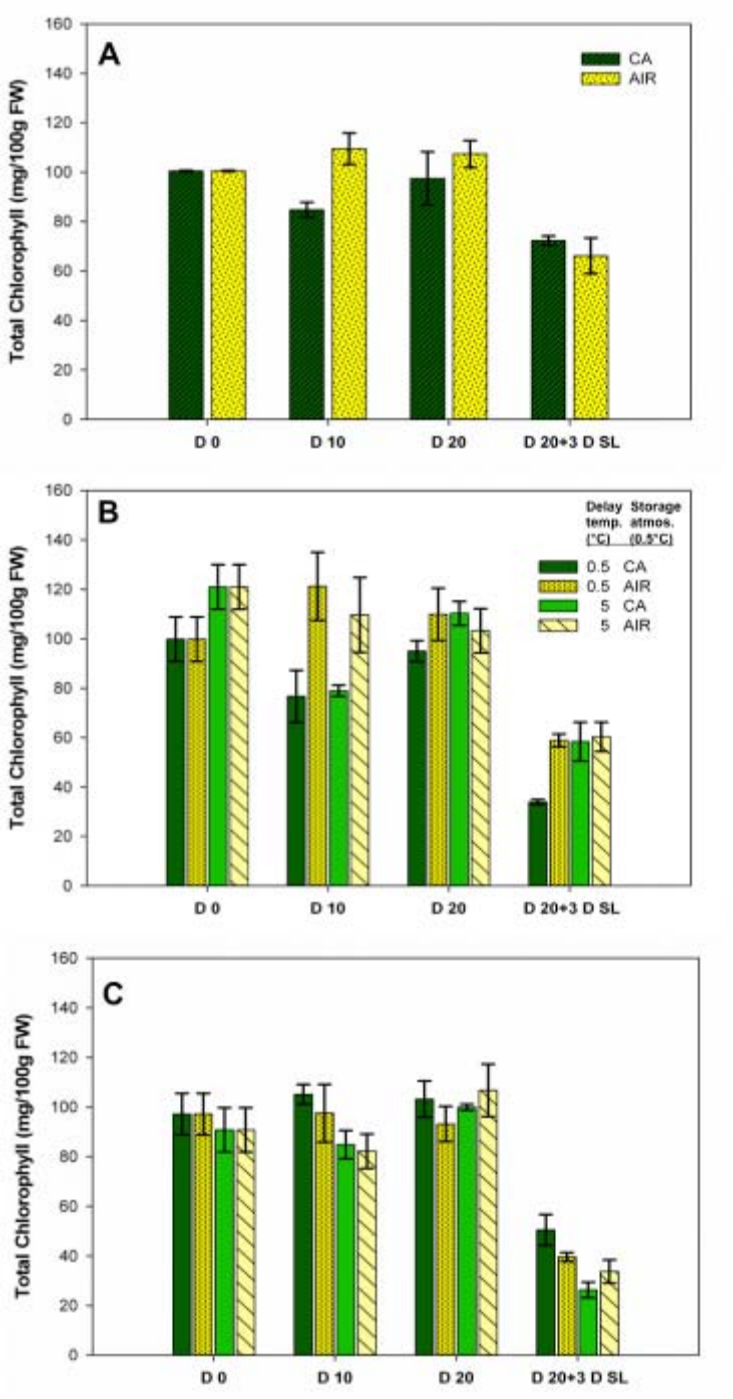
Ethylene production was significantly reduced in CA, but there was no residual effect during shelf life (Figure 235 A and B).



Note: Means ± SE of 3 replications.

Figure 235. Ethylene production of broccoli stored in air or CA at 33°F plus 3 days shelf life in air at 68°F after 5 days (A) or 10 days (B) delay in air at 33°F or 41°F

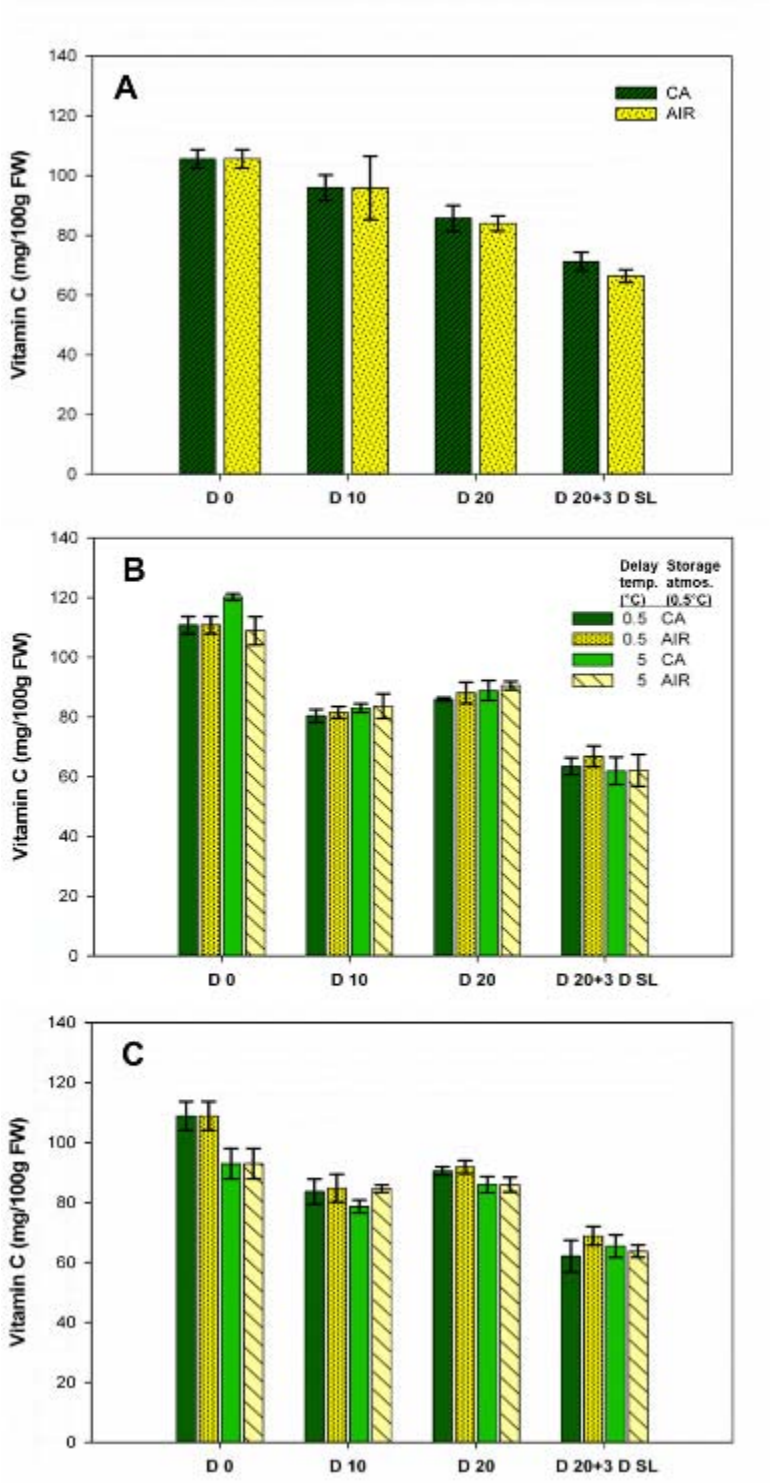
There was no beneficial effect of CA storage on chlorophyll content demonstrated in this experiment; in some cases it appeared that CA actually resulted in greater loss of chlorophyll than in air storage (Figure 236)



Note: Means ± SE of 3 replications.

Figure 236. Total chlorophyll concent of broccoli stored in air or CA at 33°F for 0, 10 or 20 days after no delay (A) or 5 days (B) or 10 days (C) delay in air at 33°F or 41°F

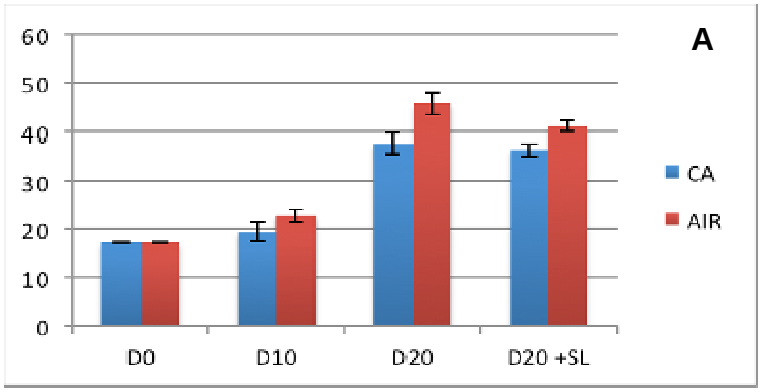
CA had no effect on the vitamin C content of broccoli in this experiment (Figure 237).

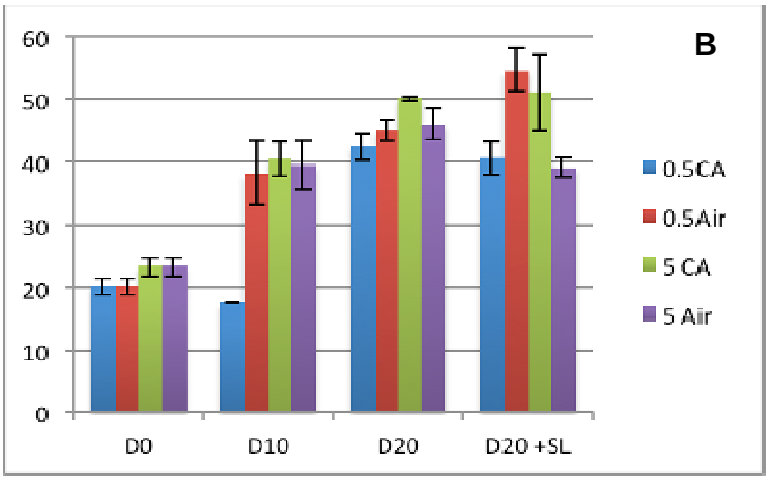


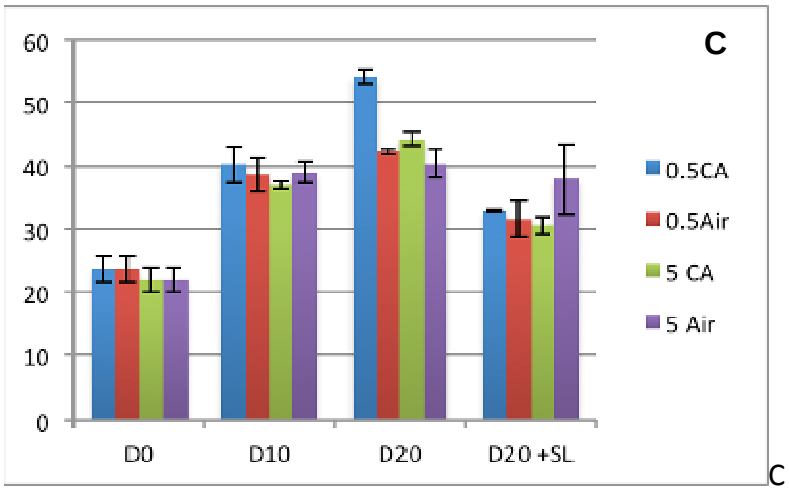
Note: Means ± SE of 3 replications.

Figure 237. Vitamin C concentration of broccoli stored in air or CA at 33°F for 0, 10 or 20 days after no delay (A) or 5 days (B) or 10 days (C) delay in air at 33°F or 41°F

CA storage delayed the increase in phenolic compounds that accompanies broccoli senescence when there was no delay (Figure 238 A) or a 5-day delay (Figure 238 B) before the CA was initiated, but with a 10-day delay before the start of CA there was no longer a reduction in the phenolics (Figure 238 C).





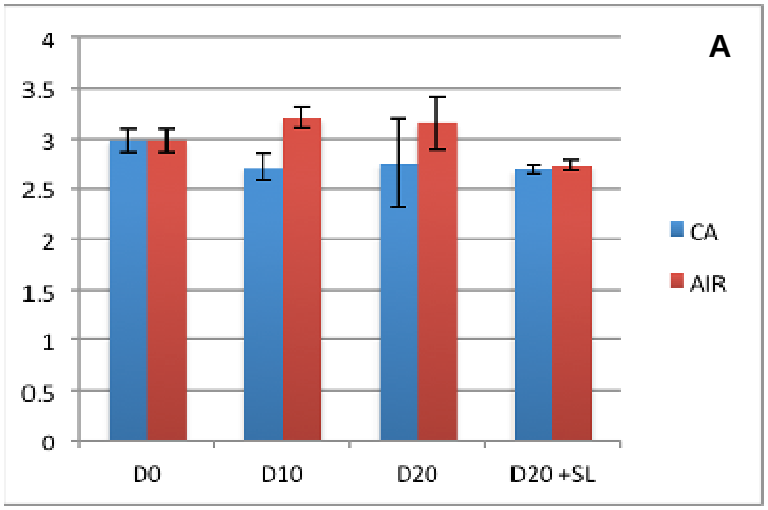


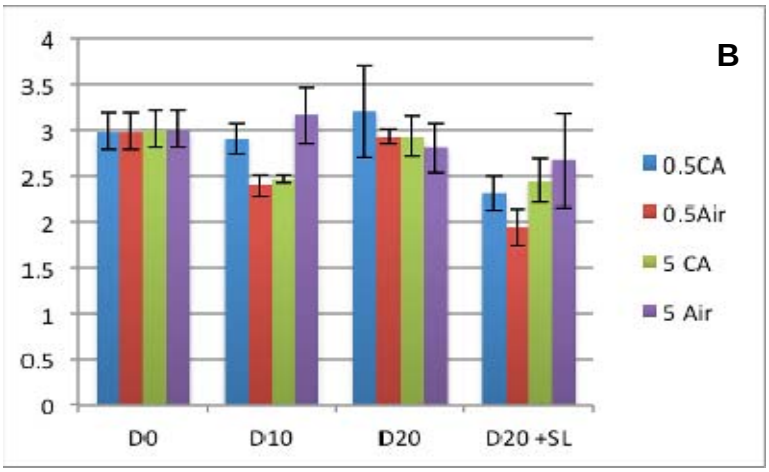
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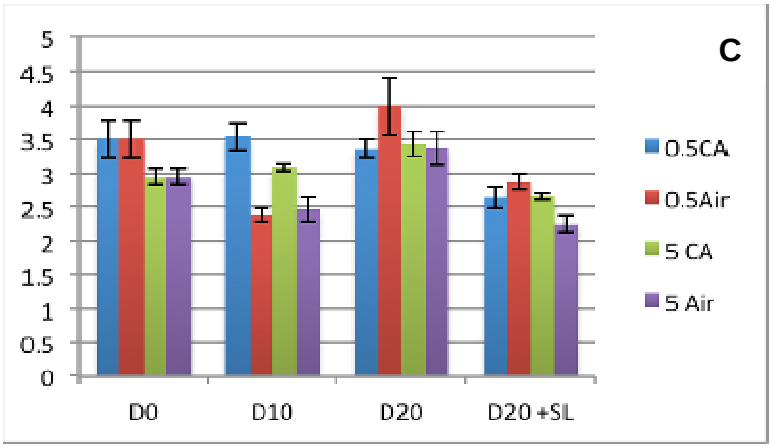
Note: Means ± SE of 3 replications.

Figure 238. Total phenolic concentration (mg GAE/ 100 g FW) of broccoli stored in air or CA at 33°F for 0, 10 or 20 days plus 3 days shelf life in air at 68°F after no delay (A) or 5 days (B) or 10 days (C) delay in air at 33°F or 41°F

CA storage did not consistently reduce protein degradation during storage, but was more effective for shorter storage times (Figure 239 A). However, even after storage for 28 or 33 days, the protein content was not greatly different from initial levels (Figure 239 B and 239 C; Table 45).







Note: Means ± SE of 3 replications.

Figure 239. Total protein concentration (mg/g FW) of broccoli stored in air or CA at 33°F for 0, 10 or 20 days plus 3 days shelf life in air at 68°F after no delay (A) or 5 days (B) or 10 days (C) delay in air at 33°F or 41°F

Table 45. Phenolics, amino acids, sugars and protein content of broccoli stored in air or CA at 33°F for 0, 10 or 20 days plus 3 days shelf life in air at 68°F with no pre-storage delay

Storage for	Phenolics mg GAE/ 100 g fw	Amino acids mg typtophan/100 g fw	Sugars mg glucose/ g fw	Protein mg/g fw
0 days	17.3±0.05	144±9.23	19.7±0.77	2.98±0.13
10 days in air	22.8±1.29	158±7.73	17.6±0.99	3.20±0.10
10 days in CA	19.4±2.01	165±12.1	16.7±0.78	2.71±0.12
20 days in air	45.7±2.26	178±6.99	11.3±0.72	3.15±0.26
20 days in CA	37.6±2.04	165±2.07	11.4±0.29	2.75±0.44
20 days in air + 3 days SL	41.0±1.15	204±22.6	15.6±1.58	2.73±0.06
20 days in CA + 3 days SL	36.6±1.27	205±15.7	16.0±1.87	2.69±0.05

Means ± SE of 3 replications.

The results of this experiment indicated that the CA for broccoli did not maintain a higher product quality or extend its shelf life compared to air storage even if the product was stored for up to 10 days at 41°F before the start of CA storage. Our conclusion is that optimum temperature management alone is sufficient to manage fresh broccoli quality during simulated shipping for up to 3 weeks in marine containers.

Furthermore, none of the various potential physiological indicators of product age or senescence that we tested appeared to be particularly suitable for judging the physiological age of broccoli or Romaine lettuce. This is because, although those factors do change over time as a function of temperature, either rising or falling as senescence progresses, the relative levels appear to vary from sample to sample and in some cases the levels may not change consistently

over time. This means that a “snapshot” of any of those factors measured without knowledge of the previous product history will not reliably indicate the product’s physiological age.

6.2.6 Controlled Atmosphere Storage Of Vine Ripe Tomatoes To Determine Carbon Dioxide Tolerance At Different Temperatures

To determine the best shipping temperature and CA for vine-ripe tomatoes we used ‘Tasti Lee’ variety fruit at the pink ripeness stage (USDA Stage 4). The fruit were obtained from a packinghouse in Ruskin, FL on the day of harvest, transported in an air-conditioned vehicle to the Postharvest Horticulture Laboratory at UF in Gainesville, and stored overnight at 20°C. Three controlled atmospheres were evaluated (Table 46) with storage for 10 days at 55°F, 59°F and 64°F: CA1: 12% O_2 plus 4% CO_2, CA2: 8% O_2 plus 6% CO_2, CA3: 3% O_2 plus 8% CO_2; and air was used as the control.

Table 46. Controlled atmospheres in experimental evaluation

Controlled Atmospheres used in the experiment			
	55 °F	**59°F**	**64°F**
Control	Air	Air	Air
CA	12% O_2 + 4% CO_2	8% O_2 + 6% CO_2	8% O_2 + 6% CO_2
CA	8% O_2 + 6% CO_2	3% O_2 + 8% CO_2	3% O_2 + 8% CO_2

After 5 days and 10 days at 55°F, 59°F or 64°F, the fruit were transferred to air at 68°F for 2 days to simulate shelf life conditions. The CA combinations chosen were those previously found to be achievable using commercial modified atmosphere packaging (MAP) from Apio Inc. (California, USA) and StePac L.A. Ltd (Israel) and the CO_2 concentrations were expected to be near the tolerance limit for pink tomatoes. The treatments were evaluated in terms of appearance, evidence of CO_2 injury symptoms, firmness, titratable acidity, soluble solids content, and aroma volatiles.

There was usually better firmness retention in CA than in air storage, with the most consistent effect seen at the highest (64°F) storage temperature (Figure 240).

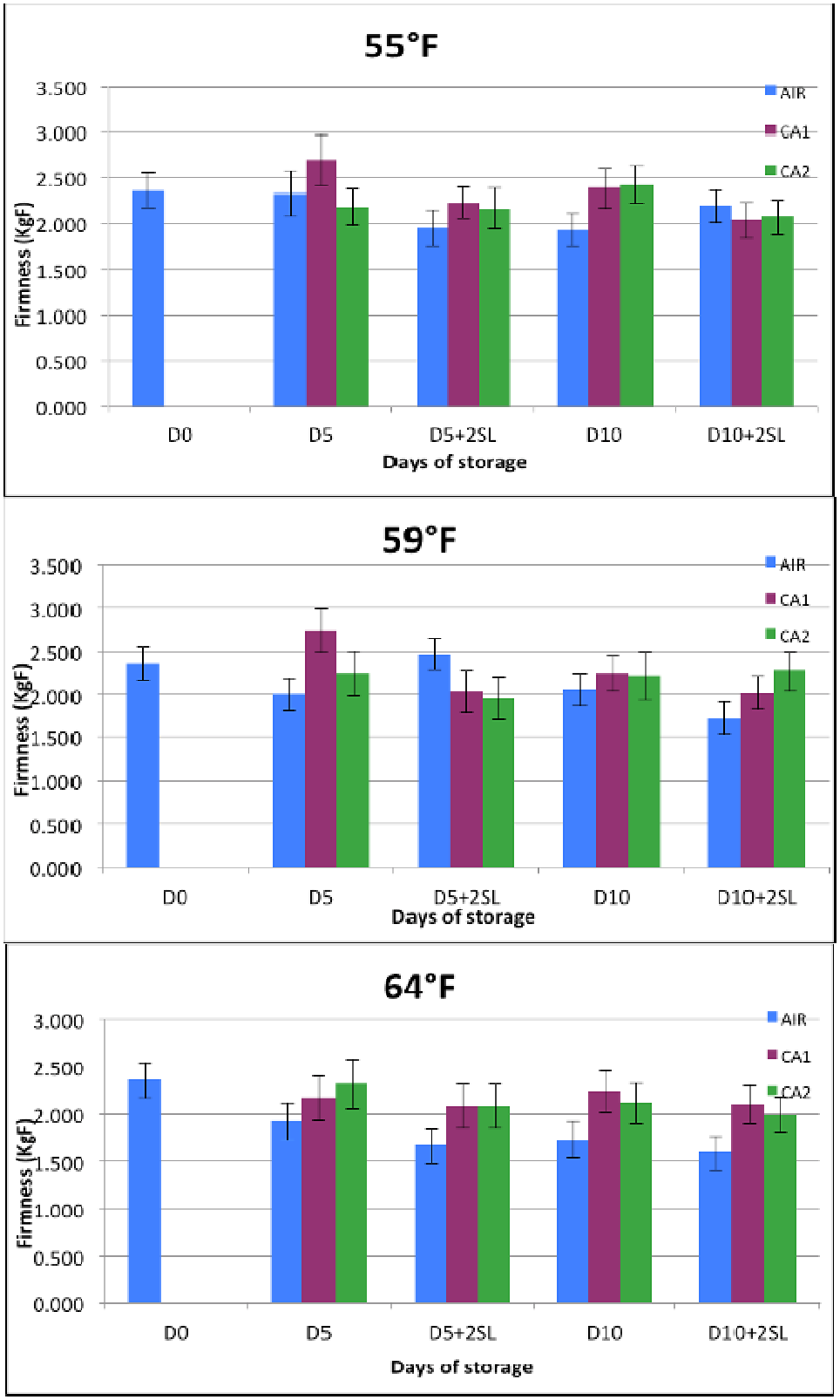


Figure 240. Firmness of pink tomato fruit during storage in air or CA for 5 or 10 days at 55°F, 59°F or 64°F, plus an additional 2 days of shelf life in air at 68°F

Total volatiles increased over time in both air and CA storage, but the increase was much greater in air storage although there was some recovery of volatile production evident when CA-stored fruit were transferred to air at 68°F for shelf life (Figure 241). There was an increase in volatiles with increasing storage temperature in air and the effect was maintained during shelf life. The opposite response was observed for CA-stored tomatoes, especially during shelf life, suggesting that the higher CO2 concentrations at the higher storage temperatures had a greater residual effect on volatiles production upon transfer to air.

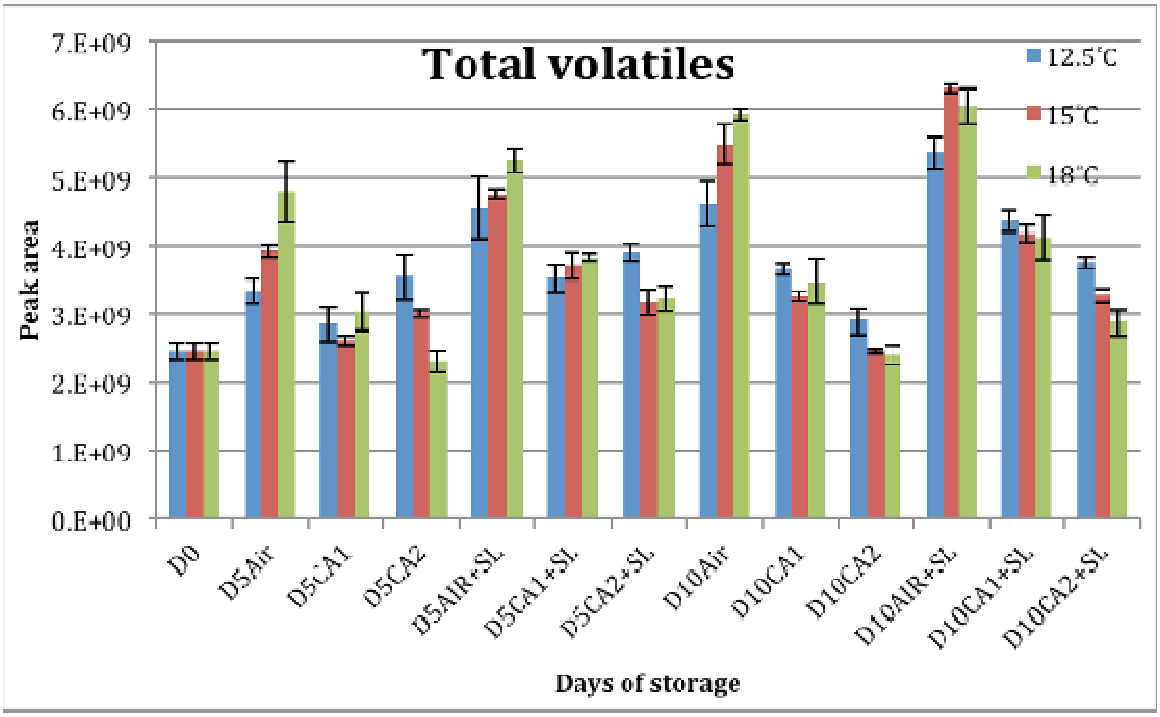


Figure 241. Total aroma volatiles of pink tomato fruit during storage in air or CA for 5 or 10 days at 55°F, 59°F or 64°F, plus an additional 2 days of shelf life in air at 68°F

Hexanal is a major tomato aroma compound that is positively correlated with tomato sourness ratings, but has also been shown to contribute positively to tomato flavor. Hexanal increased over time at all temperatures but, in CA, its contribution as a % of the total volatiles was higher than in air (Figure 242; most of the other volatiles were suppressed; data not shown).

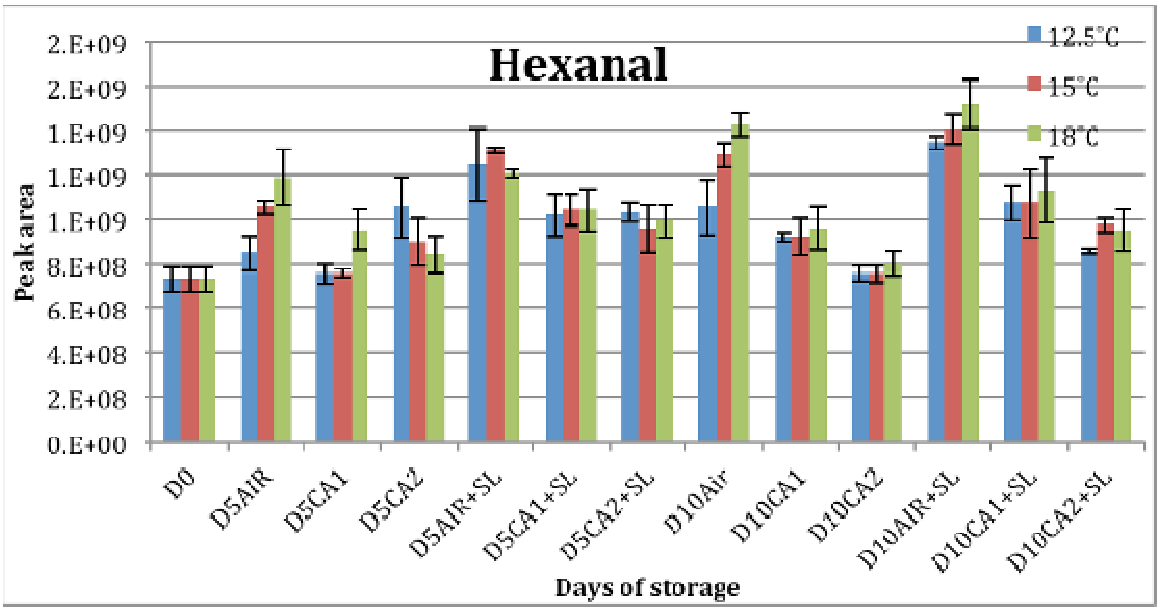


Figure 242. Hexanal content of pink tomato fruit during storage in air or CA for 5 or 10 days at 55°F, 59°F or 64°F, plus an additional 2 days of shelf life in air at 68°F

The compound 6-methyl-5-hepten-2-one (MHO) is a major volatile in the tomato aroma profile (≈30% of total peak area). MHO has been reported to impart a "fruity" and "sweet/floral" aroma to tomatoes. MHO levels were lower in elevated CO_2 concentrations (Figure 243). There was less of an effect of temperature on MHO content when comparing different atmospheres. However, there was a significant temperature effect on MHO content for air-stored fruit (18°C > 15°C > 12.5°C). MHO content was highest at 64°F, whereas it was lowest at 55°F for all atmospheres and storage durations.

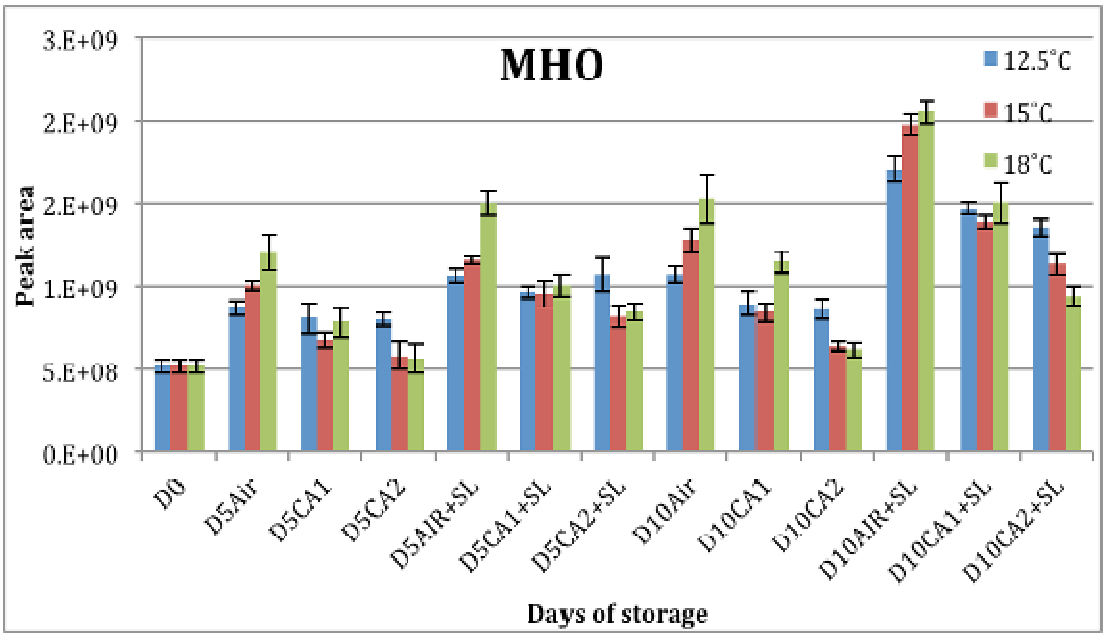


Figure 243. 6-methyl-5-hepten-2-one (MHO) content of pink tomato fruit during storage in air or CA for 5 or 10 days at 55°F, 59°F or 64°F, plus an additional 2 days of shelf life in air at 68°F

The results suggest that there is an antagonism between ripening and elevated CO_2 and reduced O_2 and that this affected the aroma volatiles, which are produced in greater amounts as ripening progresses. CA retarded ripening, and the CA-stored fruit were less ripe after shelf life than air-stored fruit. Slower ripening in CA storage would result in prolonged storage potential, but at the same time, less ripe fruit from CA would have reduced aroma volatiles than riper air-stored fruit, as shown in the results of this experiment, at least until the CA-stored fruit reach equivalent ripeness.

There was an opposite temperature effect on volatiles in CA compared to air storage, which suggests that CA alleviated chilling injury. Fruit at the higher temperatures ripened more uniformly in terms of color upon transfer to shelf life at 68°F than the fruit stored at 55°F.

Overall, tomato quality was better at higher temperatures and CA slowed ripening, which would prolong storage life. Based on visual quality evaluations, the best CA at 55°F was 8% O_2 plus 6% CO_2, since 3% O_2 plus 8% CO_2 resulted in CO_2 injury. None of the CA combinations caused CO_2 injury at the higher temperatures of 59°F and 64°F.

6.3 MAP, Including Temperature-Responsive Films, For Broccoli, Romaine Lettuce And Vine-Ripe Tomatoes

6.3.1 Introduction

Scientists at the University of Florida developed and patented thermally responsive polymers that can be custom-designed to modify the permeability of gases such as CO_2 and O_2 in a temperature-dependent manner. Since almost all commercial barrier films have fixed permeability rates that are designed for a specific respiration rate at a fixed temperature, we considered these branched-polyolefin materials to show great promise for better maintaining the composition of the headspace in modified atmosphere packaging (MAP). However, it proved impossible to scale up the new film to make it usable in our research because it does not possess the necessary strength to be used in MAP. It would probably require that the thermally responsive film be sandwiched between layers of other films, compromising the thermal responsiveness.

6.3.2 MAP For Broccoli And Romaine Lettuce

Two commercial MAP systems were tested: 1) Breatheway® Membrane Technology from Apio Inc. (California, USA) and 2) Xtend MAP from StePac L.A. Ltd (Israel). Breatheway MAP utilizes a thermally responsive polymer that is coated onto a microporous patch; the polymer is designed to undergo a phase change at a certain temperature, thus changing its gas permeability in a stepwise manner.

The Breatheway and Xtend MAP systems (Figs. 223 and 224) were tested with fresh broccoli that was obtained from a commercial grower in Moultrie, GA, and fresh Romaine lettuce that was obtained from a commercial grower in South Bay, FL. The product in waxed cartons was stored overnight at 33°F and then repacked into the two MAP systems before being stored for

22 days at 33°F. Product in the commercial packaging (without any MAP system) was used as the control. During the storage period measurements of the established atmospheres of the MAP systems were taken every other day. At the end of the storage period subjective visual evaluations of the products were conducted.



Figure 244. Apio Breatheway carton liner MAP system for Romaine lettuce



Figure 245. StePac Xtend carton liner MAP system for Romaine lettuce

Neither of the two MAP systems proved to be beneficial for the products. For Romaine lettuce, the Apio MAP system equilibrated at 4% O_2 plus 6% CO_2 (Figure 246), which resulted in CO_2 injury of the lettuce (brown stain). StePac bags equilibrated at an atmosphere of 18% O_2 plus 3% CO_2 (Figure 246), which is not near to what is usually recommended as optimal for Romaine lettuce (i.e., a low oxygen atmosphere of 1-3%).

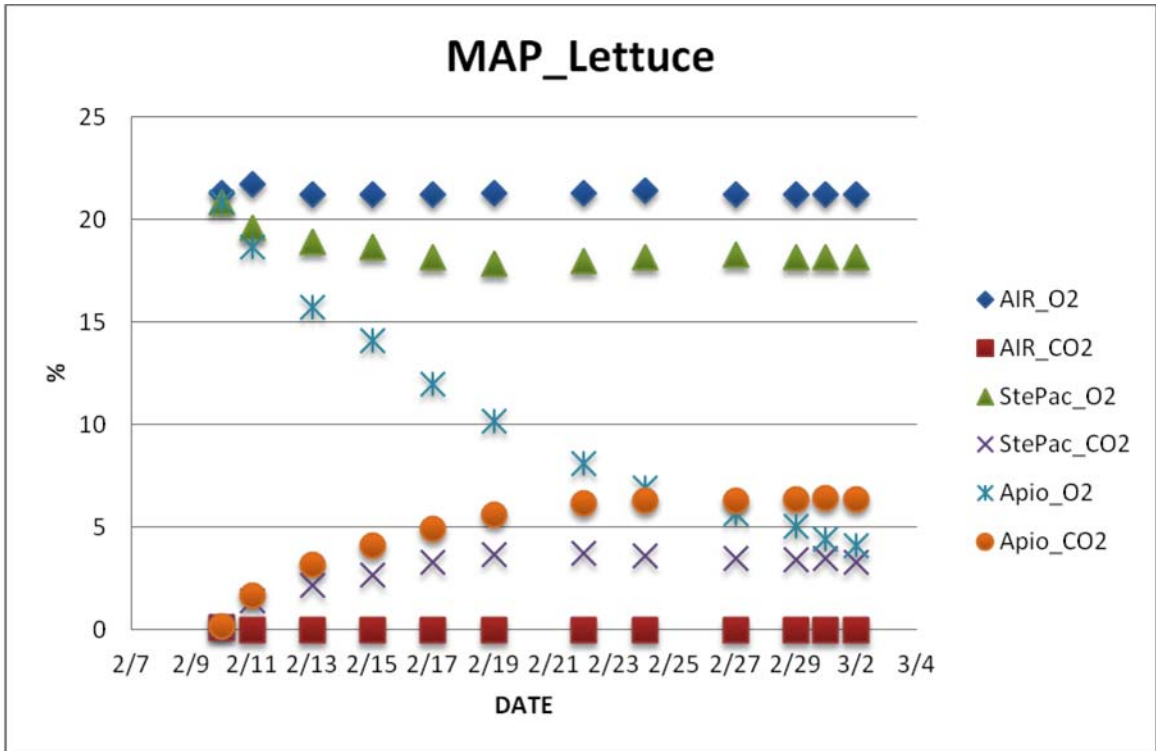


Figure 246. Atmospheres that were established during storage for 22 days at 33°F in two MAP systems (StePac and Apio) used for Romaine lettuce

After the 22 days of storage the products from all the treatments were similar (Figs. 226 and 227).

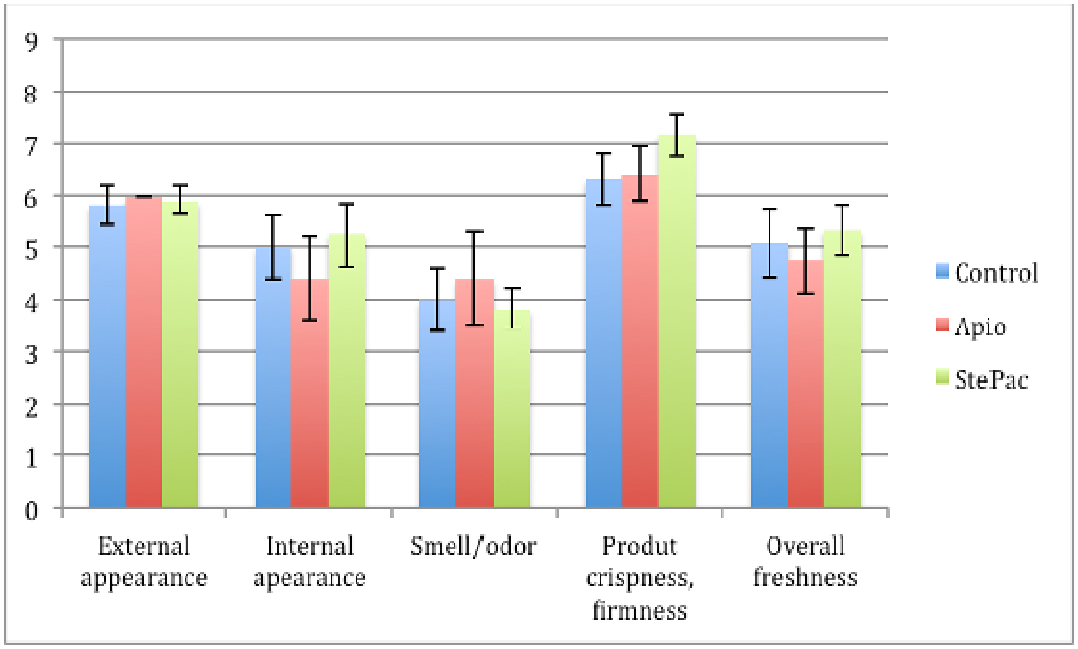


Figure 247. Visual quality ratings of Romaine lettuce stored in air, Apio Breatheway MAP or StePac Xtend MAP after 22 days at 33°F



Figure 248. Appearance of Romaine lettuce stored in air, Apio Breatheway MAP or StePac Xtend MAP after 22 days at 33°F

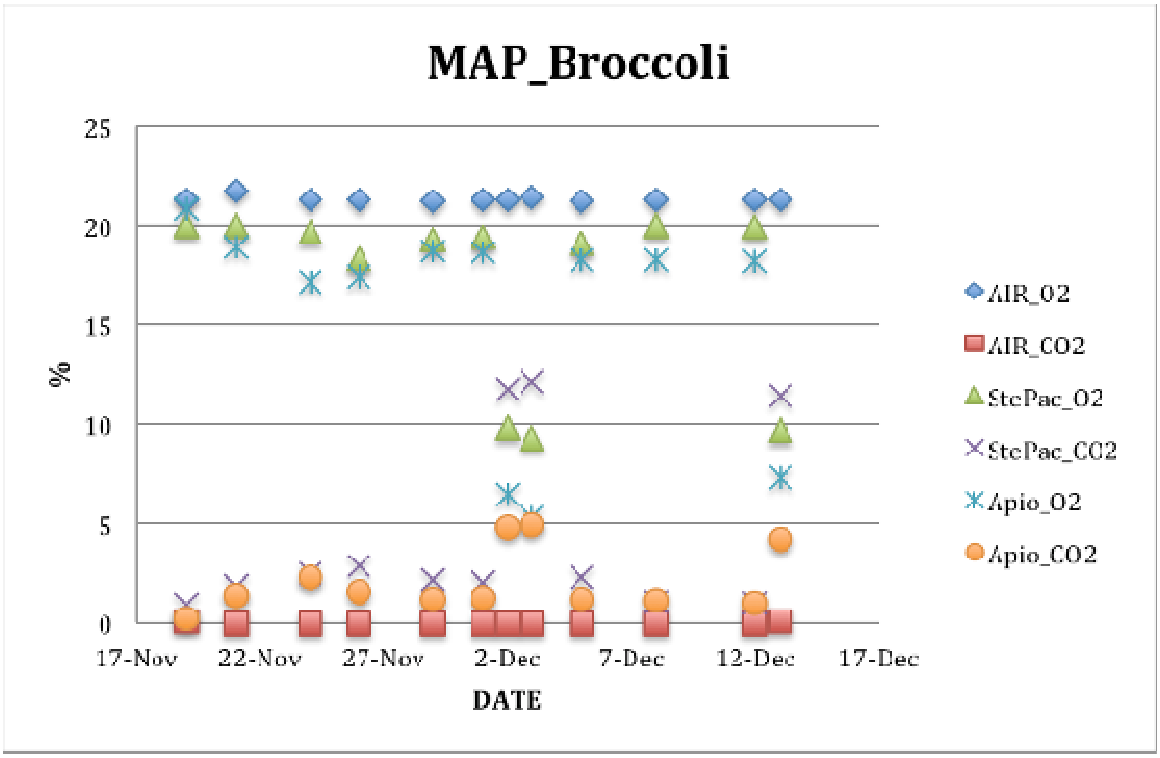


Figure 249. Atmospheres that were established during storage for 22 days at 33°F in two MAP systems (StePac and Apio) used for broccoli

AIR CONTROL



APIO BREATHEWAY



STEPAC XTEND

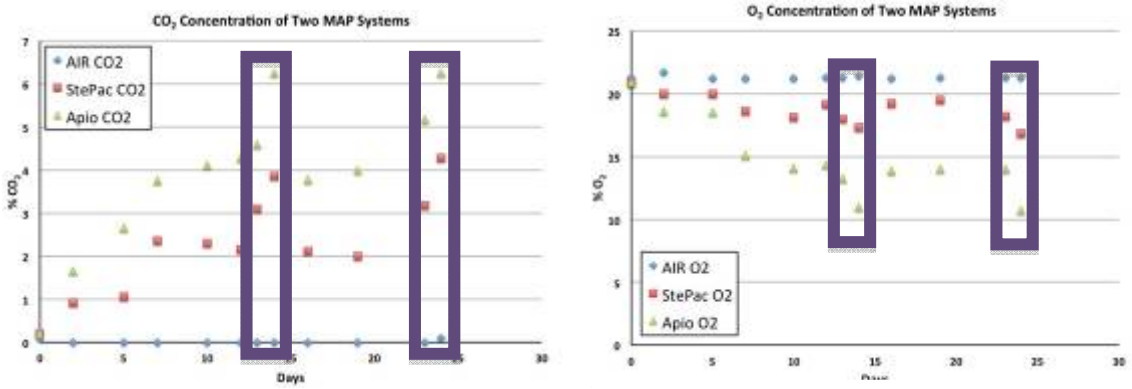


Figure 250. Appearance of broccoli stored in air, Apio Breatheway MAP or StePac Xtend MAP after 20 days at 33°F plus 2 days at 68°F

In follow-ups to the above experiments, we repeated the experiments with broccoli and Romaine lettuce comparing passive versus active MAP. Broccoli and lettuce were either immediately transferred into the Apio and StePac bags and stored at 33°F (passive MAP) or transferred into the Apio and StePac bags, which were flushed with the appropriate amounts of CO_2 and O_2 in order to initially create the most beneficial atmosphere for the products (2% O_2 plus 2% CO_2 for lettuce and 1% O_2 plus 10% CO_2 for broccoli; active MAP); the control was the product in the commercial packaging (without any MAP system) (Figs. 228 and 229).

Color changes, weight loss, chlorophyll fluorescence, vitamin C, chlorophyll a, chlorophyll b, total chlorophyll, total amino acids, and overall subjective visual quality were evaluated after 10 and 20 days of storage at 33°F plus 1 day shelf life at 68°F. Respiration rate and ethylene production were also measured at the times of evaluation.

Active MAP proved to be ineffective since neither MAP system equilibrated at the optimum atmospheres for the products at 33°F. For Romaine lettuce, the Apio MAP system equilibrated at 14% O_2 plus 4% CO_2 during storage at 33°F; after being transferred to 68°F, the Apio MAP established an atmosphere of 9% O_2 plus 6% CO_2, (Figure 251). The StePac MAP system equilibrated at 19% O_2 plus 2% CO_2 during storage at 33°F; after being transferred to 68°F, the StePac MAP established an atmosphere of 17% O_2 plus 4% CO_2 (Figure 251).



The highlighted data points represent days when storage temperature was 68°F. Storage temperature during all other days was 33°F.

Figure 251. Concentrations of CO2 (left) and O2 (right) during storage of Romaine lettuce in air or two MAP systems at 33°F and 68°F.

CO_2 injury of the lettuce (brown stain) was observed after 2 days at 68°F in both MAP systems (Figure 252). Leaf wilting was significantly reduced by MAP, but was a severe problem during 33°F storage in the control treatment and became worse after transfer to 68°F.



Figure 252. Brown Stain. CO2 injury in storage as shown by (A) healthy and (B) injured lettuce

6.3.3 MAP For Vine-Ripe Tomato

Tomato MAP experiments were conducted using pink ripeness stage 'Soraya' tomatoes obtained from a packinghouse in Ruskin, FL on the day of harvest. Three different atmospheres

were established at 55°F, 59°F and 64°F using Apio BreatheWay patches on impermeable trays with impermeable film covering (Figure 253). The MAPs were designed to establish equilibrium CO_2 concentrations 2 to 8% (Figure 254) by using holes with different diffusional areas in the sides of trays [6.35 mm (1/4 in), 12.7 mm (1/2 in) and 19.0 mm (3/4 in)]; the hole was covered by a BreatheWay patch.

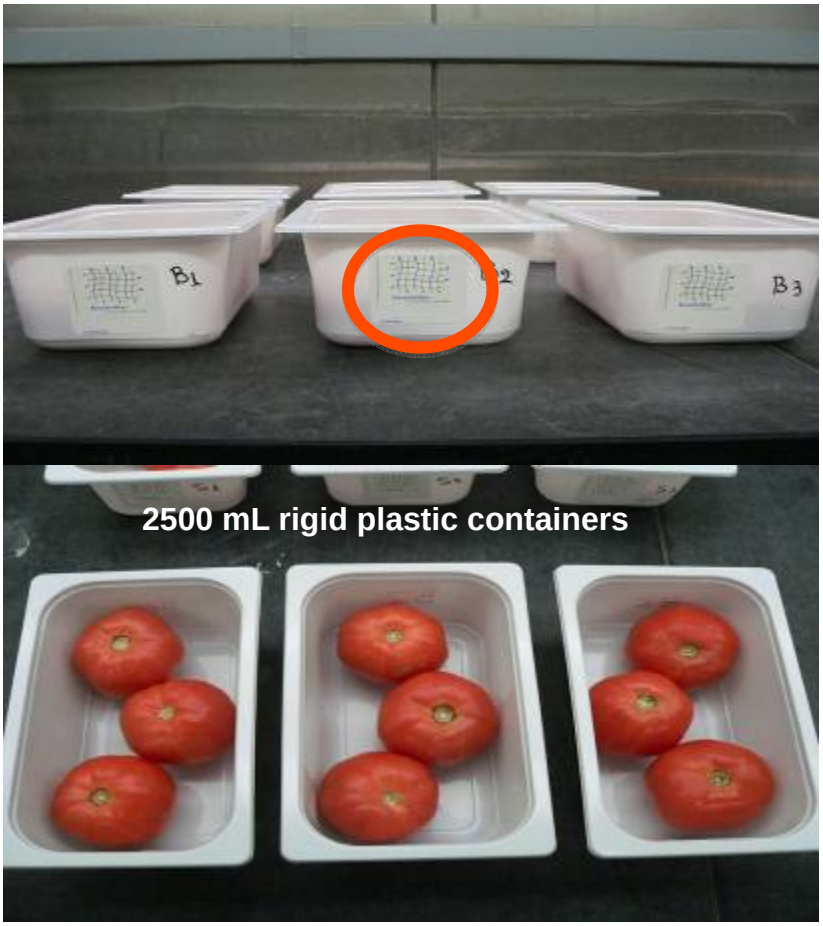
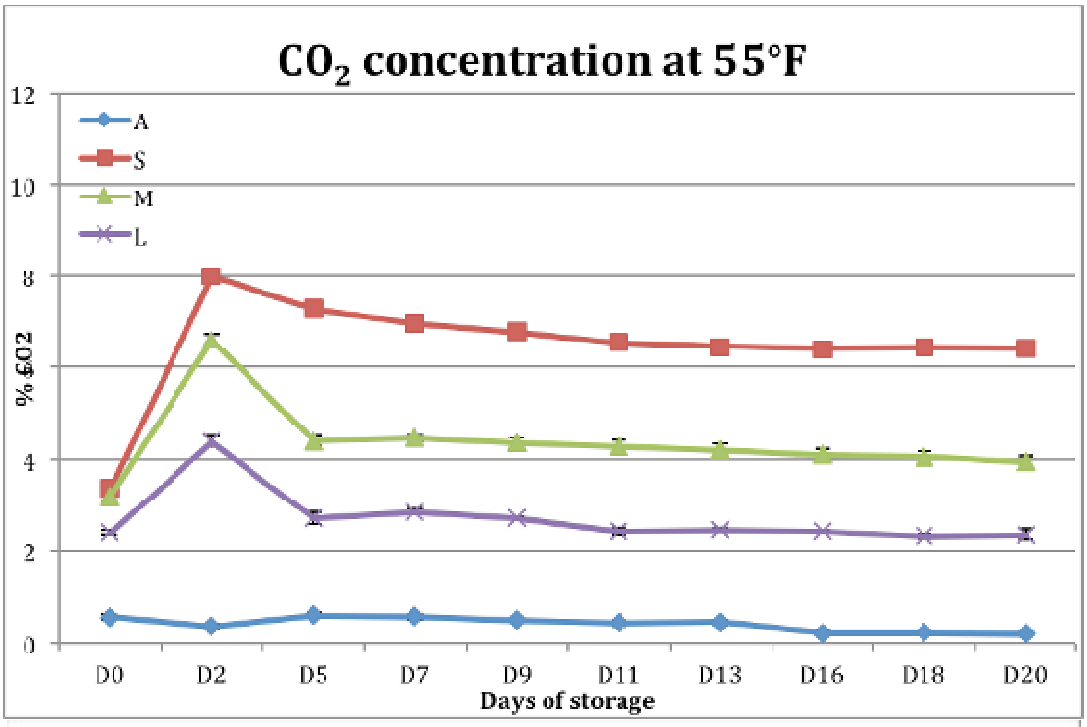
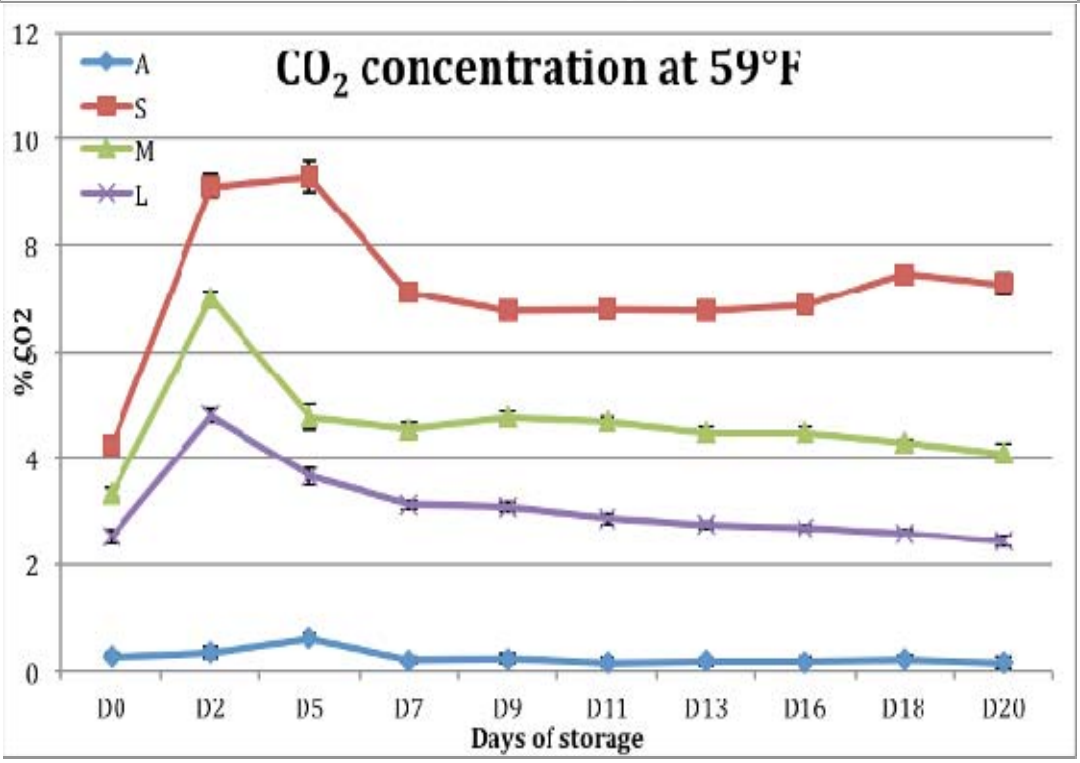
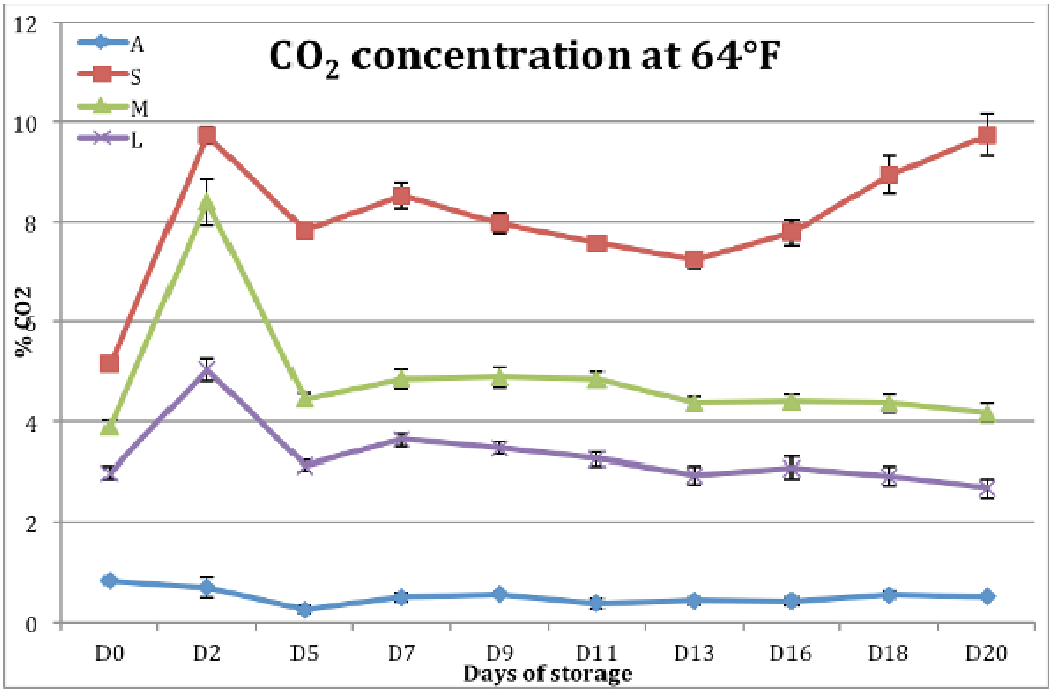


Figure 253. Side and top views of the Apio BreatheWay MAP packages containing tomato fruit; patches were attached over a hole in the side of an impermeable tray with impermeable film covering


CO_2 concentration at 55°F
12
10
8
4
2
0
% CO_2
A
S
M
L
D0
D2
D5
D7
D9
D11
D13
D16
D18
D20
Days of storage


CO_2 concentration at 59°F
12
10
8
4
2
0
% CO_2
A
S
M
L
D0
D2
D5
D7
D9
D11
D13
D16
D18
D20
Days of storage



(Key: A = air control, achieved by perforating the film lidding; S = small hole; M = medium hole; L = large hole)

Figure 254.Carbon dioxide concentrations in MAP for pink tomato during 20 days storage at 55, 59, and 64°F

Storing pink tomatoes in MAP that equilibrated at 6.5% CO_2 at 55°F resulted in visible severe CO_2 injury symptoms. Lower CO_2 concentrations at 55°F and none of the CO_2 concentrations at the higher temperatures caused injury.

Ripening, specifically color development, as shown by the pictures of fruit at 55°F in Figure 255 and the a* value (Figure 256), was progressively inhibited by higher CO_2 concentrations in the MAP and was almost completely inhibited for 20 days at the highest CO_2 concentrations (Figure 256).

A: 5 days in air at 55°F



B: 5 days in MAP with the smallest hole at 55°F



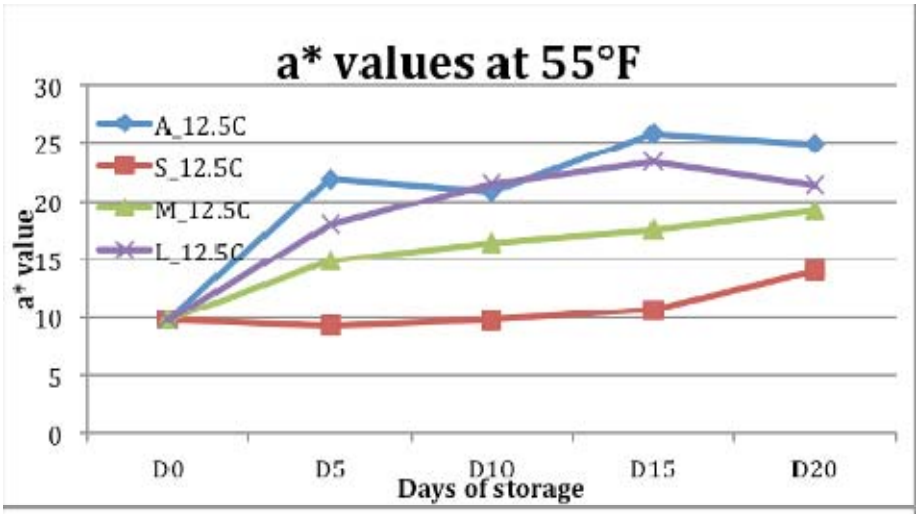
C: 20 days in air at 55°F

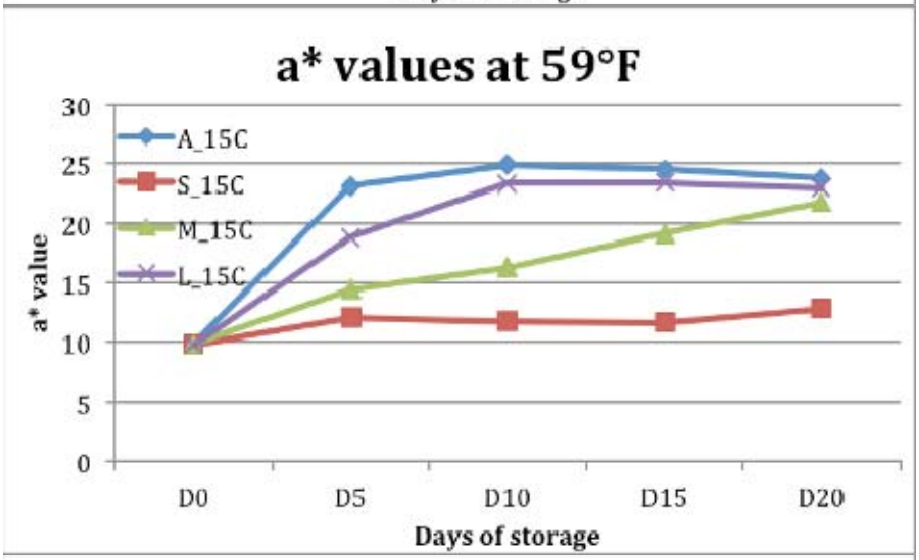


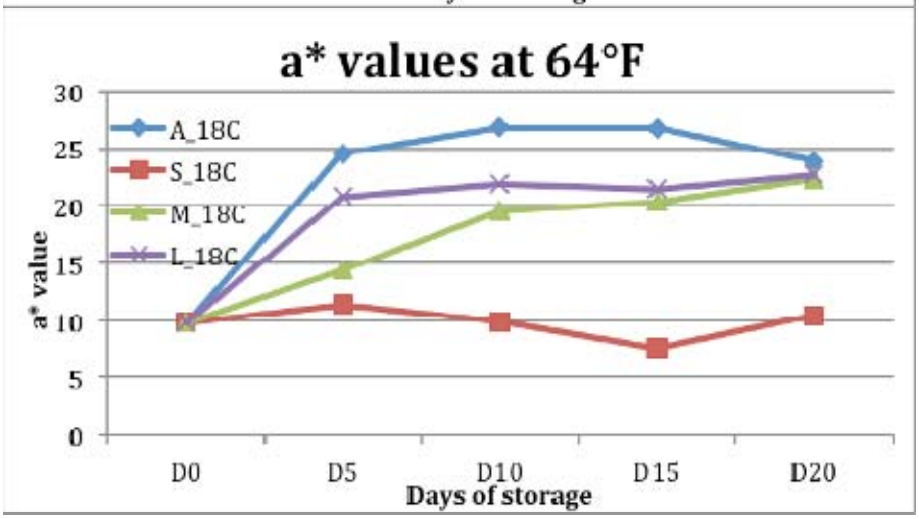
D: 20 days in MAP with the smallest hole at 55°F



Figure 255. Appearance of tomato fruit after 5 days of storage at 55°F in air (A) or containers with small (6.35 mm) holes (B) and after 20 days of storage at 12.5°C in air (C) or in containers with small holes (D)







(Key: A = air control, achieved by perforating the film lidding; S = small hole; M = medium hole; L = large hole)

Figure 256. Color (a* value) of pink tomatoes stored in MAP for 20 days storage at 55, 59, and 64°F

The highest CO_2 concentrations (6.5%) at the lowest temperature (55°F) resulted in visible severe CO_2 injury symptoms, but 4% CO_2 did not cause visible injury. Tomatoes stored at higher

temperatures with 7% or 8% CO_2 also showed no visible CO_2 injury symptoms and developed normal red color. Therefore, CO_2 tolerance of pink tomatoes at 55°F appears to be between 4 to 6% CO_2 and at least 7 or 8% CO2 at 59°F and 64°F, respectively. The best MAP and temperature combinations tested were effective in arresting the ripening process of pink tomatoes for 20 days and should be applicable to mixed load marine container shipping in the military supply chain.

6.4 Reducing The Adverse Effects Of Ethylene On FFV

To initiate our investigation of potential role of ethylene in broccoli and Romaine lettuce outturn problems, we calculated the maximum ethylene concentration that could be expected to accumulate in the mixed load marine containers. We evaluated the potential benefits of ethylene scrubbing with potassium permanganate and ethylene action inhibition by 1-methylcyclopropene (1-MCP; SmartFresh™) using a concentration of ethylene (0.6 ppm) that we judged to be quite high for the mixed load combinations of which we were aware. [Preliminary testing with aminoethoxyvinylglycine, (AVG) indicated lack of uptake by intact products when the chemical was applied in aqueous dips. Thus, AVG was not included in this research.]

Two experiments were conducted in which broccoli and Romaine lettuce heads at typical commercial maturity were stored at 33°F as in current DoD practice; the lettuce and the broccoli were stored for 35 days. The treatments included the product in air with or without 0.6 ppm ethylene and with and without 1-MCP, as well as both ethylene and 1-MCP applied. There were no apparent effects of 1-MCP or ethylene during these experiments and both the broccoli and Romaine lettuce were judged to be of acceptable quality at the end of the storage periods.

To further investigate the potential effect of ethylene produced by cross-contamination in mixed load containers on broccoli and Romaine lettuce we conducted the CA experiment described in Section 6.2 with the addition of 0.1 ppm ethylene throughout the 20-day simulated marine container shipping period. The ethylene concentration that was used was selected based on calculating the amount of ethylene likely to be produced by two, 16-lbs cartons of plums in a mixed load container with broccoli and Romaine lettuce. The results, after the visual quality evaluation, suggested that the amount of ethylene applied did not affect the quality of broccoli and Romaine lettuce (data not shown).

These results indicated that the use of ethylene scrubbing is probably not necessary during the mixed load transport of broccoli and Romaine lettuce. We therefore did not conduct any further experiments involving ethylene scrubbing or inhibition of ethylene action.

Different MAP systems for broccoli, Romaine lettuce, and pink stage tomato were tested for their ethylene permeability at 68°F with results shown below in Table 47. The two systems tested were Breatheway® Membrane Technology from Apio Inc. (California, USA) and MAP bags from StePac L.A. Ltd (Israel).

Table 47. Permeability of different MAP systems to ethylene

MAP manufacturer	Produce commodity	Effective ethylene permeability (cc/100 in^2/day)*
Apio	Broccoli	0.0520
	Romaine lettuce	0.0145
	Vine ripe tomato	18.104
StePac	Broccoli	0.0410
	Romaine lettuce	0.0141
	Vine ripe tomato	0.062

*Film permeability is usually expressed per mil film thickness.

The ethylene permeability rates were extremely low compared with typical MAP film permeability for oxygen and carbon dioxide, which are typically on the order of 10,000-fold higher than the ethylene permeability rates that we measured. The ethylene permeability rates for the broccoli and Romaine lettuce MAP systems from the two suppliers were very close. Ethylene permeability of the Apio tomato MAP was the highest of the MAP systems measured, but still relatively low compared with typical permeability values for oxygen and carbon dioxide, which are 25 or more fold higher (e.g., around 500 cc/100 in^2/day oxygen permeability for 1-mil thickness LDPE film). These results suggest that cross-contamination by ethylene within mixed container loads of produce in MAP may not be a serious problem. The MAP can serve to both protect sensitive products from exogenous ethylene and to retain endogenously produced ethylene within MAP containing ethylene producing products.

6.5 Conclusions And Recommendations

Broccoli and Romaine lettuce

Broccoli and Romaine lettuce are similar in their postharvest behavior and postharvest requirements. For both products, proper temperature management is paramount for maintenance of quality after harvest. CA and MAP provided only marginal improvement in product quality over that provided by proper temperature management alone, with CA showing slight benefit only when the products were exposed to higher than optimal temperature prior to application of CA. However, overcoming the effects of improper temperature management should not be considered a valid reason for using CA or MAP. Ethylene at levels that may be reasonably expected to occur in the mixed load shipments being used does not appear to be a significant factor affecting broccoli or Romaine lettuce quality.

We conclude from our research that broccoli and Romaine can maintain excellent quality within the military supply chain in the Pacific region with proper temperature management alone, i.e., without need for MAP or ethylene removal. A caveat to that conclusion is that the time that the

product has been in the supply chain prior to shipment can potentially result in insufficient remaining postharvest life for successful outturns.

Recommendation: We recommend that in addition to the current specifications for broccoli and Romaine lettuce, maximum allowable time and temperature prior to delivery for loading into marine containers should be addressed. For both products, precooling should be done within 2 hours of harvest and should achieve a uniform product temperature of no higher than 35°F. After that, the products should be handled at no higher than 34°F for no longer than 10 days from the day of harvest to the day of container loading. A shipping temperature of 33°F should continue to be used. Upon arrival at the destination, the products should be handled at 41°F or lower and be used or disposed of within 5 days.

Vine ripe tomato

Vine ripe tomatoes at the pink (USDA Stage 4) ripeness stage are chilling sensitive, and a temperature of 45°F is widely recommended as the lowest safe temperature to avoid chilling injury. However, this recommendation is based on research showing that no visible chilling injury symptoms develop when pink tomatoes are exposed to 45°F, but which did not consider the taste of the fruit. In fact, more recent research has shown and our research in this project has confirmed that temperature below 68°F inhibits development of aroma compounds that are critical components of tomato flavor.

We conclude from our research that the taste of vine ripe (pink) tomatoes handled in the military supply chain in the Pacific region is being compromised by the 45°F shipping temperature currently being used. A higher shipping temperature would allow the tomatoes to develop better flavor in terms of aroma, but a higher temperature would also result in reduced postharvest life. MAP can overcome the negative effect of higher shipping temperature on shelf life by slowing ripening and thus extending shelf life without compromising the tomato flavor. We found that pink tomatoes tolerate at least 4 % CO_2 at 55°F at least 7 or 8% CO_2 at 59°F or 64°F.

Recommendation: Vine ripe tomatoes at the pink (USDA Stage 4) ripeness stage should be handled at a minimum of 55°F throughout the postharvest period and shipped at 55°F in MAP that produces an atmosphere with 4% CO_2 plus not less than 4% O_2, which will result in the best combination of extended shelf life while minimizing chilling-induced flavor loss. It should be specified that pink tomatoes must not be exposed to temperature below 55°F at any time prior to container loading. Upon arrival at the destination, the products should be handled at 68-72°F to allow completion of ripening, including aroma development and be used or disposed of within 5 days.

References

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Kader, A.A. and Chordas, A. 1984. Evaluating the browning potential of peaches. Calif. Agr. 38(3&4):14-15.

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7 Final Budget

These are the Life-to-Date (04/01/11 – 09/30/13) cumulative budget figures by major budget category. The final figures, including detailed transaction history, will be included on the final public cost voucher to be submitted through WAWF.

Please direct financial inquires to Jonathan Evans at jonevans@ufl.edu.

		Life to Date Cumulative
Major Cost Elements: 04/01/11 – 09/30/13		
	Salaries	$322,066.58
	Fringe Benefits	$65,117.86
	Materials & Supplies	$29,515.76
	Other Expenses	$1,201,772.23
	Travel	$7,665.45
	Equipment	$86,347.52
Total Direct Costs:		$1,712,485.40
Overhead @48.5 MTDC		$231,279.79
Total Amount Claimed:		**$1,943,765.19**
Total Contract Amount:		**$2,079,548.00**
Residual:		**$135,782.81***

*This amount reflects final invoicing yet to be received from the subcontractor.

7.1 Equipment Record

Description	Cost	Location*
ETS Lindgren 5240 Table top test enclosure/Anechoic chamber	$8,263.00	USF-EEN
Codesource/Identec RFID handheld reader	$8,022.64	USF-EEN
National Instruments RF Downconverter	$9,899.10	USF-EEN
National Instruments IF Transceiver	$6,929.10	USF-EEN
National Instruments 2.7 GHz RF Upconverter	$8,549.10	USF-EEN
Environmental chambers (5)	$63,276.85	USF-BIO
Spectrophotometer/micro plate reader	$18,947.74	USF-BIO
Minolta chromameter	$8,382.15	USF-BIO
Centrifuge	$9,450.00	USF-BIO
Ice maker	$5,147.23	USF-BIO
Gas mixing boards (5)	$70,035.52	UF-HOS
Gas handling system (pressure regulators, manifolds, mounting racks)	$9,664.00	UF-HOS
Minolta chromameter	$5,812.00	UF-HOS
Gerstel GC-MS autosampler	10,500.00	UF-HOS
Total	**$**	

*UF-HOS = Horticultural Sciences Department, University of Florida, Gainesville, FL; USF-EEN and USF-BIO = Department of Electrical Engineering and Department of Cell Biology, Microbiology and Molecular Biology, respectively, University of South Florida, Tampa, FL.

8 Overall Conclusions

This report covers Phase II of the project, Remote Environmental Monitoring and Diagnostics in the Perishables Supply Chain. In Phase I, using wireless temperature sensors, remote monitoring (RFID), algorithms, and diagnostics, it was demonstrated that FSR shelf life can be automatically calculated in real time using web-based computer models and a fully functional prototype RFID system was developed as a result of extensive testing. Intelleflex tags were selected because they showed high accuracy in both temperature accuracy and environmental simulation tests, had a longer communication range than other tested tags, and were based on a class 3 communication protocol, making them future-ready in terms of adaptability to other systems and RFID readers.

In Phase II we validated two RFID front end systems (Caen and Intelleflex) and the shelf life algorithm for FSR developed in Phase I. After successful validation, both RFID systems were updated with two major additions: 1) remote server database access and storage for temperature and shelf life data, and 2) data processing algorithms for enhanced shelf life prediction and smart cold chain logistics. Furthermore, both systems were programmed with a new shelf life model for MRE rations in addition to the existing FSR model. It is important to note that development of different tag-reader systems from the two manufacturers was completed simultaneously for two main reasons. First, the compatibility of the back-end system (the REMS database) was proven by successfully interfacing it to two different front-end hardware systems. Compatibility is important because it provides flexibility when choosing an RFID enabled wireless sensor system, as the technology keeps improving due to developments in low power electronics, as well as readers and tags with higher sensitivities resulting in significant increases in communication range. Second, since the overall market for RFID-enabled shelf life monitoring is still in its early stages compared to more mature technologies, having two different operational front-end systems will provide a more robust and safer list of options for any possible future adoption. Nevertheless, as far as project requirements are concerned, both systems are completely viable options, whereas the Intelleflex system has the slight advantage of improved communication range when their tags are coupled with their own HMR-9090 handheld readers.

Development of reliable predictive models for combat rations presents unique challenges related to multiple ration components, menu changes, different suppliers, use of performance-based product formulation, and highly variable and extreme operating environments. These issues notwithstanding, the quality and shelf life of selected FSR and MRE menu items when exposed to extreme ambient temperatures was determined using measurements of the physical and compositional characteristics of the products and evaluation of the sensory quality. The results of these measurements and evaluations provide invaluable information on the rate of FSR/ MRE physical and chemical deterioration when exposed to adverse conditions. The quality and shelf-life determinations also provided data for development of algorithms to iterate each quality factor for each FSR and MRE menu item with specific time increments. The algorithms were validated and calibrated, and software was developed for models to predict remaining shelf life from a handheld reader.

Simulation of mixed marine container loads of FFV within the Pacific region showed that outturn problems with broccoli and Romaine lettuce shipped at 33°F are probably not related to inherently limited shelf life or to exposure to ethylene produced by other products. Rather it is critical to know the time and temperature history of broccoli and Romaine lettuce before accepting those products for such shipments. It was also shown that the quality of vine ripe tomatoes in mixed marine container loads of FFV within the Pacific region can be improved by using a higher shipping temperature of 55°F instead the currently specified 45°F as long as the tomatoes are handled in an appropriate MAP.

As a result of these efforts, the NSRDEC Combat Feeding Directorate now has an improved RFID- based portable solution to monitor and track the environmental temperature, to accurately estimate the remaining shelf life of FSR and MRE rations, and the tools to efficiently utilize this data, as well as guidelines to improve the quality of FFV within the military supply chain.

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Appendix A – System Specification Sheets



Intelleflex TMT-8500

Temperature Monitoring Tag

- Temperature monitoring for perishable foods and pharmaceuticals
- Reliable reads/writes at 100m or without unpacking
- Onboard memory stores 3,600 temperature samples
- Two year battery life — based on typical use cases
- Based on ISO and EPCglobal standards

The Intelleflex TMT-8500 Temperature Monitoring Tag is an XC3 Technology™ RFID tag that combines high sensitivity temperature sensing functionality with ISO standards-based RFID wireless communications. This combined functionality provides market leading visibility, efficiency and improved ROI for perishable foods and pharmaceutical cold chain management by enabling solutions that leverage the benefits of RFID (including real time data access, long range reads, and autonomous data collection with no line of sight restriction) without impacting existing business processes.

The TMT-8500 is based on the ISO C3 (ISO 18000-6.1 C Chapter 11) and EPCglobal Gen 2 Class 1 protocols, with extended memory (60kbits) for data storage, and a microcontroller temperature sensing application. Support for the ISO and EPCglobal protocols enables the TMT-8500 to provide extended RFID capabilities including enhanced read/write sensitivity equating to read ranges in excess of 100 meters, superior battery power management and the full functionality and configurability of a microcontroller-based temperature sensing application.
The TMT-8500 is configurable for both single use and multiple-use applications.

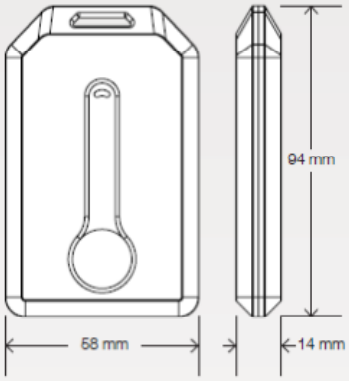
Product Features

RF Interface	ISO 18000-6.1 (Manchester BAP), EPCglobal C1G2
Read Range	100 meters or more in free space in ISO Class 3 mode. Global read support (except for Japan)
Security	User Access, Block Memory Access, Air Interface and Tag Authentication security layers
Memory	Standard EPC tag ID memory plus 60 kbits of extended memory for Sensor, User and WayPoint Data – configurable by the end user. Up to 3,600 temperature samples that can be logged in the sensor memory
Sampling Interval	User configurable from one (1) minute to five (5) days
Start Sample Time	User configurable: selects a time offset delay to start data logging from initial button press or set a specific date and time to start data logging

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Alarms	Four (4) configurable thresholds: Two user configurable high temperature and two low temperature alarms	
Logging Modes	Multiple data logging modes for increased storage capacity and increased monitoring time	
Temperature Range	The operating temperature measurement range is -30ºC to +70ºC (-22ºF to +158ºF)	
Temperature Accuracy	The maximum temperature measurement error variance is indicated in the table below	
	Temperature Range	**Allowable Variance**
	-22ºF to 0ºF (-30ºC to -18ºC)	±2ºF (±1.1ºC)
	0ºF to +122ºF (-18ºC to +50ºC)	±1ºF (± 0.5ºC)
	+122ºF to +158ºF (+50ºC to +70ºC)	±2ºF (±1.1ºC)
Temperature Resolution	0.1ºC (1/10th degree) over full temperature range	
Compliance	NIST, FAA	
Clock Accuracy	Real-time clock and timer accuracy of ±1 minute/month	
Battery/Battery Life	3V Lithium battery, UL rated; meets UN Part III, sub-section 38.3 test criteria. Two year battery life — based on typical use cases	
SLPM	Shelf Life Prediction Modeling (SLPM) capability at multiple levels of sophistication are supported, from generic and custom on-tag calculations to sophisticated analytics using software APIs	
Environmental Specifications	**Environment**	**Tolerance**
	Operational Temperature	-30ºC to +70ºC (-22ºF to +158ºF)
	Storage Temperature	-30ºC to +80ºC (-22ºF to +176ºF)
	Vibration	IEC 60068-2-36
	Shock (drop)	IEC 60068-2-32
	Dust / Water	IP67
Interface	Single dual color (red and green) LED and single button for user control and tag status	
Size & Weight	94mm H x 58mm W x 14mm D (3.7" H x 2.3" W x 0.55" D) & 45g	
Packaging	FDA Compliant packaging available	

Design



For More Information

To learn more please visit our website or contact us directly. We look forward to hearing from you.

www.intelleflex.com

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+1 408 200 6500 International/Direct

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Intelleflex HMR-9090

Handheld Barcode/ RFID Reader

- Industry-leading read/write reliability and performance
- Works with Intelleflex tags to monitor temperature and other conditions inside pallets and containers—without unpacking
- Support for ISO/IEC 18000-6 and EPCglobal C1G2 standards
- Rugged, ergonomic design
- Exceptional ease of use

The Intelleflex HMR-9090 multi-protocol handheld RFID reader provides superior performance and read/write reliability for a wealth of applications. Built with Intelleflex XC3 Technology™, it supports ISO/IEC 18000-6 and EPCglobal C1G2 industry standards. It delivers the ability to read/write in RF-challenging environments including metals, liquids and inside packaging and containers.

With the HMR-9090, your mobile workers have a comprehensive on-demand data capture solution that delivers real-time connectivity for mission critical business applications in warehouses and loading docks, as well as worksite or in-transit environments. With the HMR-9090 and Intelleflex Extended Capability RFID™ tags, you can reliably read and monitor temperature history inside pallets of perishable foods or pharmaceutical packaging—without unpacking or opening the container.

- Perishable food producers, packers, shippers and retailers can easily and cost-effectively track and monitor the temperature of produce on-demand to maximize shelf life and improve quality.
- Pharmaceutical and biologics companies can monitor the temperature inside packaging and containers in transit every step of the way between the factory and the customer to ensure product integrity, efficacy and quality.
- Construction, harvesting and shipping companies can easily monitor assets and products in the field.

The HMR-9090 supports wireless printing and headsets while the ergonomic design provides comfort in scan intensive applications. The HMR-9090's flexible network connectivity and discovery capabilities enable easy integration into existing networks. The multi-user/multi-tasking software supports multiple simultaneous sessions so that applications can interact with the reader, greatly simplifying both system and application design.

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Product Features

Advanced Design	**High Monostatic Receive Sensitivity** High read/write accuracy in very challenging RF environments	
	FPGA with Embedded Processor Custom designed for high sensitivity; field upgradeable	
	Maximum Transmit Output Power Maximum range with passive tags	
	Low Power Consumption Suitable for handheld terminal use	
Standards	**EPCglobal C1G2** Global interoperability with passive tags	
	ISO/IEC 18000-6 Manchester battery assisted passive tags have range over 100 meters	
Configurability	**Multiprotocol** Reader supports C1G2 tags and high performance ISO Class 3 tags	
	Performance Profile Tuning Enables performance tuning for speed, range, or balanced mix	

Specifications

Physical Characteristics	**Dimensions**	10.75" L x 4.7" W x 7.7" H (27.3 cm x 11.9 cm x 19.5 cm)
	Weight	35.4 oz / 1 kg (includes battery, scanner, and radio)
	Keyboard	53-key; Terminal Emulation (5250, 3270, VT)
	Display	QVGA color
	Power	Removable, rechargeable 7.2 volt Lithium Ion 2200 mAh battery pack, 15.8 watt hours
Processor Characteristics	**CPU**	Intel® XScale™ Bulverde PXA270 processor at 624 MHz
	Operating System	Microsoft Windows Mobile 5.0/6.1 Premium Edition
	Memory (RAM/ROM)	64 MB/128 MB
	Application Development	PSDK, DCP, and SMDK available through Motorola Developer Zone



The HMR-9090 supports the Intelleflex Family of Tags:

- STT-8000
- SMT-8100
- SXT-8110
- TMT-8500
- BAT-8300

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Processor Characteristics (continued)	**Bar Code Options**	2D imaging engine reads symbologies and captures grayscale images and signatures with intuitive laser aiming
User Environment	**Operating Temperature**	-4° F to 122° F / -20° C to 50° C
	Charging Temperature	32° F to 104° F / 0° C to 40° C
	Storage Temperature	40° F to 158° F / -40° C to 70° C
	Humidity	5% to 95% condensing
	Drop Specification	Multiple drops to concrete: 6 ft/1.8 m across the operating temp range
	Tumble	2000 one-meter tumbles at room temperature (4000 hits)
	Environmental Sealing	IP64 (electronic enclosure, display, and keypad)
	Electrostatic Discharge	+/-15 kVdc air discharge; +/-8 kVdc direct discharge; +/-8 kVdc indirect
RFID	**Standards Supported**	EPCglobal C1G2, ISO/IEC 18000-6 (Manchester mode BAP)
	Nominal Read Range (C1G2)	0.2 ft to 10 ft / 6 cm to 305 cm
	Nominal Read Range (C3)	0.2 ft to 100 ft / 6 cm to 30 m
	Nominal Write Range (C1G2)	1 ft to 2 ft / 30 cm to 61 cm
	Nominal Write Range (C3)	0.2 ft to 50 ft / 6 cm to 15 m
	Field	70-degree cone (approx.) measured from nose of device
	Antenna	Integrated, linearly polarized
	Frequency Range	US: 902-928 MHz; Europe 865.7-867.5 MHz
	Output Power	US: 1 W (2W EIRP); Europe 0.5 W
	C1G2 PIE Forward Link Tari	25 - 6.25 usec
	C3 Manchester Forward Link Rates	8 - 128 Kbps
	Miller Backscatter Link Frequencies, M Ratio	BLF: 80 - 320 KHz, M: 4 – 128
	Reverse Link Data Rates (BLF/M)	2.5 – 80 Kbps



The TMT-8500 Temperature Monitoring Tag provides the ability to access temperature data on-demand without unpacking pallets or opening containers.

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Wireless Data Communication	**WLAN**	802.11 a/b/g
	Output Power	100 mW (US, International)
	Data Rate	Up to 54 Mbps
	Antenna	Internal
	Frequency Range	Country dependent (802.11a-5 GHz, 802.11b/g-2.4 GHz)
	PAN (Bluetooth Support)	Bluetooth Version 1.2 with BTExplorer (manager) included
Peripherals and Accessories	**Cradles**	Single-slot serial/USB, 4-slot Ethernet, 4-slot charge only
	Printers	Supports extensive line of printers and cables
	Charger	4-slot universal battery charger
	Other Accessories	Cable adapter module; snap-on magnetic stripe reader; modem module; full set of cables
Regulatory	**General**	Approved for use in the United States; additional countries in process
	Electrical Safety	Certified to UL60950-1, CSA C22.2 No. 60950-1, IEC 60950-1
	EMI/RFI Radio Versions	US: FCC Part 2 (SAR), FCC Part 15, RSS210 Europe: EN 301-893, EN 300 328, EN60950-1
	Laser Safety	IEC Class 2/FDA Class II in accordance wi/IEC 60825-1, 21CFR1040.10
Warranty	The HMR-9090 is warranted against defects in workmanship and materials for a period of one year (12 months) from date of shipment, provided the product remains unmodified and is operated under normal and proper conditions	

Ordering Information - FPO

Part Number	Description
HMR-9090 RFID Reader	HMR-9090 RFID Reader; North America 902 – 928 MHz frequency band

Specifications are subject to change without notice.

For More Information

To learn more please visit our website or contact us directly. We look forward to hearing from you.

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CAENRFID
THE ART OF IDENTIFICATION

easy2log®

CAEN A927Z
Gen2 RFID Temperature Logger



Key features

- EPC C1G2/ISO18000-6C compatible
- Frequency range: 860 MHz ÷ 928 MHz
- Read range: approx. 10m in air (2.5m on metal) @ 2W ERP
- Unique ID plus long EPC code (512 bit)
- Memory capacity: 8000 samples (16 kbyte)
- Programmable sampling interval
- Programmable temperature thresholds
- Battery life: 3 or 5 years (see ordering options)
- Temperature range: -20°C to +70°C
- Accuracy:
  0.1°C @ -10°C to +40°C,
  0.2°C in outer range
- Dimensions: 130.4x23.4x12.7 mm^3
- Battery charge measurement through RF

Temperature samples can be retrieved with standard dock-door or mobile Gen2 UHF RFID readers!

easy2log® can be easily customized for special requirements in terms of sampling modes, product health algorithms, rest of life prediction algorithms, additional sensors and so on.*

* Only for orders of a minimum lot of production.

CAEN RFID's easy2log® Temperature Logger (Mod. A927Z) is a low cost, semi-passive UHF tag that allows to monitor temperature sensitive products during transportation or storage.

Being compliant to the EPC C1G2/ISO18000-6C standards, easy2log® can be used with most of the Gen2 UHF RFID readers available on the market without requiring any additional equipment.

The Logger is configurable either in Continuous or Over-Threshold logging modes, allowing the storage of up to 8000 temperature samples with programmable sampling time. Once programmed, the tag will start to monitor the life of your temperature sensitive product, thus allowing to identify any problems occurred along the whole cold chain by just performing an inventory cycle.

Its low cost, small footprint, robust design and long battery lifetime (3 or 5 years versions available) allow easy2log® to be not only a pallet-tag but also a case-tag, giving a very localized measurement of the temperature (monitoring of different areas of interest within a single cargo).

WORKABOUT PRO

Specifications



Weight: (w/o battery)
1 lb (455 g)

Weight: (w/o battery)
0.86 lb (390 g)

Model Variants
- WORKABOUT PRO C - Model 7527C-G2
- WORKABOUT PRO S - Model 7527S-G2

Platform
- PXA270 520 MHz, 32 bit RISC CPU
- 256 MB Flash ROM
- 128 MB RAM

Operating System
- Windows® CE 5
- Windows Mobile® 6 Classic, Professional

Wireless Communications
Optional expansion modules for:
- 802.11a/b/g Compact Flash Radio available on C model
- 802.11b/g Compact Flash Radio available on all models
- GPRS EDGE – 850/900/1800/1900 Voice and Data
- 3G HSDPA – 850/1900/2100MHz Voice and Data
- Integrated Bluetooth® Class II, V 2.0 + EDR
- Note: All expansion modules are available factory configured or user installable

Barcode Applications
- ID laser scanning in standard range, long range, and auto range configurations
- 1D linear imager
- 2D area imager
- Optional bolt-on pistol grip

RFID Module Options
- HF Module
  Frequency: 13.56 MHz
  Tags supported: ISO 15693, Philips® ICode™; TI Tagit™; Tagsys (C210, C220, C240, C270)
  Read/write range up to: 3.15 in (8 cm)
- MIFARE™ module
  Frequency: 13.56 MHz
  Tags supported: ISO 14443 A&B, MIFARE™
  Read/write range up to: 1.97 in (5 cm)
- LF module
  Frequency: 125 KHz, 134.2 KHz
  Tags supported: EM 4x0x, EM 4x50; Hitag 1 & 2; ISO HDXA & FDXB
  Read/write range up to: 2.76 in (7 cm)
- UHF module
  Frequency: 868 MHz or 915 MHz
  Tag supported: EPC Class 1 Gen 2, other protocols depending on regions
  Read range up to: 98.425 in (250 cm)



External Connectors
- One tether connection with full RS232 and USB On-The-Go (USB 1.1) functionality
- One Low-Insertion Force (LIF) docking connector
- DC Power Jack

User Interface
- Color / Touch display
  3.7 in (9.398 cm)
  Full VGA 480 x 640 resolution
  Transflective, portrait mode TFT
  Sunlight readable (for outdoor use)
  High-reliability adjustable LED Backlight featuring a bright 165 cd/m2 output
- Touchscreen (standard)
  Passive stylus or finger operation
  Signature capture
- Keyboards
  Full alpha-numeric (C model)
  Numeric (S model)
  Backlit, high durability hard-capped keys
- Audio
  90 db mono speaker
  Mono microphone
  86 db beeper standard
  95 db beeper w/ auto range laser

Programming Environment
- HTML, XML
- Psion Mobile Devices SDK
- Hardware Development Kit (HDK)
- .NET and C++ programming using Microsoft® Visual Studio® 2005
- Java programming supporting JDK 1.2.2 or higher
- Standard Protocol APIs Windows® sockets (CE.net)



Application Software
- Internet Explorer® 6.0
- Psion Voice Dialer and Contacts Manager incl. Windows® CE 5
- PTX Connect VoIP
- Terminal emulation software, supports IBM 5250, IBM 3270, HP2392, ANSI and TESS
- Mobile Control Centre (MCC) device management

Expansion Slots
- One SD/MMC memory card slot
- End-cap USB Interface supports GPS expansion module.
- 100-PIN expansion interface: supports PCMCIA (type II), GPRS/EDGE and other third-party expansion modules developed using Psion Hardware Developer's Kit.
- Flex cable interface supports scanner (serial) and imager (USB) modules
- One Type II CF Card Slot

Power Management
- Optional 3.7V, 3300 mAh standard capacity battery
- Optional 3.7V, 4400 mAh high capacity battery
- Advanced smart battery with gauge
- Built in charger
- Rechargeable, user replaceable backup battery pack

Environmental
- Withstands multiple drops from 6 ft (1.8 m) or 26 drops (on 12 edges, 6 corners, 8 faces) from 5 ft (1.5 m) to concrete while powered on and configured with accessories such as WiFi radio, scanner / imager and pistol grip.
- Rain/Dust: IP65, IEC 60529
- Operating temperature: -4°F to 122°F (-20°C to +50°C)
- 5%-95% RH non-condensing
- Storage temperature: -40°F to 140°F (-40°C to +60°C)
- ESD: +/- 8kVdc air discharge, +/-4kVdc contacts

Physical Dimensions
- WORKABOUT PRO C:
  8.78" x 2.95"/3.94" x 1.22"/1.65"
  (223 mm x 75/100 mm x 31/42 mm)
- WORKABOUT PRO S:
  7.87" x 2.95"/3.94" x 1.22"/1.65"
  (200 mm x 75/100 mm x 31/42 mm)

Approvals
- Safety: CSA/UL60950-1, IEC 60950-1, EN60950-1
- EMC: FCC Part 15 Class B
  EN 55022
  EN 55024
  EN301 489
- Laser: IEC 60825-1, Class 2
  FDA 21 CFR 1040.10.
  1040.11 Class II
- Bluetooth®: 1.2
- In Vehicle Cradle: e Mark

A complete list of accessories is available at: www.psion.com

Product is ROHS Compliant.

* Note this product will carry the CE Mark.
* Specifications are subject to change without notice.

WORKABOUT PRO

For more information, please visit www.psionteklogix.com

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The V-Tag Model INF-VT-SEN-150 is a compact active RFID tag for:

- Real Time Location System (RTLS)
- Temperature
- Humidity
- Shock
- Battery level

Real Time Location is accomplished by setting up a virtual boundary of fixed tags attached to walls, fences and posts around the location being monitored. The moveable tags then calculate their own positions based on the signals received from the fixed tags and from other neighboring tags. Tags may be configured as either fixed or moveable using software commands.

Specification Sheet
Model INF-VT-SEN-150

V-Tag Model INF-VT-SEN-150

Dimensions	2.75in x 2.25in x 0.75in
Real Time Location System	Typical RTLS Accuracy: 10 feet indoors, 20 feet outdoors. The accuracy is influenced by the spacing of the fixed tags and the total number of tags deployed.
Temperature	–50°C to +85°C with accuracy of ±1.5°C
Humidity	0%RH to 100%RH with accuracy of ±3.5%RH
Shock	3-axis coverage 0g to 120g with accuracy of ±5g
Battery Level	Accuracy of ±0.003V
Latency	Immediate alert messages for sensors threshold events. Maximum latency for shock threshold event message is 50ms after event. Maximum latency for bounding box departure event message is 15 seconds after event. Maximum latency for humidity threshold event message is 15 seconds after event. Maximum latency for temperature threshold event message is 15 seconds after event. Maximum latency for battery level threshold event message is 1 hour after event.
Reporting	User selectable for data logging purposes. The default reporting interval is 1 hour allowing network sizes of up to 2,000 tags. The minimum reporting interval is 15 minutes allowing network sizes of up to 500 tags. The maximum reporting interval is 24 hours allowing network sizes of up to 48,000 tags.
Range	Uses tag to tag networking. Maximum range per hop is 300ft. Maximum number of hops is 20.
Frequency Band	2.4 GHz
Certifications	FCC Part 15C – Low Power Transceiver
Battery Life	1 year
Battery	3V Renata Model: CR2477N Li/MnO2 Replaceable



InfinID Technologies, Inc. : One West Mountain Street, Unit 12 : Pasadena, CA 91103
626-793-2019, ext 206 : sales@infinIDTech.com : www.infinIDTech.com/assetworx/





Model	Sensor Transponder EV3-ST
RFID Protocol	ISO 18000-7:2008 + DoD 18000-7 RFID equipment guidelines
Frequency	433.92 MHz
Range	350 feet unobstructed when mounted to a container
Antenna	Omni-directional internal
Power	A' size 3.6 V primary lithium (Li-SOCl2), user replaceable
Battery life	> 4.5 years with 2 collections/day, temp/humidity 1 sample/min, light 30 samples min, shock event triggered
Communications	USB (mini port)
Weight	5.6oz (158.8g)
Dimensions	6.5" L x 2.37" W x 1.42" H 16.26 cm x 5.52 cm x 3.61 cm
Operating Temperature	-30 C to +70 C
Storage Temperature	-40 C to +70 C
Dust and Moisture	IP 64
Beeper	Audible beeper for tag location and status indication
Memory	512 kbytes, user configurable between data and sensor data, where either can be from 0-512 kbytes
Sensors	Scan rate: user programmable: 2 sec-60 min User defineable alarm thresholds Temperature: range: -30 to 70 C, resolution 0.5 C Humidity: range: 0%-100% RH, resolution: 0.5% RH Shock event (up to 250 g) Light sensor
Compliance	FCC Part 15.240 and Part 15.231 IC certified RSS-210, HERO no restrictions EMI safe on any aircraft
Low-Battery Indicator	From interrogator or on LED panel

evigia Demanding More from Wireless Sensing

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Ann Arbor MI 48108

Call us at (734) 302-1140
Visit us on the web at www.evigia.com
Email us at info@evigia.com

About Evigia

Evigia is the industry leader in utilizing integrated sensor and ASIC technologies to dramatically improve the functionality and cost of Active RFID hardware products. These advances allow significant improvement in the performance and cost of asset-management supply chains. The network's functionality, visibility, and security control are dramatically increased, while the underlying hardware products themselves benefit from smaller size, lower power consumption, and lower cost with our solution approach. The EV3-Series family of products are fully compliant and interoperable within the ISO 18000-7 standard. Let us show you how Evigia's solutions can improve your supply chain networks.

Appendix B – Poster

Presented At The Institute Of Food Technologists (IFT) Meeting In Chicago, July 2013

Chemical Degradation of Ascorbic Acid in First Strike Ration Foods Exposed to Abuse Temperatures

M. Cecilia N. Nunes[1] and Yavuz Yagiz[2],

[1]*Department of Cell Biology, Microbiology and Molecular Biology, University of South Florida*

[2]*Department of Food Science and Human Nutrition, University of Florida*

Abstract

The First Strike Ration (FSR) is a compact lightweight product composed of several food items designed to be consumed by the Warfighters during short duration high intensity combat operations and to enhance food consumption, nutritional intake and mobility. Although it is known that FSR has a minimum two years shelf life when stored at 27°C, there is limited information on changes in the composition of individual FSR items exposed to abuse temperatures. The objective of this study was to evaluate the effect of refrigerated (4°C) versus ambient (27°C) or abuse temperatures (38, 49 and 60°C) on chemical degradation of ascorbic acid (AA) in various FSR items (applesauce, bacon cheddar, Italian, and BBQ sandwiches) that were enriched with AA to act as an antioxidant and/or to increase the nutrient content. Our results showed that, AA degradation profiles were similar for sandwiches stored at different temperatures. However, storage duration had a more significant effect on AA degradation than temperature. On contrary, AA degradation in applesauce was greatly influenced by temperature. For applesauce, the higher the exposure temperature the higher the AA degradation, whereas for sandwiches, the shorter the exposure time, the lower the AA degradation. After approximately two years at refrigerated or ambient temperatures, AA retention in applesauce was approximately 80 and 34%, respectively compared to 7% retention at 60°C. For sandwiches, refrigeration showed no advantage over ambient storage as after two years AA retention was similar (5%). These results suggest that chemical degradation of AA differs depending on the nature of the food system, reaction medium, temperature and exposure time. In foods with high moisture content (≈72%) and low pH (≈3.5) such applesauce, AA degradation may be greatly influenced by temperature whereas in foods with lower moisture content (≈28%) and higher pH (≈5) storage duration may have a greater impact than temperature.

Introduction

The First Strike Ration (FSR) is a compact lightweight product composed of several food items designed to be consumed by the Warfighters during short duration high intensity combat operations and to enhance food consumption, nutritional intake and mobility. Although it is known that FSR has a minimum two years shelf-life when stored at 27°C (Zanchi, 2012), there is limited information on changes in the composition when exposed to abuse temperatures. All components of this ration have high calorie content and some items are either enriched with AA to increase the nutrient content or have added AA to act as an antioxidant. However, exposure to high temperatures during prolonged periods of time may result in accelerated degradation of AA (Baiano et al., 2004). During storage of food products, degradation of AA is considered one of the major causes of loss of nutritional value, affecting also flavor and color. Under anaerobic conditions, AA is degraded via several steps into furfural (Fig. 1) which is an important intermediate compound of the Maillard reaction (Yuan and Chen, 1998; Murata et al., 2007). Furthermore, AA degradation is also accelerated in food systems with high a_w and low pH whereas some sugars present may protect from degradation (Gregory III, 2007). The ***objective*** of this study was to evaluate the effect of refrigerated (4°C) versus ambient (27°C) or abuse temperatures (38, 49 and 60°C) on chemical degradation of AA in various FSR items.



Fig. 1. Ascorbic acid degradation pathways.

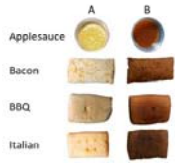


Fig. 2. Color change in FSR items exposed to abuse temperature. (A) initial, (B) after 8 weeks at 60°C.

Material and Methods

FSR Items. Applesauce, known as "Zapplesauce" (Fig.3A), consists of apple, maltodextrin, water, sugar and *ascorbic acid*. This product is enhanced with maltodextrin which can preserve glycogen in the muscles and liver and increase the endurance of the soldiers, and it is also a source of vitamin C, providing 520% of the recommended daily values. Bacon in Cheddar Sandwich (Fig. 3B) is prepared from bread and cured bacon, and contains *ascorbic acid* to inhibit fat oxidation. Honey BBQ Beef Sandwich (Fig. 3C) is also a high source of protein made up of about 21% meat and is prepared mainly from bread water and barbecued beef. It also contains *ascorbic acid* as an antioxidant. Italian-Style Sandwich (Fig. 3D) is a high source of protein, made up of about 21% meat and is prepared mainly from bread, tomato sauce, marinated cooked sausage, pepperoni, and mozzarella cheese powder. It also contains *ascorbic acid* as an antioxidant. ***Storage Conditions***. Three replicated packages per FSR item were used for initial quality evaluation, and a total of 180 packages/FSR item were distributed among five temperature-controlled chambers that were set at 4, 27, 38, 49°C and 60°C and stored during a 8 to 112 weeks, depending on the temperature. ***Moisture Content*** was determined by the standard gravimetric method. ***pH*** of the samples was determined using a pH meter (Accumet model 15, Fisher Scientific, CO, USA). ***Ascorbic Acid Content*** was conducted using a Hitachi LaChromUltra UHPLC system with a diode array detector and a LaChromUltra C18 4.6µm column (2 × 50 mm) (Hitachi, Ltd., Tokyo, Japan).

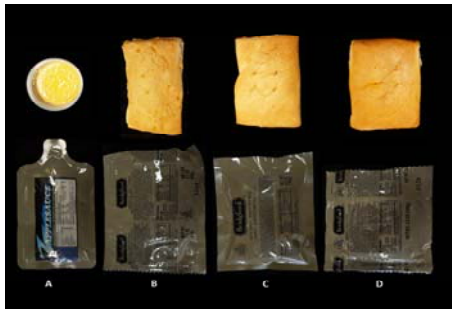


Fig. 3. FSR items: applesauce (A), bacon (B), honey BBQ (C) and Italian style(D) sandwiches.

Results

- Our results showed that, AA degradation profiles were similar for sandwiches stored at different temperatures (Fig 4B-D). However, storage duration had a more significant effect on AA degradation than temperature.
- On contrary, AA degradation in applesauce was greatly influenced by temperature (Fig. 4A). For applesauce, the higher the exposure temperature the higher the AA degradation, whereas for sandwiches, the shorter the exposure time, the lower the AA degradation.
- After approximately two years at refrigerated or ambient temperatures, AA retention in applesauce was approximately 80 and 34%, respectively compared to 7% retention at 60°C.
- For sandwiches, refrigeration showed no advantage over ambient storage as after two years AA retention was similar (5%).

Conclusions

Results suggest that chemical degradation of AA differs depending on the nature of the food system, reaction medium, temperature and exposure time. In foods with high moisture content (≈72%) and low pH (≈3.5) such applesauce, AA degradation may be greatly influenced by temperature whereas in foods with lower moisture content (≈28%) and higher pH (≈5) such as meat sandwiches, storage duration may have a greater impact than temperature (Table 1). Results from this work will also provide knowledge about the impact of abuse temperatures on the quality and shelf life of soldier food in particular and on civilian shelf stable foods in general. The temperatures used in this study are within the range normally encountered in temperate and warm regions of the world and because shelf stable foods are transported, stored and retailed without refrigeration, exposure to these abuse temperatures may easily occur, causing losses in their nutritional value and premature deterioration. Therefore, such studies may provide valuable information to food product developers and manufactures on how to improve the formulation of shelf stable foods than can be subjected to abuse temperatures throughout the supply chain. Furthermore, these types of studies may provide opportunities to all participants involved in the supply chain (either militaries or civilians) to properly train the persons responsible for the quality control of foods at the handling, transportation, storage, distribution and retail levels.

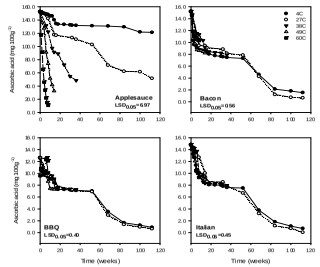


Fig. 4. Ascorbic acid degradation in applesauce and three type of sandwiches (bacon cheddar, honey BBQ and Italian style) stored at refrigerated, ambient and abuse temperatures.

Table 1. Moisture content and pH of applesauce and sandwiches stored at refrigerated, ambient and abuse temperatures.

FSR Item	Temperature (°F)	MC (%) Initial	MC (%) Final	pH Initial	pH Final
Applesauce	40	72.31	71.82	3.73	3.50
	80		72.65		3.54
	100		71.95		3.68
	120		75.53		3.69
	140		73.02		3.59
Bacon Cheddar	40	23.26	24.16	5.30	5.10
	80		28.24		4.98
	100		23.68		4.95
	120		23.00		5.07
	140		21.68		4.83
Honey BBQ	40	34.20	30.85	4.78	4.63
	80		32.25		4.62
	100		32.27		4.58
	120		32.95		4.62
	140		31.57		4.50
Italian Style	40	28.75	27.18	4.95	4.79
	80		31.35		4.76
	100		30.22		4.63
	120		29.32		4.76
	140		28.48		4.61

Acknowledgements

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