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1. REPORT DATE (DD-MM-YYYY) 01-06-2004		2. REPORT TYPE Final Technical Report		3. DATES COVERED (From - To) August 2002-December 2003	
4. TITLE AND SUBTITLE Moisture Content of Commercial Items Used in the MRE				5a. CONTRACT NUMBER SPO103-02-D-0024	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Coburn, John F.				5d. PROJECT NUMBER STP 2009	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Rutgers, The State University of New Jersey The Center for Advanced Food Technology Cook College N.J. Agricultural Experiment Station				8. PERFORMING ORGANIZATION REPORT NUMBER FTR 203	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Defense Logistics Agency 8725 John J. Kingman Rd. Fort Belvoir, VA 22060-6221				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Distribution Statement A. Approved for public release. Distribution unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT The Combat Rations Network (CORANET) is a Defense Logistic Agency (DLA) sponsored manufacturing technology program to improve the quality, reduce the cost, and increase the productivity of operational rations while increasing DLA's surge capability in the area of military rations. This report summarizes results obtained in STP 2009 the objective of which is to verify and test the specification requirements for production of selected commercial baked items in MREs. The time between when the Combat Ration Assembler receives either a Government-furnished or a Commercially acquired item until final packaging is completed may be critical to shelf-life. Interim storage may be at ambient humidity levels and temperatures that overwhelm bulk packaging resulting in item changes detrimental to shelf-life. The mechanism by which shelf-life is shortened may include starch retro-gradation (at levels not normally seen as "staling") or non-enzymatic browning (again at levels below product rejection). Hypothetically, once these two reactions are initiated subsequent reduction in moisture level may be too late to stop continued degradation. In the final analysis, it is the water activity rather than absolute moisture level which determines the shelf life and properties of bakery items. Given this					
15. SUBJECT TERMS Combat Rations, Military Rations, Manufacturing Technology Program, Defense Logistics Agency, MRE, Food Storage, Shelf Life, Bakery Items					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT U	18. NUMBER OF PAGES 149	19a. NAME OF RESPONSIBLE PERSON John F. Coburn
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U			19b. TELEPHONE NUMBER (Include area code) 908-445-6132

COMBAT RATION NETWORK FOR TECHNOLOGY IMPLEMENTATION

“Moisture Content of Commercial Items Used in the MRE”

Final Technical Report STP 2009

Results and Accomplishments (August 2002 – December 2003)

Report No: FTR 203

CDRL Sequence: A004

June 2004

CORANET CONTRACT NO. SPO103-02-D-0024

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“Moisture Content of Commercial Items Used in the MREs” (CORANET STP # 2009)

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1.0 Overview

A Short Term Project (STP) was established under the CORANET II Contract the objective of which is to verify and test the specification requirements for production of selected commercial baked items in MREs. The specification requirements will include selection of test methods and protocols required to assure current or improved quality levels for a period of 3 years.

The time between when the Combat Ration Assembler receives either a Government-furnished or a Commercially acquired item until final packaging is completed may be critical to shelf-life. Interim storage may be at ambient humidity levels and temperatures that overwhelm bulk packaging resulting in item changes detrimental to shelf-life. The mechanism by which shelf-life is shortened may include starch retro-gradation (at levels not normally seen as “staling”) or non-enzymatic browning (again at levels below product rejection). Hypothetically, once these two reactions are initiated subsequent reduction in moisture level may be too late to stop continued degradation. Hence, moisture level in the re-packaged product, without knowing its history (or being able to measure other properties) may be insufficient to assure shelf-life and safety.

2.0 Summary

All three Combat Ration MRE Assemblers (Ameriquial Foods, SOPAKCO, and Wornick Foods) as well as Bakery Item Producer Sterling Foods USA participated as Industry Partners in the Moisture STP. Wornick provided the four Bakery Items from their inventory for MRE assembly: Combos, Oatmeal Cookies, Vegetable Crackers, and Lorna Doones. Samples of each of the 4 were pulled at time of receipt and subsequently at 30, 45, 60 and 90 days of interim storage. These samples were used for the laboratory testing at Rutgers University / CAFT. Each of the four Industry Partners placed Temperature/ Humidity Data loggers in the storage areas of their respective Plants (the data loggers were supplied by Rutgers University / CAFT who subsequently downloaded the collected information).

Indoor Temperature and Absolute Humidity levels were found to be well correlated with those recorded at the closest Weather Bureau Weather Stations thus providing a basis for defining target extremes (design conditions) for guidance.

Moisture absorption, as measured by package headspace relative humidity, was strongly dependent on the packaging employed and the integrity of that packaging. The Combos and Lorna Doones were supplied by the bakery packaged in either an intermediate quantity package or in a vending machine package both employing metallized PET structures which are very good barriers. These items were not affected by the Assembler storage conditions. The Vegetable Crackers, although supplied in bulk, were sufficiently protected to provide 3 to 6 months interim storage life. Bulk Oatmeal Cookies were not well protected and as a result were unable to survive the interim storage and still be below the maximum allowable moisture content. Test by sensory panel confirmed that crispness and overall likeness dropped significantly from the time the product was received at the Assembler site.

Considerable differences exist between stated moisture contents depending on the methods used. In the final analysis, it is the water activity rather than absolute moisture level which determines the shelf life and properties of bakery items. Given this reality, direct measurement of water activity was included along with the conventional oven and vacuum oven methods for quantifying moisture.

3.0 Recommendations

The following recommendations are put forward:

1. The minimum packaging to be employed by bakery item suppliers should be defined and included as part of the procurement contract between the Assembler and the vendor.

2. Water Activity should be established as the "moisture" measurement for MRE baked items replacing the determination of absolute moisture levels. The result would lead to both greater speed and accuracy. Several steps should be taken to implement this recommendation. For quick evaluation, we suggest starting with a "round robin" using the overwrapped bakery items on-hand from STP #2009, Phase II would be the proposed approach to transition.

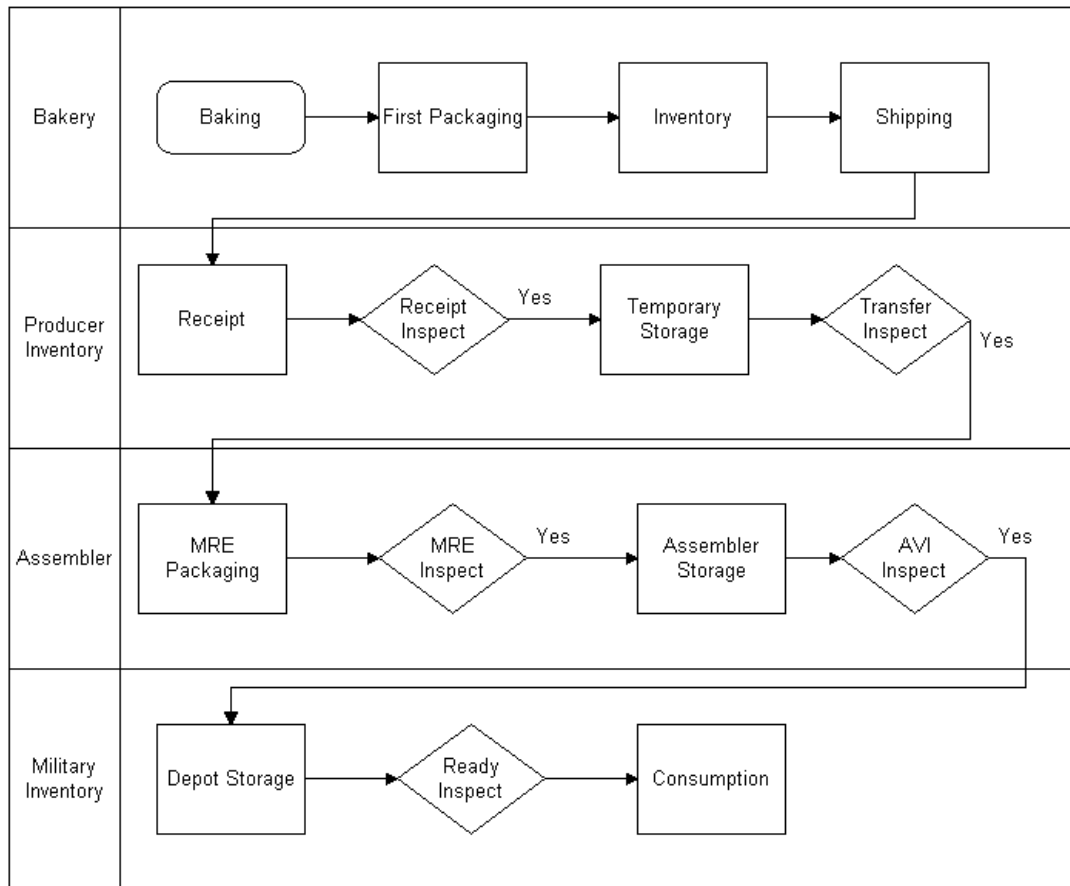
3. Since bakery items do absorb moisture from the environment, the impact of "open-time" (exposure to plant humidity during time between case opening and overwrap) on moisture levels of bakery items should be determined. Normal practice at the assembler is generally believed to be acceptable but verification is recommended. Plant humidity levels are available from STP 2009. Although earlier tasks measured sorption isotherms, a short extension of the STP would determine the necessary kinetics. Suggestions for this task arose at the In-Process-Review.

4. Extend the Plant Humidity data analysis to a full year. Data has already been collected but analysis was limited to 7 months consistent with the STP 2009 scope of work. Modest effort is all that is needed to include the additional 5 months resulting in the full year analysis.

4.0 Introduction

This Short Term Project consisted of three Phases: Phase I "In-Process Storage Control and Acceptance", Phase II "Product Quality and Methods Definition" and Phase III "Storage Life and Validation". Phase I data collection was initiated simultaneously with award of the STP Delivery Order in order to gain as much as possible of the remaining summer season of greatest temperature/humidity. Phase I results are described in the Report Sections under "Interim Storage Conditions". Testing Laboratory analysis (Phase II), including Sensory Properties, of the Bakery Products was conducted at the Rutgers University Food Science Department and reported in Report Sections under "Bakery Item Properties" and "Bakery Item Matrix Structure". Phase III "Storage Life and Validation" is to be conducted at the U.S. Army Soldier Systems Command, Natick. That activity is beginning following that covered by this report and will be the subject of a separate document. A description of the Phase III Study is included in this report, however, in the last Section "Storage Life and Validation".

Process Flow Chart



The distribution system Flow Chart outlines the flow of the Bakery Items from Baking at the bakery source through to consumption of the item as part of the MRE. Time of inventory is shown in 2 stages: Producer Inventory (that time prior to over-wrapping with foil-laminate) and Assembler Inventory (that time following over-wrap). Following AVI Inspection and Military Acceptance, the items enter the Military Inventory.

The interim storage period referred-to in the following section “Interim Storage Conditions” is labeled on the Flow Chart as “Producer Inventory – Temporary Storage”. The Phase III period to be conducted at Natick coincides with the Flow Chart location “Assembler – Assembler Storage”. Since the bakery items at that point are in their final over-wrap, this stage does not differ from “Military Inventory – Depot Storage”.

5.0 Interim Storage Conditions

5.1 Weather

The National Climate Data Center (NCDC) was the principal source of weather data for the four locations of the Study. The Weather Stations corresponding to each Processing Plant/Warehouse were:

- | | |
|---------------------------|--------------------------------------|
| 1. McAllen Texas | McAllen Miller International Airport |
| 2. San Antonio Texas | San Antonio International Airport |
| 3. Evansville Indiana | Evansville Regional Airport |
| 4. Mullins South Carolina | Florence Regional Airport |

Although the NCDC Report Number 81, “Climatology of the United States” provides historical data, 1971 – 2000, for Temperature, Precipitation, and Heating and Cooling Degree Days, Humidity-related data is not included (Relative Humidity, Dew Point). Fortunately, “Weatherbase” did provide both Relative Humidity and Dew Point records although in some cases limited to 14 years. Weatherbase, through Weatherbase.com provides weather data from additional sources to the NCDC.

5.1.1 Temperature

In order to extent observations and recommendations from the temperature data recorded during the active period of the Study, Historical Data from the associated weather station was used to define “normal”. The following temperature statistics were reported:

Monthly/Annual-	Mean
	Maximum (Average)
	Minimum (Average)
	Highest Recorded
	Lowest Recorded.

McAllen Miller International Airport

Element	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
NCDC													
Max	70	74	81	86	90	94	96	96	92	86	78	71	84
Mean	60	64	71	76	81	85	86	86	83	76	68	62	75
Min	50	54	60	66	72	75	76	76	73	66	59	52	65
WeaBase													
Avg	61	64	69	75	80	83	85	85	82	76	67	62	74

AvgHi	72	76	81	86	91	94	96	96	93	87	78	73	85
AvgLo	50	53	57	64	70	73	74	74	71	65	56	51	63
Highest	92	96	102	105	106	104	105	104	102	100	97	95	106
Lowest	22	19	31	40	50	61	65	64	50	42	30	26	19

San Antonio International Airport

Element	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
NCDC													
Max	62	67	74	80	86	91	95	95	90	82	71	64	80
Mean	50	55	62	69	76	82	84	84	79	71	60	52	69
Min	39	42	50	57	66	72	74	74	69	59	49	41	58
WeaBase													
Avg	51	55	62	70	76	82	85	85	80	71	60	53	69
AvgHi	62	66	74	80	86	92	95	95	90	82	71	64	80
AvgLo	39	43	50	58	66	72	74	74	69	59	48	42	58
Highest	89	97	100	100	103	105	106	108	103	99	94	90	108
Lowest	-	6	19	31	43	53	62	61	46	27	21	6	-

Evansville Regional Airport

Element	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
NCDC													
Max	40	45	56	67	77	86	89	88	81	70	56	44	67
Mean	31	36	46	56	66	75	79	77	69	57	46	36	56
Min	23	26	35	44	54	64	68	65	57	45	36	27	45
WeaBase													
Avg	32	36	45	57	66	75	79	76	69	58	46	36	56
AvgHi	40	45	55	68	77	86	89	87	81	70	55	44	67
AvgLo	23	26	35	45	54	64	68	65	57	45	36	27	46
Highest	74	79	84	91	95	104	105	102	103	94	83	77	105
Lowest	-21	-23	-9	23	28	41	49	43	33	21	-3	-15	-23

Florence Regional Airport

Element	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
NCDC													
Max	56	60	67	76	83	89	92	91	86	76	68	59	75
Mean	45	48	55	63	71	78	82	80	75	64	55	47	64
Min	33	36	43	51	59	67	71	69	64	51	43	36	52
WeaBase													

Avg	47	49	54	64	71	78	80	79	74	64	55	46	64
AvgHi	58	60	65	76	83	90	90	90	85	76	67	57	75
AvgLo	37	38	43	52	60	67	70	69	64	53	43	36	53
Highest	83	83	88	93	102	108	104	106	101	102	87	81	108
Lowest	12	12	18	31	41	50	57	54	41	28	16	11	11

5.1.2 Humidity

In order to extent observations and recommendations from the humidity data recorded during the active period of the Study, Historical Data from the associated weather station was used to define “normal”. The following humidity statistics were reported by WeatherBase:

Monthly/Annual- Average Relative Humidity
 Average Morning Relative Humidity
 Average Evening Relative Humidity

McAllen Miller International Airport

Element	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
WeaBase													
Avg	75	75	73	73	74	74	72	72	76	74	75	74	74
AvgAM	-	-	-	-	-	-	-	-	-	-	-	-	-
AvgPM	-	-	-	-	-	-	-	-	-	-	-	-	-

San Antonio International Airport

Element	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
WeaBase													
Avg	-	-	-	-	-	-	-	-	-	-	-	-	-
AvgAM	80	80	79	82	87	88	87	86	85	83	81	80	83
AvgPM	51	48	45	48	52	49	43	42	46	46	48	50	47

Evansville Regional Airport

Element	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
WeaBase													
Avg	-	-	-	-	-	-	-	-	-	-	-	-	-
AvgAM	80	80	78	73	75	75	78	82	83	83	80	81	79
AvgPM	66	61	56	50	52	52	54	54	52	50	59	67	56

Florence Regional Airport

Element	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
WeaBase													
Avg	69	66	63	62	68	81	80	79	75	74	68	67	71
AvgAM	-	-	-	-	-	-	-	-	-	-	-	-	-
AvgPM	-	-	-	-	-	-	-	-	-	-	-	-	-

5.2 Indoor/Outdoor Environment

Dickson Temperature & Humidity Data Loggers (TP120) were deployed to each Combat Ration Assembler site on 26 August 2002. Two data loggers were sent to each location and one changed-out/returned in October 2002 with the second exchanged in April 2003. The redundancy allowed for continuous logging while also providing insurance against failure. The Data Loggers were programmed to collect a data-point each hour which was subsequently downloaded at the Rutgers University, Demo Site, Piscataway, NJ. The Temperature/Humidity results shown below for the Indoor Environment is the mean daily from the hourly data.

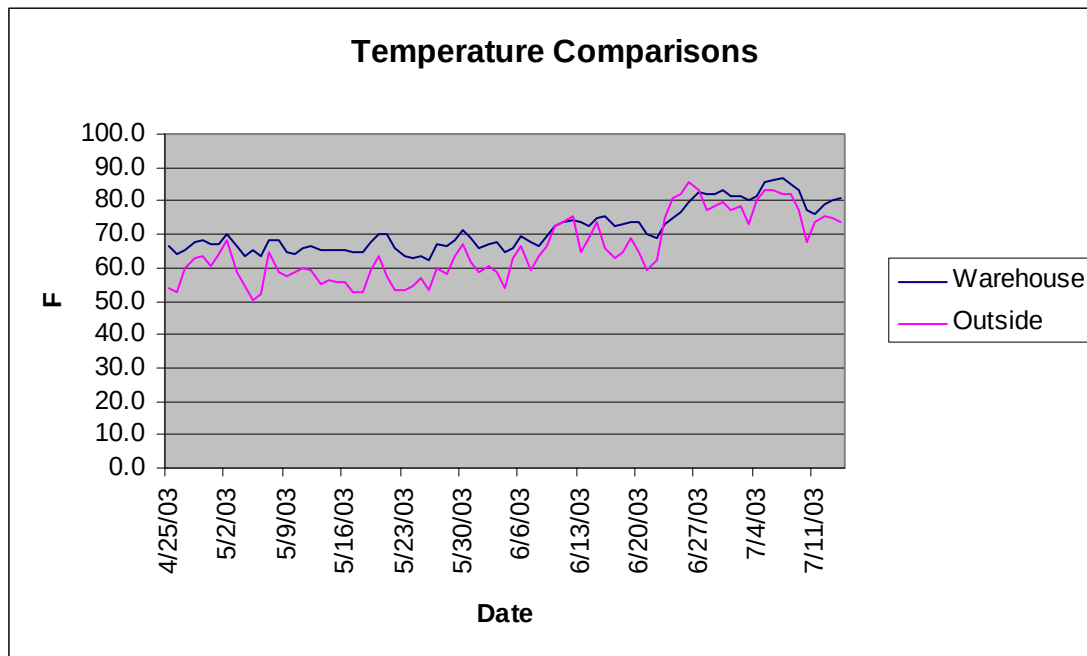
The outdoor environment data is that obtained from the local weather stations as identified in the Weather section of this report. With respect to Temperature, the mean daily temperature is available and was used in the Indoor/Outdoor comparison. Continuous records are available for the period 1 September 2002 through April 2003 and are used in this report. Daily Mean Relative Humidity is not reported by the Weather Stations, however, Minimum and Maximum Daily Relative Humidity, as well as Mean Wet Bulb Temperature is. An estimate of the Mean Relative Humidity was obtained by averaging the Minimum and Maximum and the Mean Wet Bulb Temperature (coupled with the Mean Temperature, Dry Bulb) was used to derive the Mean Absolute Humidity.

5.2.1 Demo Site Indoor/Outdoor

In order to more directly compare indoor/outdoor environmental conditions without the further variable of the proximity to the local weather station, two data loggers were deployed at the Rutgers Demonstration Site. The inside logger was hung in a clothespin bag out of any obvious drafts and the second was suspended below a trailer (to protect it from direct contact with rain or exposure to direct sunlight). Data was logged every hour and the Mean Daily calculated for each of temperature and relative humidity. Data are reported for the period 25 April through 15 July 2003. The late initiation of this experiment is the result of such not being part of the original plan.

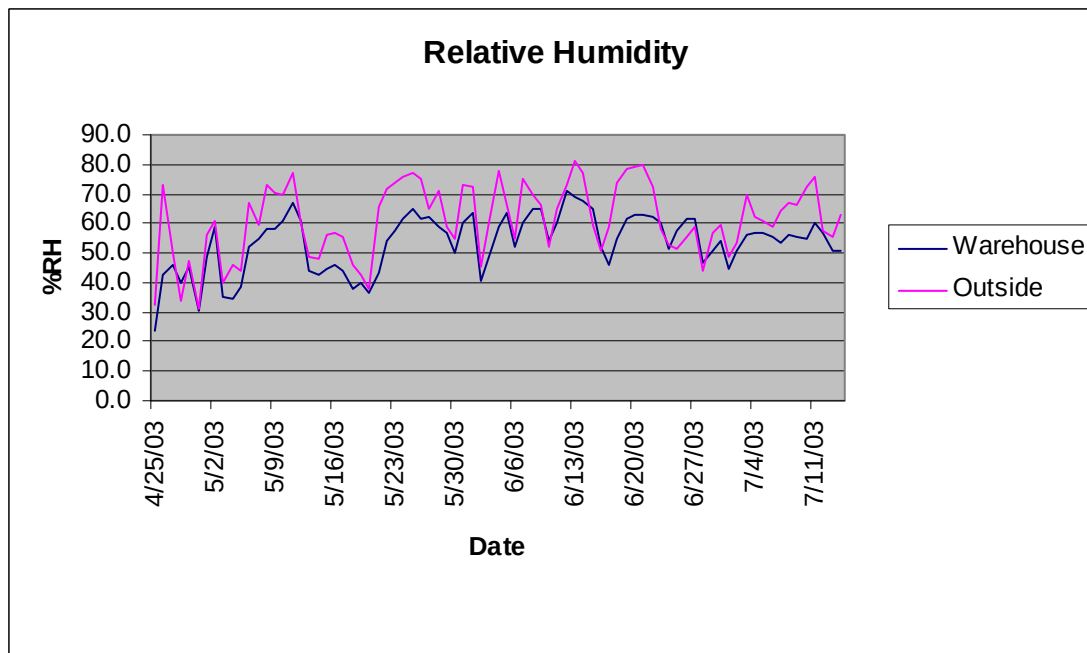
The Correlation Coefficient for the Temperature Comparison between Indoor (Warehouse) and Outdoor was 0.925858. This value is considered significant and as can be seen from Figure 1, Indoor temperature does indeed track the Outdoor with Indoor being 5 to 10 degrees less.

Figure 1 Demo Site Temperature Comparisons



The Correlation Coefficient for the Relative Humidity Comparison between Indoor (Warehouse) and Outdoor was 0.813766. This value is not as significant as that for temperature but as can be seen from Figure 2, Indoor humidity tracks the Outdoor.

Figure 2 Demo Site Humidity Comparison

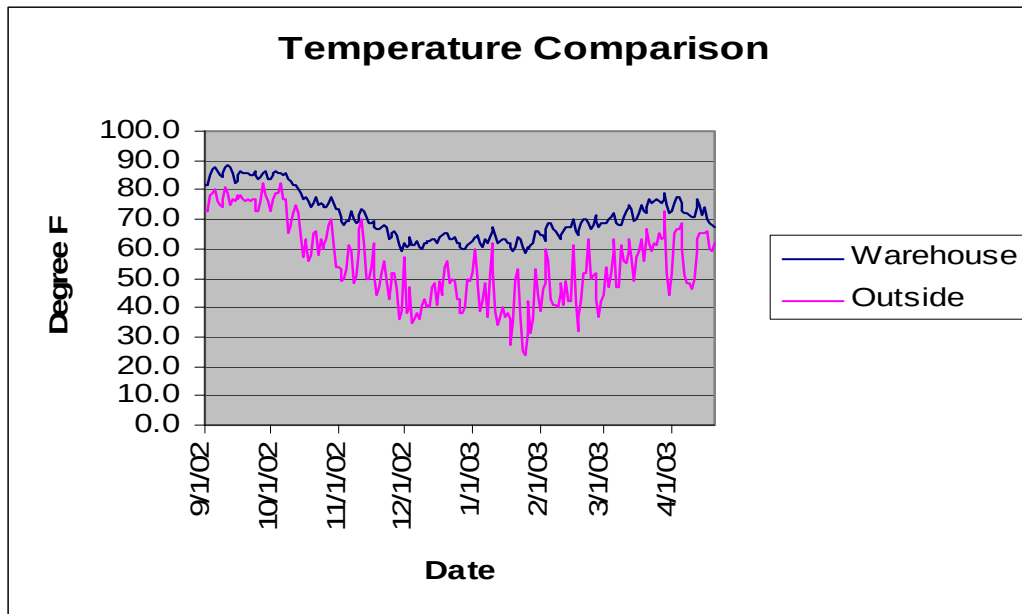


If instead of Relative Humidity as the basis of correlation, the Absolute Humidity is used, the correlation coefficient becomes even better than that for the temperature. Based on Mean Relative Humidity to derive absolute humidity, the Correlation Coefficient for Absolute Humidity Indoor/Outdoor is 0.940194.

5.2.2 Data Logger SOPAKCO Location

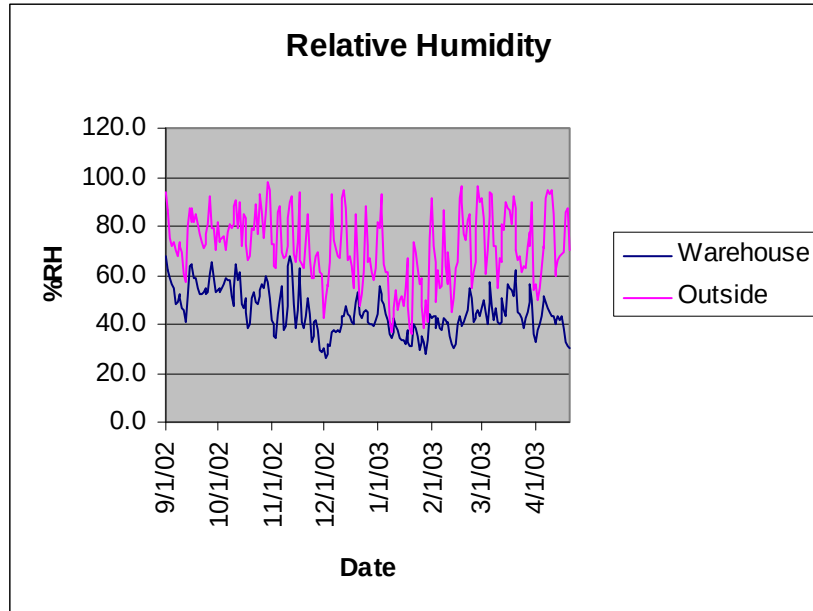
The Correlation Coefficient for the Temperature Comparison between Indoor (Warehouse) and Outdoor was 0.910185. This value is considered significant. As can be seen from Figure 3, Indoor temperature tracked the Outdoor but was as much as 20 degrees warmer during January and February. Either space conditioning within the warehouse and/or distance between the warehouse location and the airport location could account for the absolute difference even within the correlation.

Figure 3 Logger SOPAKCO Location



The Correlation Coefficient for the Relative Humidity Comparison between Indoor (Warehouse) and Outdoor was 0.637915. This value is not as significant and as can be seen from Figure 4, Indoor humidity does not appear to track the Outdoor. However, as was the case for the Demo Site, if instead of Relative Humidity as the basis of correlation, the Absolute Humidity is used, the correlation coefficient becomes even better than that for the temperature even though only a Minimum and Maximum Relative Humidity were available to estimate the True Mean. Based on such a Mean Relative Humidity to derive absolute humidity, the Correlation Coefficient for Absolute Humidity Indoor/Outdoor is 0.945616. The Mean Wet Bulb Temperatures were also available from the Weather Service and provide a second means for deriving the Mean Absolute Humidity. Where the Absolute Humidity used for correlation Indoor/Outdoor is Wet Bulb, The Correlation Coefficient remains high at 0.927188.

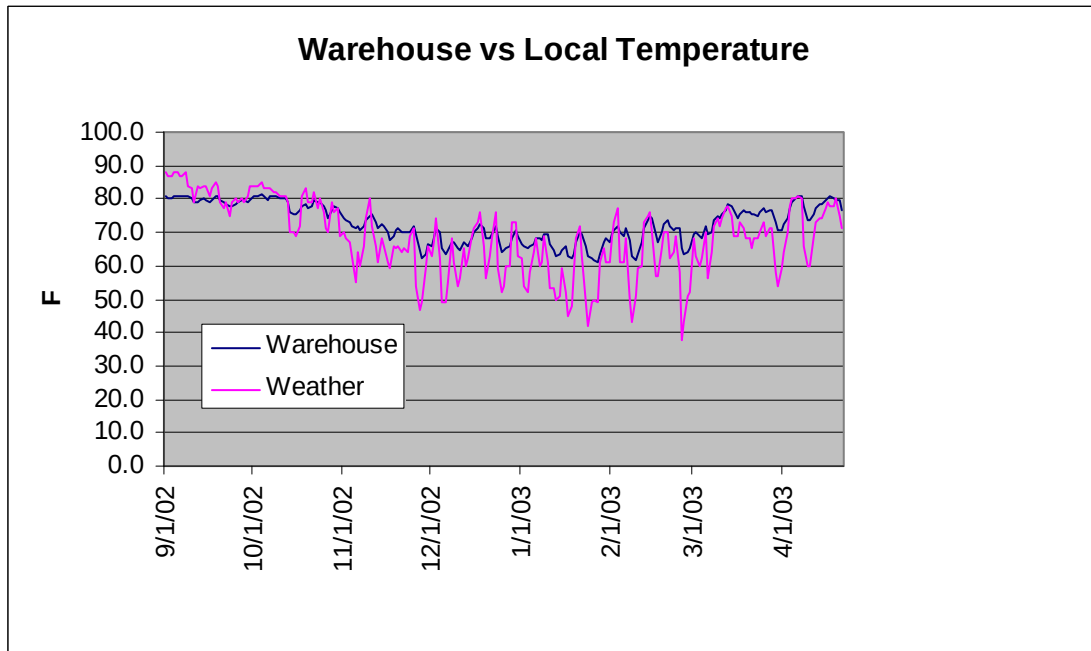
Figure 4 Logger SOPAKCO Location



5.2.3 Data Logger Wornick Location

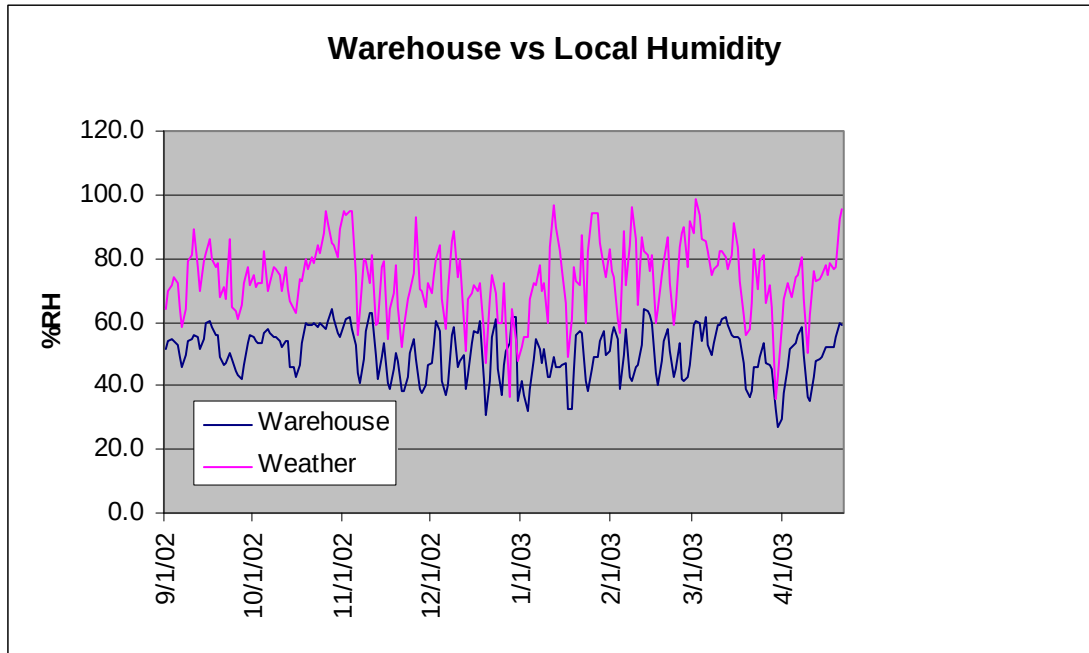
The Correlation Coefficient for the Temperature Comparison between Indoor (Warehouse) and Outdoor was 0.902313. This value is considered significant. As can be seen from Figure 5, Indoor temperature tracked the Outdoor.

Figure 5 Logger Wornick Location Temperature



The Correlation Coefficient for the Relative Humidity Comparison between Indoor (Warehouse) and Outdoor was 0.597111. This value is not significant as can be seen from the Figure 6. However, as above, if instead of Relative Humidity as the basis of correlation, the Absolute Humidity is used, the correlation coefficient becomes even better than that for the temperature even though only a Minimum and Maximum Relative Humidity were available to estimate the True Mean. Based on such a Mean Relative Humidity to derive absolute humidity, the Correlation Coefficient for Absolute Humidity Indoor/Outdoor is 0.956. The Mean Wet Bulb Temperatures were also available from the Weather Service and provide a second means for deriving the Mean Absolute Humidity. Where the Absolute Humidity used for correlation Indoor/Outdoor is Wet Bulb, the Correlation Coefficient remains high at 0.959.

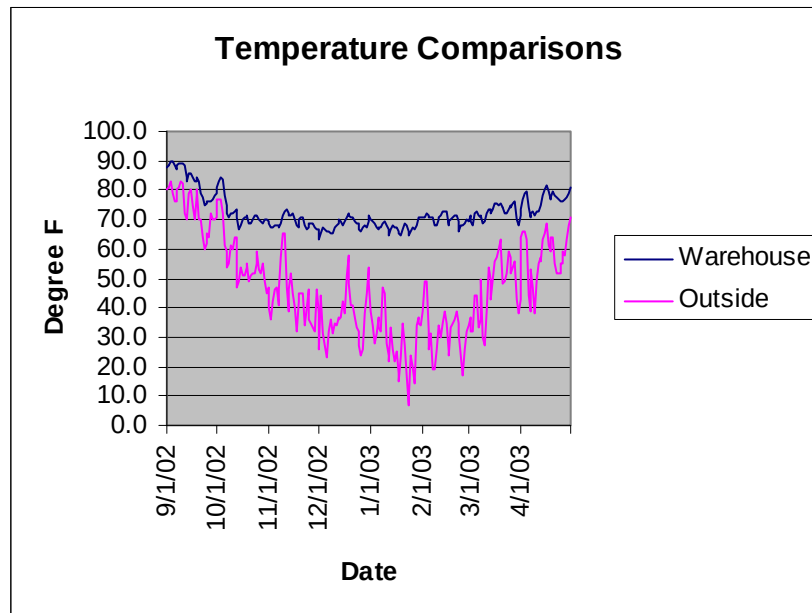
Figure 6 Logger Wornick Location Relative Humidity



5.2.4 Data Logger Ameriquil Location

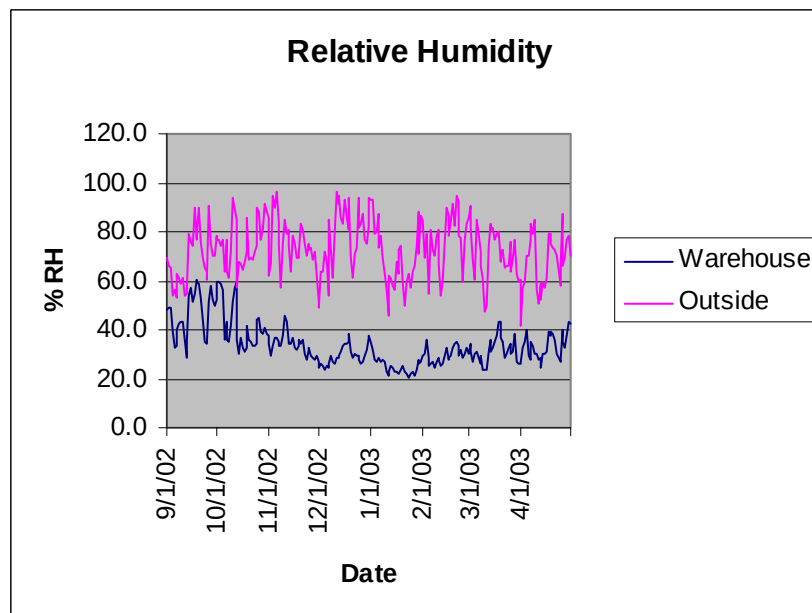
The Correlation Coefficient for the Temperature Comparison between Indoor (Warehouse) and Outdoor was only 0.858794 and as can be seen from Figure 7, Indoor temperature did not track the Outdoor during colder months.

Figure 7 Logger Ameriquel Location Temperature



The Correlation Coefficient for the Humidity Comparison between Indoor (Warehouse) and Outdoor was 0.360849. This value is not even as significant and as that for temperature but as can be seen from the Figure 8. However, as above, based on the Absolute Humidity, the correlation coefficient becomes significantly better: 0.964769 and 0.947065 for the cases derived from Weather Station Relative Humidity and Wet Bulb, respectively.

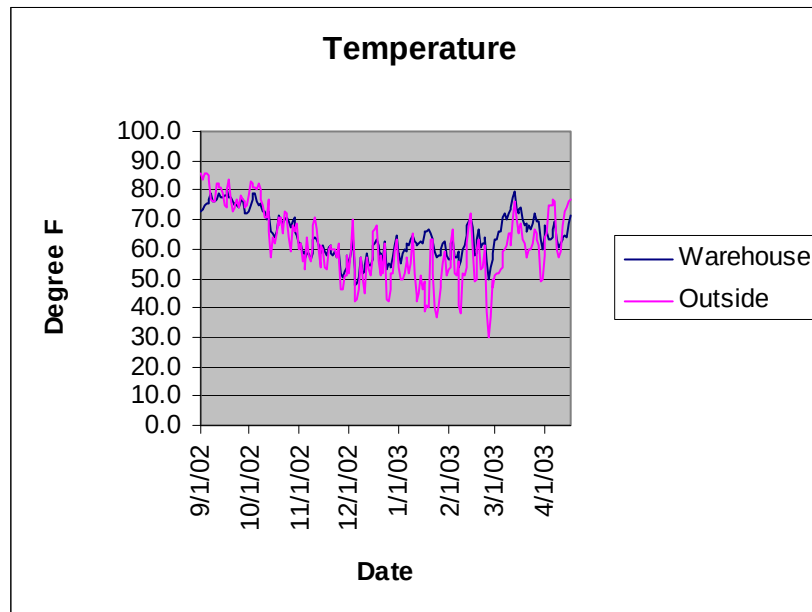
Figure 8 Logger Ameriquel Location Relative Humidity



5.2.5 Data Logger Sterling Location

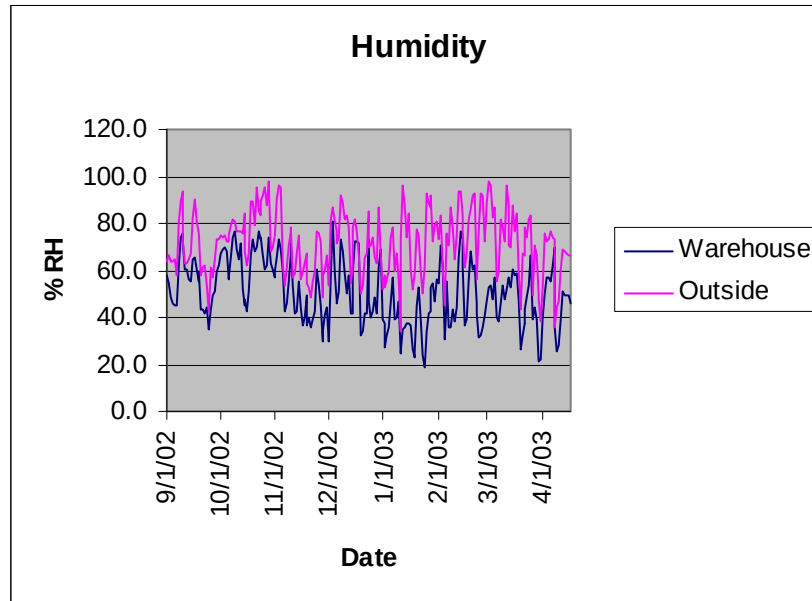
The Correlation Coefficient for the Temperature Comparison between Indoor (Warehouse) and Outdoor was 0.82036. This value is considered marginally significant. As can be seen from Figure 9, Indoor temperature tracked the Outdoor but was as much as 20 degrees warmer during January and February. The Location 182/189 data indicated a change in correlation following December 31, 2002. Communication with personnel at that location confirmed that changes were occurring and a second correlation (0.943085) was calculated for the period from September through December (neglecting the period from December through April).

Figure 9 Logger Sterling Location Temperature



The Correlation Coefficient for the Relative Humidity Comparison between Indoor (Warehouse) and Outdoor was 0.641633 (September through April) or 0.797084 for (September through December). Very little differences between the time periods are seen, however, when Absolute Humidity is used as the basis for correlating Indoor/ Outdoor Humidities: September – December; 0.941561 and 0.961112, September – April, 0.932911 and 0.958927.

Figure 10 Logger Sterling Location Relative Humidity



5.3 Predicting Indoor Environment

In order to predict the Indoor environment to which a bakery item might be exposed, regression analysis of Indoor conditions (y) was conducted against Outdoor conditions (x). Values in Figures 11, 12 and 13 include intercept, slope, standard error of estimate and correlation coefficient for each of the locations.

5.3.1 Temperature

Figure 11

	Temperature			
Location	Intercept	Slope	StdErr	Correlation
FMT	28.8	0.650	2.57	0.925858
SOPAKCO	40.8	0.548	3.39	0.910185
Wornick	40.5	0.471	2.47	0.902313
Ameriqua	58.5	0.299	2.98	0.85874
Sterling	32.7	0.522	4.35	0.82036
Rev Sterling	18.7	0.715	3.00	0.943085

The Location Sterling data indicated a change in correlation following December 31, 2002. Communication with personnel at that location confirmed that changes were occurring and therefore the values shown as “Rev Sterling” differ in that they are based only on the time period prior to changes, i.e. September 1, 2002 through December 31, 2002. Location Ameriqua is characterized as having a lower slope (sensitivity of Indoor Temperature change with that of Outdoor) and therefore suggests conditioned space.

5.3.2 Humidity (Absolute Humidity)

Figure 12

	NCDC Avg Reported Rel Humidity			
Location	Intercept	Slope	StdErr	Correlation
FMT	0.884	0.860261	5.12	0.940194
SOPAKCO	0.760438	0.815514	7.41	0.945616
Wornick	1.196949	0.552918	4.94	0.955947
Ameriqua	0.897797	0.702174	3.94	0.964769
Sterling	0.277418	0.710644	7.62	0.932911
Rev Sterling	0.519885	0.687913	7.93	0.941561

Figure 13

	NCDC Wet Bulb Temperatures			
Location	Intercept	Slope	StdErr	Correlation
FMT	0.884	0.860261	5.12	0.940194
SOPAKCO	1.031792	0.761868	7.98	0.927188
Wornick	1.236272	0.559392	4.68	0.959
Ameriqua	0.956921	0.689328	4.91	0.947065
Sterling	0.138765	0.766361	5.29	0.958927
Rev Sterling	0.431371	0.718793	5.66	0.961112

In both Figure 12 and 13 (Absolute Humidity), the values given for FMT are derived from a true measure (data logger) of the outside Mean Daily Relative Humidity rather than derived from either a Daily Avg of the Min/Max Relative Humidity or the Mean Daily Wet Bulb Temperature.

Although the difference in Standard Error of Estimate in the Figure 13 compared to Figure 12 approach is not dramatic (5.596 vs 5.868), the Absolute Humidities derived from the Wet Bulb approach will be used for further reference since the values represent a true mean as contrasted to Min/Max average (particularly where the occurrence of rain yields 100% Relative Humidity).

5.4 Interim Storage

Bakery items intended for inclusion in the MRE are received at the Ration Assembler in bulk cases with various packaging. Upon receipt a temperature/humidity data logger was placed inside the packaging and allowed to record results for the interim storage period prior to foil-laminate over-wrapping (up to 90 days). The time period was matched to that recorded for the Indoor Plant temperature and humidity. All results were from a single Combat Ration Assembler location, Wornick Foods, McAllen, Texas. CORANET Partner Wornick handled all data acquisition and provided sample material for laboratory testing.

Four Bakery Items were selected as models for testing: Oatmeal Cookies, Shortbread Cookies (Lorna Doone), Vegetable Crackers, and Filled Pretzel (Cheddar & Nacho Cheese Combos).

5.4.1 Bakery Items

5.4.1.1 Oatmeal Cookies

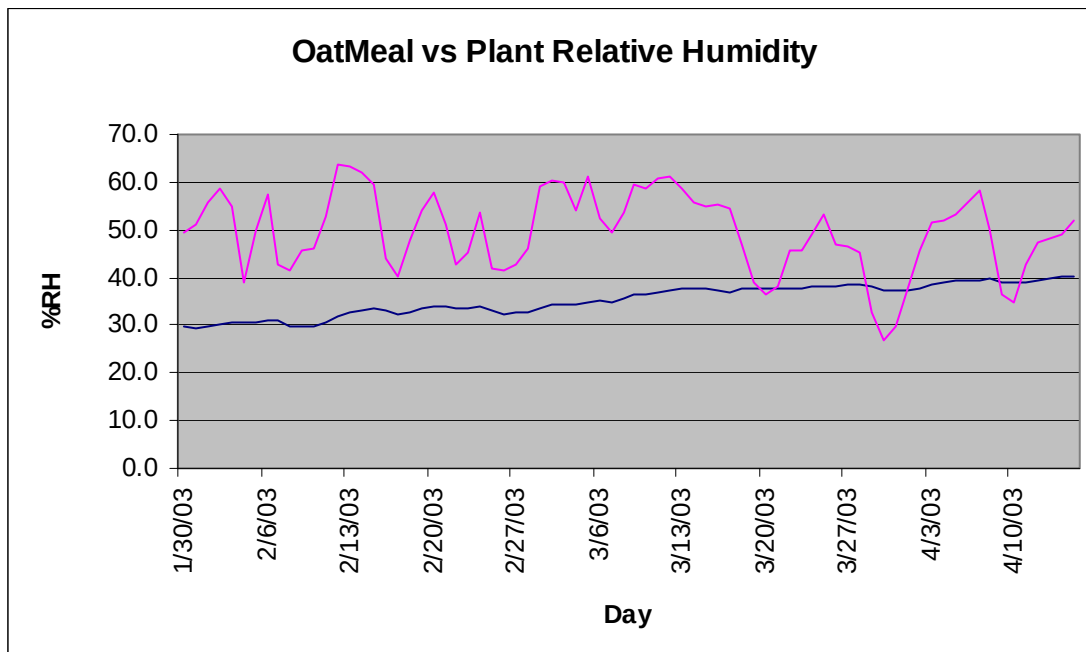
The Oatmeal Cookies are packaged 32 each in a polypropylene package. There are 12 packages per carton. The carton measured 5" x 13.25" x 15" giving it a volume of 994 in³ (16,289 cc) and a surface area of 680 in² (4,387 cm²).

Figure 1



Photo 1, Courtesy of Wornick Foods

Figure 2



The time period of study begins on 29 January 2003 when the recorder noted a change and ended on the shipping date from Wornick of 16 April 2003 (73 days).

The correlation of the Mean Daily Temperature between Plant and Package was high (correlation coefficient of 0.961375).

Correlations between Mean Daily Humidities were poor either based on Relative Humidity (-0.146633) or Absolute Humidity (0.680). Using a 5-point running average regression only resulted in a minor improvement (0.696). By far the best correlation was obtained with a simple Time Series Regression of the Product Relative Humidity (0.971).

A time dependent behavior is explained by diffusion control which greatly outweighs the daily variations of plant environment. The average daily change in Package Daily Relative Humidity was 0.145%/day which for a product weight of 6.120 Kg corresponds to 926 mg water/day (from the sorption isotherm for Oatmeal cookies, vacuum method, a 1% increase in A_w corresponds to an increase of 0.0010435 g water/g cookie). If a water vapor transmission rate of 0.025 g/100 in² day (20C) is used for Polypropylene film, the box area of 680 in² would result in a transfer of 170 mg water/day.

The observation that the moisture increase of the oatmeal cookies was 5 times the through the film amount, one concluded that the packages were poorly sealed and the barrier integrity was compromised.

5.4.1.2 Shortbread Cookies

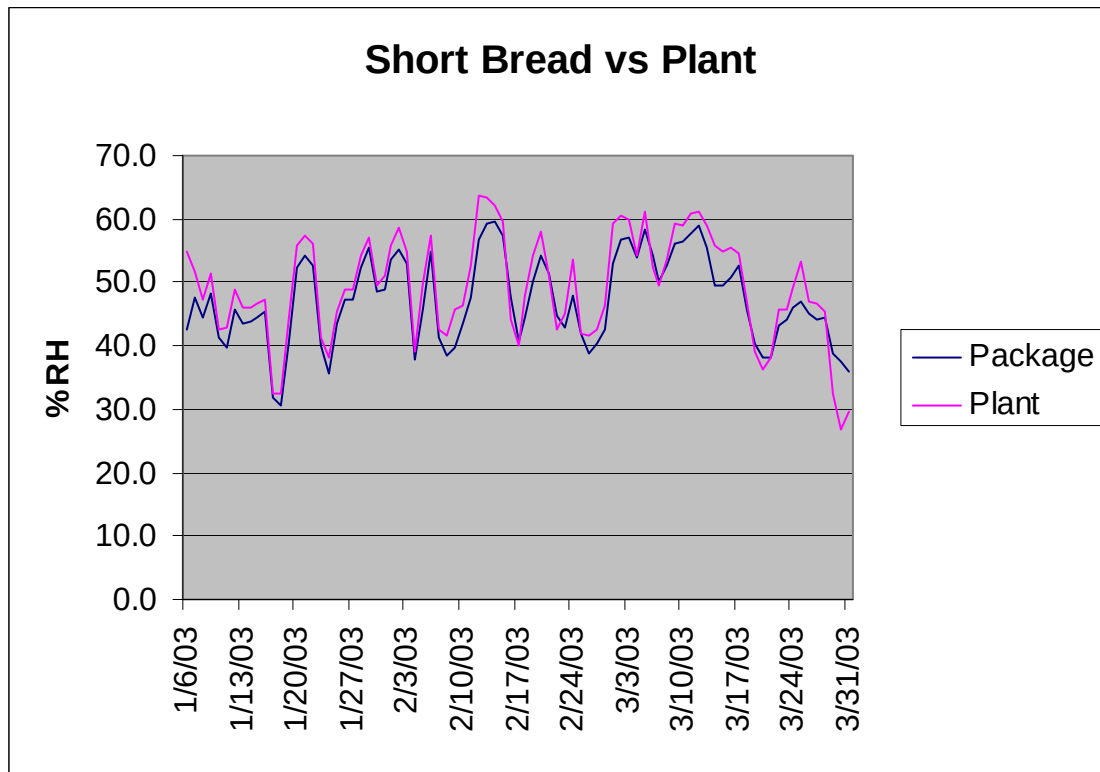
The Shortbread Cookies are packaged 6 each in a metallized, co-extruded, oriented-polypropylene package (vending machine package). There are 120 packages per carton. The data logger was inside the outer carton but outside the cookie packages.

Figure 3



Photo 2, Courtesy of Wornick Foods

Figure 4



The time period of study begins on 6 January 2003 when the recorder noted a change and ended on the shipping date from Wornick of 31 March 2003 (85 days).

The correlation of the Mean Daily Temperature between Plant and Package was weak (correlation coefficient of 0.834179).

Correlations between Mean Daily Humidities were high either based on Relative Humidity (0.940766) or Absolute Humidity (0.975). Unlike the Oatmeal case above, humidity response was coincident rather than time series dependent. Such behavior can be explained by the absence of a film barrier between the package data logger and the plant environment.

5.4.1.3 Vegetable Crackers

The Vegetable Crackers are packaged 475 each in a 3 mil High Density Polyethylene Liner, with top/bottom corrugated pads, along with sheets of corrugated paper separating the cracker rows. The carton measured 10" x 10.25" x 14.5" giving it a volume of 1486 in³ (24,451 cc) and a surface area of 792 in² (5,110 cm²). The data logger was inside the Liner.

Figure 5

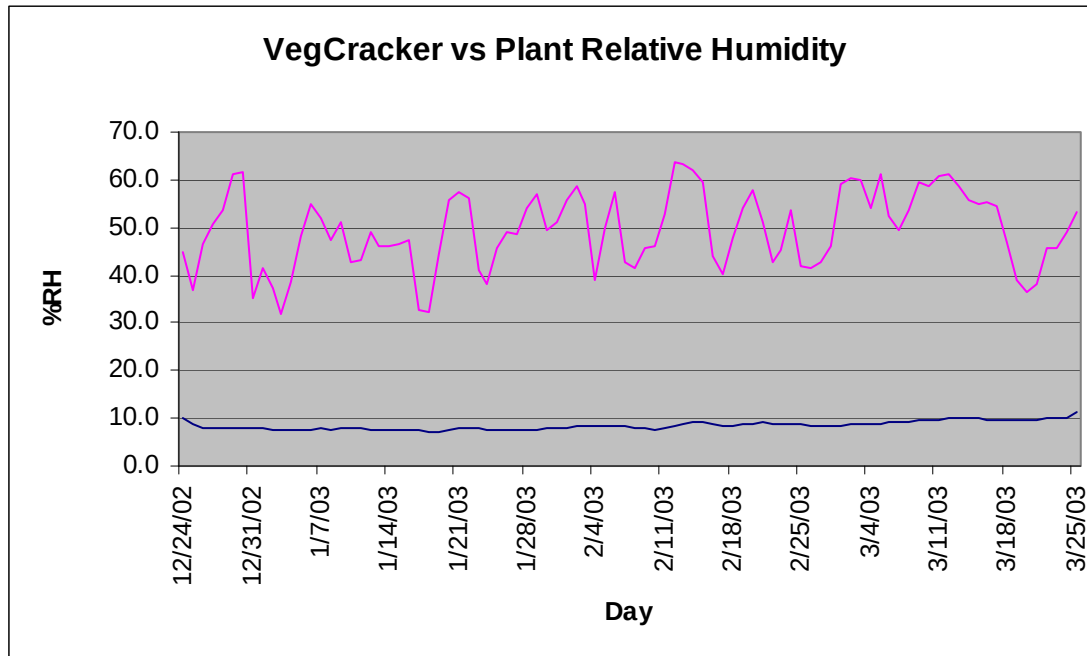


Photo 3, Courtesy of Wornick Foods



Photo 4, Courtesy of Wornick Foods

Figure 6



The time period of study begins on 26 December 2002 when the recorder noted a change and ended on the shipping date from Wornick of 25 March 2003 (xx days).

The correlation of the Mean Daily Temperature between Plant and Package was strong (correlation coefficient of 0.971849).

Correlations between Mean Daily Humidities were weak either based on Relative Humidity (0.315) or Absolute Humidity (0.777). Similar to the Oatmeal case above, humidity response was more time series dependent (0.857) than coincident.

As above, time dependent behavior is explained by diffusion control which greatly out weighs the daily variations of plant environment. The average daily change in Package Daily Relative Humidity was 0.0268%/day which for a product weight of 9.376 Kg corresponds to 205 mg water/day (from the sorption isotherm for vegetable crackers, vacuum method, a 1% increase in A_w corresponds to an increase of 0.00082 g water/g cookie). If a water vapor transmission rate of 0.025 g/100 in² day (20C) is used for high density polyethylene film, the box area of 792 in² would result in a transfer of 198 mg water/day.

The observation that the moisture increase of the oatmeal cookies was approximately the through the film amount, one concludes that the packages were well sealed.

5.4.1.4 Combos

The Cheddar & Nacho Cheese Combos are packaged 1.75 lbs in a metallized Oriented Polypropylene (OPP) Linear Low Density Polyethylene bag, with 6 bags per case. The data logger was inside the outer carton but outside the Combos bags.

Figure 7



Photo 5, Courtesy of Wornick Foods

The data logger download failed and no data is available for the interim storage of this bakery item. Given the placement of the logger, it is expected that identical results to that of the Shortbread Cookies would have been obtained.

5.4.2 Impact of Storage Time

5.4.2.1 Vegetable Crackers

Based on the kinetics for moisture diffusion through the Interim Storage packaging, a calculation can be made of what duration of interim storage can be accommodated before the maximum moisture specification is exceeded.

The moisture specification for Vegetable Crackers is for an average maximum less than 3.5%. Using the moisture isotherm for Vegetable Crackers given later in this report, a corresponding Water Activity (A_w) is 0.136. The initial moisture measured as headspace relative humidity, and therefore Water Activity was 0.080. Since the measured change in relative humidity, A_w , is 0.000268 / day the maximum allowable will be reached in 209 days, $(0.136-0.080)/0.000268$.

Therefore, based on the above calculation, one could store Vegetable Crackers packed as the experimental case for a period of 209 days before exceeding the specification. This observation is based on moisture levels only and does not address any other degradation which might occur in sensory properties or matrix structure.

5.4.2.2 Oatmeal Cookies

A similar calculation, based on the kinetics for moisture diffusion through the Interim Storage packaging, can be made of what duration of interim storage can be accommodated for the specific Oatmeal Cookie product before the maximum moisture specification is exceeded.

The moisture specification for Oatmeal Cookies is for an average maximum less than 3.6%. Using the moisture isotherm for Oatmeal Cookies given later in this report, a corresponding Water Activity (A_w) is 0.459. The initial moisture measured as headspace relative humidity, and therefore Water Activity was 0.300. Since the measured change in relative humidity, A_w , is 0.00145 / day the maximum allowable will be reached in 110 days, $(0.459-0.300)/0.00145$.

Therefore, based on the above calculation, one could store Oatmeal Cookies packed as the experimental case for a period of 110 days before exceeding the specification. This observation is based on moisture levels only and does not address any other degradation which might occur in sensory properties or matrix structure.

6.0 Bakery Item Properties

6.1 Sampling Procedure

Samples of selected baked good items were collected for three different sets of evaluations.

- 1) Samples of products for the establishment of sorption isotherms.
- 2) Samples of products for the evaluation of the effect of actual storage conditions on product quality over time.
- 3) Samples of products packed in the protective foil laminate pouches for the purpose of conducting preliminary evaluation of changes in quality at accelerated storage conditions.

Samples for the Sorption Isotherm Studies:

The sample quantities for the four (4) items are listed below:

Amount of Product Needed from Each MRE Baked Item for Testing

Item's Name	Sorption Isotherms Amount of Product (cases)
Combos	2
Oatmeal Cookies	10
Shortbread Cookies	7
Vegetable Crackers	3

The samples were shipped from the Assembler's site to CAFT-FMT Rutgers University, 120 New England Ave, Piscataway, NJ 08854. The products were shipped packed in the original boxes/cases. When needed the cases were packed in outer boxes with insulation in order to protect the product from physical damage or wetness.

Samples for the Bulk Storage Studies over 90 Days Period:

The total samples needed for this part of the project and the quantities needed on each Sampling Event are listed below:

Amount of Product Needed from Each MRE Baked Item for Testing

Item's Name	Bulk Storage Evaluation Total Amount Needed (cases)	Amount of Product Needed Per Sample Event
Combos	2	2 Packages
Oatmeal Cookies	2	5 Over-Wrapped Trays
Shortbread Cookies	2	40 Retail Packs
Vegetable Crackers	5	115 Individual Crackers

Once the baked product was received at the Packer/Assembler plant, the product needed for the Storage Study (i.e. 2 cases of each product) was MARKED CLEARLY and put in storage in proximity to the regular product, but in a way that prevented it from being lost or used for other reasons inadvertently.

The initial sample for time "1 Day" was taken out of one of the cases and sent to CAFT-FMT Rutgers University, 120 New England Ave, Piscataway, NJ 08854.

Note: A temperature and relative humidity RECORDER was placed in one of the boxes of each retained "storage study" product. The PACK with the RECORDER was sent with the product to Rutgers at the very LAST sampling (after 90 days). Detailed procedure for placing the recorder with the product is given below.

Sampling events, five for each of the four products occurred on the following schedule, starting with day "0" as the day the item was received at the Assembler's Storage Facilities.

Sampling Events on days: 1, 30, 45, 60, and 90.

The partial cases were resealed after each Sampling Event and put back in storage.

Since the product for this phase of the study was not shipped in the original cases, specific procedures were devised for each of the four products.

For CHEESE COMBOS:

One of the two (2) retained cases was opened and two (2) of the six (6) bags containing the product were removed.

The bags were MARKED CLEARLY with the Date and TIME they were removed for shipping to Rutgers. They were then placed in a plastic bag for protection against wetness farther packed in a padded well sealed case.

For OATMEAL COOKIES:

Place the Temperature/RH recorder in the center of the case to be sent last to us at Rutgers.

For each sampling event one of the five (5) retained cases (containing 115 cookies) was sent to Rutgers as is.

The case was MARKED CLEARLY with the Date and TIME it was removed for shipping.
The case was to be over-wrapped for protection against wetness and then sealed and sent to Rutgers.

For SHORTBREAD COOKIES:

One of the two (2) retained cases was opened and forty (40) of the one hundred & twenty (120) packs containing the product were removed.

The bags were MARKED CLEARLY with the Date and TIME they were removed for shipping to Rutgers.

The bags were then placed in a plastic bag for protection against wetness and then packed in a padded case, sealed and sent to Rutgers.

For VEGETABLE CRACKERS:

One of the two (2) retained cases was opened and one hundred and fifty (150) of the four hundred and seventy five (475) individual crackers were removed.

The Vegetable Crackers were placed in plastic bags, about 30 crackers in each bag. These bags were MARKED CLEARLY with the Date and TIME the crackers were removed for shipping.

The bags were then placed in a lined and padded case, sealed and sent to Rutgers. Special care was taken to stabilize the product in the shipping case to prevent breakage.

Samples of Product Packed in Foil Laminate Pouches – Phase II:

50 packs of each of the four products were sent to Rutgers once the Assembler packed them in the Military Aluminum Foil Pouch. The samples were taken from a regular packing run of these items, using the product lots employed for the Sorption Isotherm and Bulk Storage Studies. (The product that was sampled above.)

The DATE of packing was marked on the pouches. Pouches placed in padded boxes and sent to CAFT-FMT Rutgers University, 120 New England Ave, Piscataway, NJ 08854.

Procedure for Placing the Temp/RH Recorder with the Baked Products:

Pre-programmed Temperature and Relative Humidity Recorders were sent to the Assembler's plant. These recorders were packed for the shipping in marked Ziplock bags. The Serial numbers and placement directions are tabulated below.

Measurements of Temperatures and RH at Product Level

Product Name	Recorder Type	Recorder ID #
Combos	TP120 8/N	0222163
Oatmeal Cookies	TP120 8/N	0222167
Shortbread Cookies	TP120 8/N	0222175
Vegetable Crackers	TP120 8/N	0222193

The recorders were taken out of the Ziploc bags and placed with the product that was used for storage over 90 days period, and for sending "SPOT" samples to Rutgers University. Special care was taken to assure that there was nothing blocking the humidity and temperature sensors.

Placement of the recorders with the product was carried out shortly (24 - 48 hrs) after the product was received at the Assembler's plant.

The DATE and TIME of placing the recorders was noted and communicated via email to Dori Orr (avigdororr@aol.com) and John Coburn coburn@foodfac1.rutgers.edu) at Rutgers. The serial # of the recorder accompanied all communications.

For COMBOS:

One of the two (2) retained cases was opened and one (1) of the six (6) bags containing the product was carefully slit open at the top. The slit made large enough to slide the recorder into the pack.

Once the recorder was placed inside that pack, the pack was resealed well with 2" Scotch Tape, and MARKED CLEARLY to prevent the lost or misuse. The case was also be resealed.

The PACK with the RECORDER was sent with the product to Rutgers at the very LAST sampling (after 90 days).

For OATMEAL COOKIES:

One of the five (5) retained cases was opened and a few cookies removed to make space for the recorder. The plastic bag containing the product, in this case was not sealed. Once the recorder was placed the bag was folded unsealed, just to return it to "original" conditions. The case was resealed and MARKED CLEARLY to prevent the lost or misuse of the recorder/product.

The PACK with the RECORDER is to be sent with the product to Rutgers at the very LAST sampling (after 90 days).

For SHORTBREAD COOKIES:

One of the two (2) retained cases was opened and four (4) of the one hundred and twenty (120) over-wrapped packs containing the product were carefully removed from the center of the box to create an open space to accommodate the RECORDER. The recorder was then placed in the case.

Once the recorder was placed inside that case, the case was resealed well with 2” Scotch Tape, and MARKED CLEARLY to prevent the lost or misuse of the recorder/product.

The PACK with the RECORDER was sent with the product to Rutgers at the very LAST sampling (after 90 days).

For VEGETABLE CRACKERS:

One of the two (2) retained cases was opened and about fifteen (15) of the four hundred and seventy five (475) Vegetable Crackers were carefully removed from the center of the box. The open space created accommodated the RECORDER, which was then placed in the case.

Once the recorder was placed inside that case, the case should be resealed well with 2” Scotch Tape, and MARKED CLEARLY to prevent the lost or misuse of the recorder/product.

The PACK with the RECORDER was sent with the product to Rutgers at the very LAST sampling (after 90 days).

6.1.1 Type of Tests Conducted

Product quality changes were documented by measuring:

- Moisture Content
- Water Activity
- Sensory Attributes
- Mechanical Texture Parameters
- Heat Capacity Changes (DSC)
- Crystallization (X-Ray Diffraction)
- Color (L, a, b)

6.2 Moisture Content and Water Activity of Product During Storage

6.2.1 Moisture Specification Levels

Current Military Moisture Level Specifications

<u>Product Name</u>	<u>% H2O (wet basis)</u>		<u>Maximum</u>
	<u>Average</u>	<u>Minimum</u>	
Vegetable Crackers	2.0 to 3.5	1.5	4.0
Cheese Combo			2.6 5.0
Shortbread Cookies			4.0
Oatmeal Cookies			5.0

The water content specifications are based on using the Vacuum Oven method. It requires a special oven equipped with a vacuum pump. It is not a rapid method and laboratory-to-laboratory differences in techniques might result in different measurements.

6.2.2 Moisture Content and Water Activity Definitions

Moisture Content – Definition:

Moisture content is measured indirectly as the weight loss upon drying.

A “fresh” or “wet” sample is weighed into a previously tarred small dish. The net weight of the “wet” sample is calculated. The sample is then placed in an oven and dried for a period of time. The dish with the “dry” product is weighed again.

The difference in product weight before and after drying is presumed to be water.

Note: The method of drying might greatly influence the results.

Water Activity - Definition

Water Activity is expressed as the decimal fraction of the relative humidity it is in equilibrium with.

For example: If a cookie is placed in an environment with 32% relative humidity and it neither loses nor gains weight, the cookie would then be considered at equilibrium with that environment. By definition we would say that this cookie has 0.32 Water Activity (Aw).

Water Activity is a measure of the “Availability of Water.” This characteristic has implications on the rate of chemical reactions and on the ability of microorganisms to grow on the food product in question. It Has Implications on Shelf-Life

6.2.3 Moisture Content Measurements-Methodology Development

** Vacuum Oven Method vs. Conventional Oven Method

** Grinding the samples: Blender vs. Mortar & Pestle

** Time of drying: 24 hrs vs. 48 hrs vs. 72 + hrs

** Open aluminum dishes vs. Covered aluminum dishes

Moisture Content Methodology Development		
Comparing Weighing Dishes Design		
Open Dish vs. Dish with Cap		
Trail	<<<<Weighing Dish Design>>>>	
#	Opened	Sealed
	% H ₂ O w.b.	% H ₂ O w.b.
1	2.66	2.76
2	3.23	3.27

The sealed dish and opened dish methods gave results that are within 1 to 3% of each other. This difference was kept to a minimum as long as desiccators were used for cooling the samples and weights were taken quickly.

Moisture Content Methodology Development		
Comparing Grinding Techniques		
Blender vs. Mortar & Pestle		
Trail	<<<<<<Grinding Technique>>>>>>	
#	Blender	M&P
	% H ₂ O w.b.	% H ₂ O w.b.
Set 1	2.18	2.47
Set 2	2.68	2.74
Set 3	3.21	3.29
Set 4	3.05	3.07
Set 5	4.38	4.37
Set 6	3.39	3.41
Set 7	4.66	4.69
Note: There is a slight tendency for moisture level results from M&P preparations to be higher than of those prepared by a blender. However, with the exception of the first set the difference is insignificant		

Moisture Content Methodology Development				
Comparing Drying Techniques				
Vacuum Oven Method vs. Conventional Oven Method				
Trail #	<<<<<<<<<<Drying Technique>>>>>>>>>			
	Vacuum	100C	Difference	%
	% H ₂ O w.b.	% H ₂ O w.b.		Difference
1	2.66	3.23	0.57	17.65
2	2.76	3.27	0.51	15.60
3	2.71	3.25	0.54	16.62
4	2.68	3.21	0.53	16.51
5	2.74	3.29	0.55	16.72
6	3.10	4.75	1.65	34.74
7	3.23	4.74	1.51	31.86
8	3.56	4.78	1.22	25.52
9	3.54	4.66	1.12	24.03
10	3.05	4.38	1.33	30.37
11	3.07	4.37	1.30	29.75
12	3.05	4.38	1.33	30.37
13	3.39	4.66	1.27	27.25
14	3.41	4.69	1.28	27.29
15	3.42	4.72	1.30	27.54
16	2.67	3.65	0.98	26.85
17	2.58	3.63	1.05	28.93
18	3.12	4.57	1.45	31.73
19	3.52	4.52	1.00	22.12
20	3.54	4.39	0.85	19.36
21	3.44	4.47	1.03	23.04
Note: The data above illustrate that measuring the moisture content of Vegetable Crackers using the Conventional method consistently give results that are about 15% to 30% higher than the Vacuum Oven Method.				

The data above illustrates that measuring the moisture content of vegetable crackers using the Conventional Oven Method consistently give results that are about 15% to 30% higher than those obtained by the vacuum method.

Conclusions of Methodology Development

- A) The Vacuum Oven Method consistently gave lower moisture content results than the Conventional Oven Method.
- B) The grinding and homogenizing the sample in preparation for drying did not have significant difference on the results.
- C) 90% + of the moisture was removed from the samples within 24 hours in both drying methods. However, "Full" drying (no further changes in samples' weights) was accomplished after 48 hours and remained stable to 120 hrs (maximum time period tested).
- D) The results were practically the same using the open or covered aluminum dishes, as long as desiccators were used to hold the samples before weighing.

6.2.4 Moisture Content and Water Activity Measurements

6.2.4.1 Procedures for Measuring Water Content and Water Activity in Cookies and Crackers

Sampling:

Water content analysis was always carried out in duplicates (samples A & B) and each sample was divided into two or three dishes for drying and weighing. The samples were taken from a variety of packages/containers depending on the product (each product had its own package arrangement) and on the phase of the study we were sampling. For example during the sorption isotherm part of the study the cookies/crackers were placed inside specially prepared tubs (see picture).

In each sampling event several cookies/crackers were taken from the master bag, box or tub and placed in small marked Ziploc bags. The air from the bag's headspace was squeezed out and the bag was sealed immediately.

Preparing the Samples:

The product was then grounded and "homogenized" using a laboratory blender or a Mortar and Pestle, or modified Mortar & Pestle "In-the-Bag" (see section on Methodology Development). Grinding time was kept to a minimum. The ground product was immediately placed back in the Ziploc bag, and the sealed bag was placed in a second bag to minimize moisture migration into or out of the product.

Water Activity Measurements:

At this stage samples were taken for Water Activity (A_w) measurements. The ground product was placed in special plastic canisters to fill about a third of the dish. The dish was then sealed with a cap. A_w measurements were taken within an hour of sample preparation.

Water Activity Meter

by: Aqua Lab



Weighing and Drying:

“Homogenized” product was spooned out of the marked bags into marked and pre-weighed aluminum dishes. The dishes with the “wet” product were weighed and then placed in either Vacuum Oven or Conventional Oven for drying. Moisture content was measured using both the Vacuum Oven and the Conventional Oven methods on all samples (see section on Methodology Development). After about 48 hrs the aluminum dishes with the dried product were taken out of the oven and placed in desiccators to cool down to room temperature. Once at room temperature the dishes with the dried product were taken.

Vacuum Oven



Conventional Oven Showing Drying Dishes Inside and in an Open Desiccator



Calculations:

The moisture content was calculated from the resulting measurements by weight difference between the sample's net weight before and after drying. The % moisture was calculated in two ways: A) "As is" or wet

basis, by dividing the moisture content by the original net sample weight. B) Dry basis, by dividing the moisture content by the net weight of the sample after drying.

6.2.4.2 Water Content and Water Activity Results

Storage Test Sampling Events

Five samples were taken for each of the four products

Sampling Events on days:

1
30
45
60
&
90

Day “0” is defined as the day the item was received at the Assembler’s Storage Facilities

The tables below summarize the measurements of water content and water activity of cookies and crackers stored in a commercial assembler operation for a period of 90 days. It is evident in this section and throughout the study that the conventional oven method and the vacuum oven method give moisture content results, which differ significantly from each other. It is also evident that there are large initial variations within the products’ lots. For example the shortbread cookies are packed in small 6 count metalized PET pouches. Analyzing cookies from different packs that otherwise should have had the same product ‘history’ showed significant differences in water activity (0.117 to 0.228) and moisture content (1.51% to 2.74%, vacuum oven method).

Moisture Content & Aw of Product from Storage at Wornick Foods

Shortbread Cookies

Time in Storage (days)	Aw - Water Activity	% H2O (Vac Method)	% H2O (Oven Method)
0	0.170	2.07	
	0.161	2.18	3.39
	0.152	1.99	3.31
	0.228	2.74	3.61
	0.117	1.51	2.98
	0.153	2.08	3.31
0 MRE	0.147	2.13	3.11
	0.157	2.43	3.32
30	0.144	2.48	3.18
	0.131	1.49	3.17
45	0.139	2.36	3.30
60	0.173	2.21	3.28
90	0.216	2.29	3.49

Note: Product Lot #3157, Wornick Lot #3007124

Shortbread cookies are packed in high barrier metalized PET and so are not affected significantly by fluctuations in relative humidity during storage.

Moisture Content & Aw of Product from Storage at Wornick Foods

Vegetable Crackers

Time in Storage (days)	Aw - Water Activity	% H2O (Vac Method)	% H2O (Oven Method)
0	0.092	2.67	3.00
0 MRE	0.120	2.67	3.65
	0.085	1.85	3.00
30	0.172	3.42	4.72
45	0.189	3.52	4.52
60	0.213	3.54	4.47
90	0.157	2.19	3.68

Note: Product Lot #2350A. Wornick Lot # 3008122.

Wornick Moisture measurement at T=0 was 3.3%

Vegetable Crackers bulk pack includes a bag-in-a box feature. The bag is of high density PE and oversized in a way that allows for a large overlap fold at the top, once the crackers were placed in the box. This provides a reasonable protection for an intermediate storage periods. However, this type bag will not protect the product well if exposed to very high humidity air for prolonged periods or if exposed to liquid water.

Moisture Content & Aw of Product from Storage at Wornick Foods

Oatmeal Cookies

Time in Storage (days)	Aw - Water Activity	% H2O (Vac Method)	% H2O (Oven Method)
0	0.314	4.70	6.09
0 MRE	0.328	4.74	6.05
30	0.365	5.33	6.23
45	0.382	5.00	6.19
60	0.440	5.92	6.68
90	0.425	5.23	6.71

Note: Product Lot____, Wornick Lot #____

The Oatmeal Cookies bulk wrap did not provide sufficient protection against moisture changes as influenced by relative humidity in storage. The bags containing the cookies were not sealed properly leaving large openings at the top. Over the 90 days storage the Oatmeal Cookies gained moisture. It should be pointed out that the moisture content of the Oatmeal Cookies was boarder-line spec from the start. Even though the storage test was carried during the (relatively low RH) winter months the product quality was judged inferior after 60 to 90 days storage (see texture and sensory sections).

**Moisture Content & Aw of Product
from Storage at Wornick Foods**

Cheese Combos

WHOLE			
Time in Storage (days)	Aw - Water Activity	% H2O (Vac Method)	% H2O (Oven Method)
0	0.040	1.18	2.37
	0.056	0.97	3.84
0 MRE	0.076	1.35	2.92
	0.070	1.29	2.95
30	0.046	0.55	2.64
	0.044	0.60	2.37
45	0.055	1.07	2.28
60	0.043	0.56	2.10
90	0.050	1.29	2.82

Note: Product Lot #3014, B6,

Moisture Content & Aw of Product from Storage at Wornick Foods

Cheese Combos

SHELL			
Time in Storage (days)	Aw - Water Activity	% H2O (Vac Method)	% H2O (Oven Method)
0	0.050	1.52	2.29
	0.060	1.20	2.90
0 MRE	0.095	2.15	
	0.069	1.42	
30	0.047	0.51	2.35
45	0.064	1.48	2.25
60	0.044	0.41	1.93
90	0.059	1.71	2.44

Note: Product Lot #3014, B6,

The Combos are packed well in a metalized PET sealed pouch. There was no trend of moisture gain or loss. However, there is a fairly large variation in apparent moisture content sample to sample, because of several reasons. The weight ratio between the shell and the cheese core is very inconsistent, from near empty centers to overflowing. The core is sensitive to oxidation, which influence its weight. The amount of salt on the surface is highly variable. And clean separation of core from shell for analytical purposes is difficult.

Moisture Content & Aw of Product from Storage at Wornick Foods

Cheese Combos

CENTER			
Time in Storage (days)	Aw - Water Activity	% H2O (Vac Method)	% H2O (Oven Method)
0		0.73	3.20
	0.134	0.72	7.08
0 MRE		0.81	
30	0.078	0.72	3.56
45	0.064	0.50	3.11
60	0.128	0.72	2.45
90	0.112	0.74	5.61

Note: Product Lot #3014, B6,
The composition of the center is susceptible
to oxidation which influence results

In conclusion:

The materials and seal integrity of bulk packaging of cookies and crackers in intermediate storage is very important in maintaining moisture content within specification limits. More precise instructions should be given in the spec for the type of bulk bags required and they should be sealed.

6.2.5 Water Sorption Isotherms

For each product there is a set relationship between Water Activity and Water Content. It is important to note that water activity and not moisture content is more closely related to quality changes mechanisms such as chemical reaction rates and microbial growth. The establishment of sorption isotherms illustrate those relationships and help us understand what changes in storage temperature or in water content might mean to shelf life. Also, this relationship allows us to measure water activity and infer moisture content (if desired). Water activity is easier to measure, it is quicker and it is easy to calibrate. Moisture content techniques don't have standards by which to calibrate lab to lab methodologies. Aw measurements can be calibrated easily and simultaneously by the use of salt solutions (which are available commercially). For example what is the impact of packing cookies at 70F and 5% moisture content on the water activity and product quality and shelf life as this product is stored at 100F. The establishment of sorption isotherms describe those relationships for us.

6.2.5.1 Temperature & Humidity Control

In order to establish sorption isotherms a procedure was established to assure that the products are kept at known and stable temperature and relative humidity conditions for a period of time to reach equilibrium.

The different levels of relative humidity were set and maintained by using a series of saturated salt solutions. The salts used and their relative humidity at saturation is given in the table below.

Saturated Salt Solutions Water Activity & Relative Humidity

Salt Name	Aw	80F	100F	120F
		% RH	% RH	% RH
Drierite	0.000	0.0	0.0	0.0
LiCl	0.111			11.1
LiCl	0.112		11.2	
LiCl	0.113	11.3		
MgCl ₂	0.308			30.8
MgCl ₂	0.318		31.8	
MgCl ₂	0.326	32.6		

K ₂ CO ₃	0.432	43.2		
MgNO ₃	0.462			46.2
MgNO ₃	0.492		49.2	
NaBr	0.568	56.8		
KI	0.665		66.5	
KI	0.684	68.4		
NaCl	0.745			74.5
NaCl	0.748		74.8	
NaCl	0.752	75.2		
Total number of Conditions:		7	6	5

Storage temperatures were maintained by using environmental chambers set at 80F, 100F and 120F. Temperature was monitored using data loggers.

Special tubs were prepared (see pictures). The saturated salt solutions were placed at the bottom of the tubs. A wire mesh divider was secured to separate between the solution and the product. The product was then layered on top of the wire mesh base and wire mesh dividers were used to assure free circulation of air within the tub. The tubs were sealed and placed in the environmental chambers for the duration of the study.

Empty Constant RH Tub with Wire Mesh dividers and Salt Solution on the Side



Constant RH Tub with Shortbread Cookies



Constant RH Tub with Combos showing the Wire Mesh Dividers



Environmental Constant Temperature Chamber

with

Constant RH Tubs Filled with Products



Products for Moisture Isotherm determination were placed under 20 different conditions of temperature (3) and relative humidity (5 to 7). Initiation of the test took place shortly after product arrival at Rutgers.

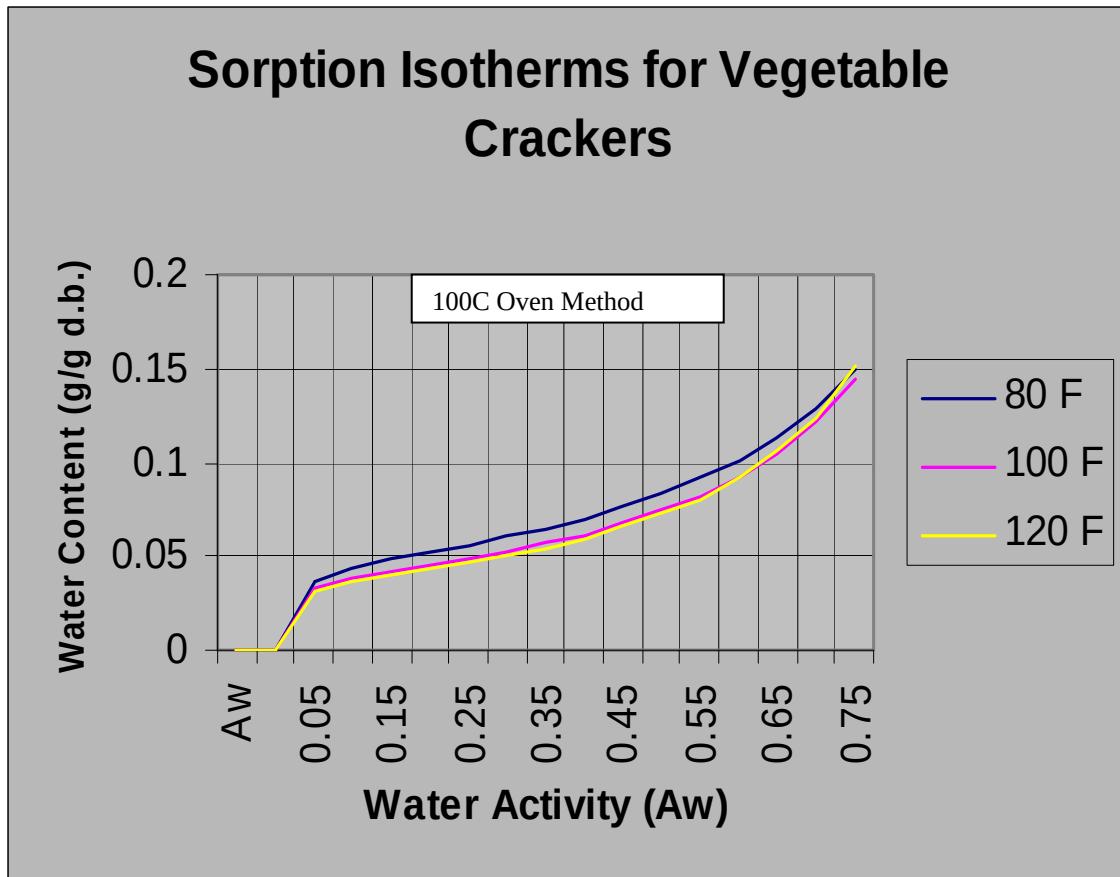
- | | |
|----------------------|---------|
| • Shortbread Cookies | 1/21/03 |
| • Cheese Combos | 1/21/03 |
| • Vegetable Crackers | 1/29/03 |
| • Oatmeal Cookies | 2/4/03 |

To assure that equilibrium was achieved samples were taken periodically and A_w (and moisture content) were taken. When no changes in A_w or water content were evident it was concluded that equilibrium was achieved and final moisture content was recorded.

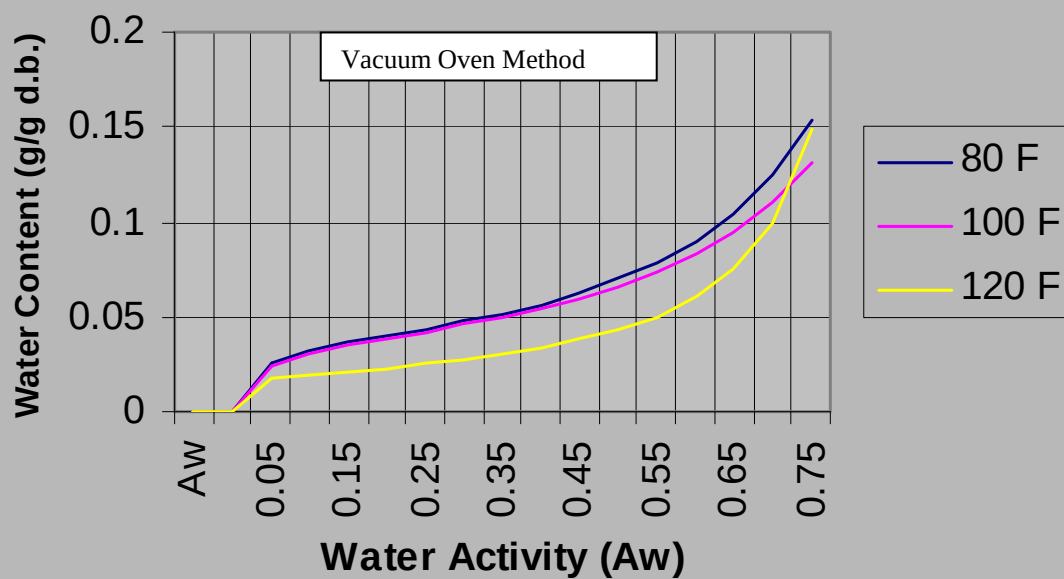
6.2.5.2 Moisture Sorption Isotherms

The following graphs illustrate the sorption isotherms of the Selected Baked Goods in this study. Sorption Isotherms were constructed using water content data obtained by two drying methods (vacuum oven and conventional oven). The sorption isotherms show the relationship between the amount of moisture contained in the product and the relative humidity in the air at specific storage temperature. This

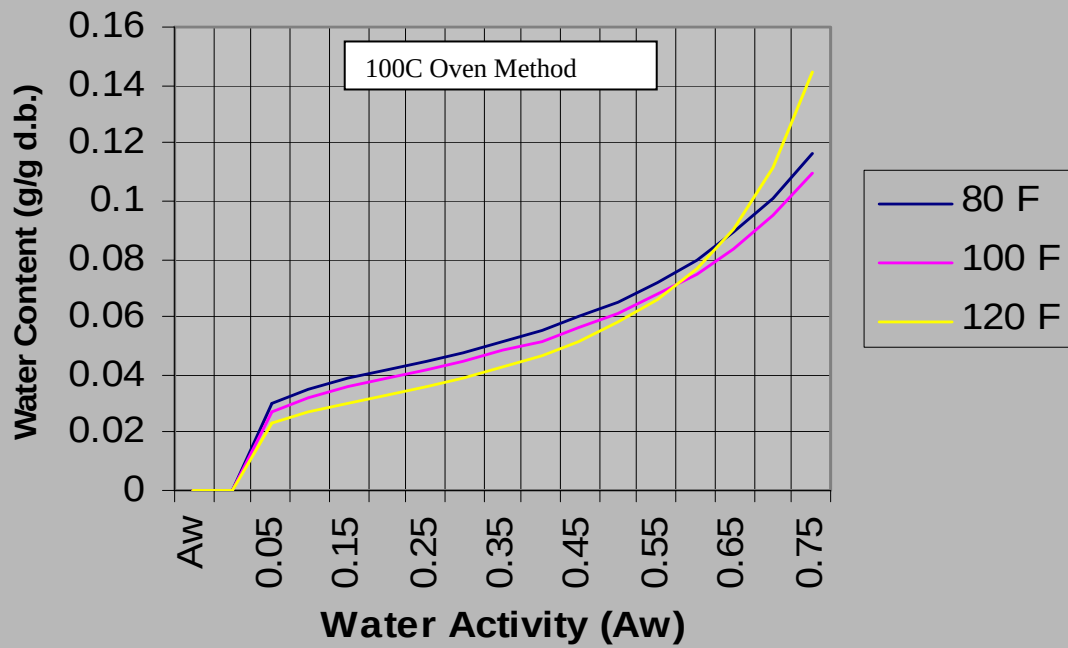
relationship is shown at equilibrium. The experimental raw data and the tabulated form of the sorption isotherms as calculated using Iglesias and Chirife, 1982 method is presented in Appendix A.



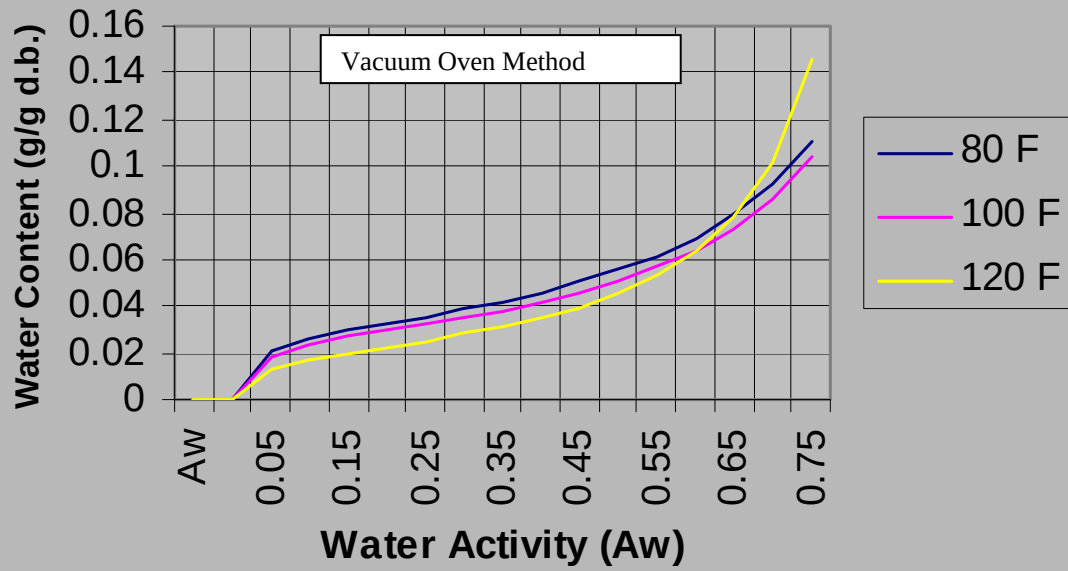
Sorption Isotherms for Vegetable Crackers



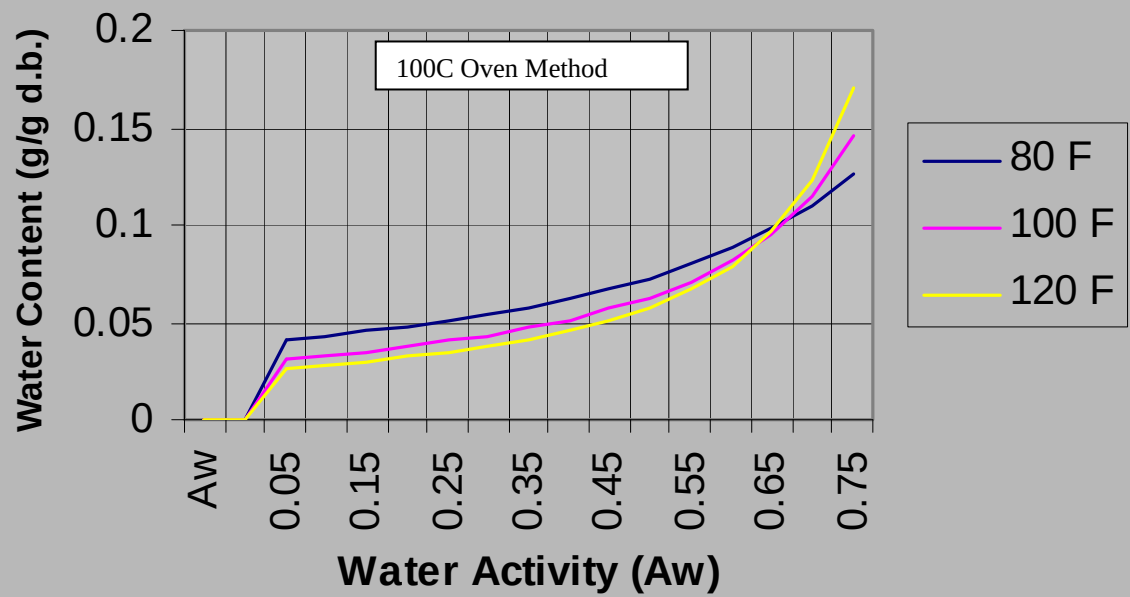
Sorption Isotherms for Shortbread Cookies



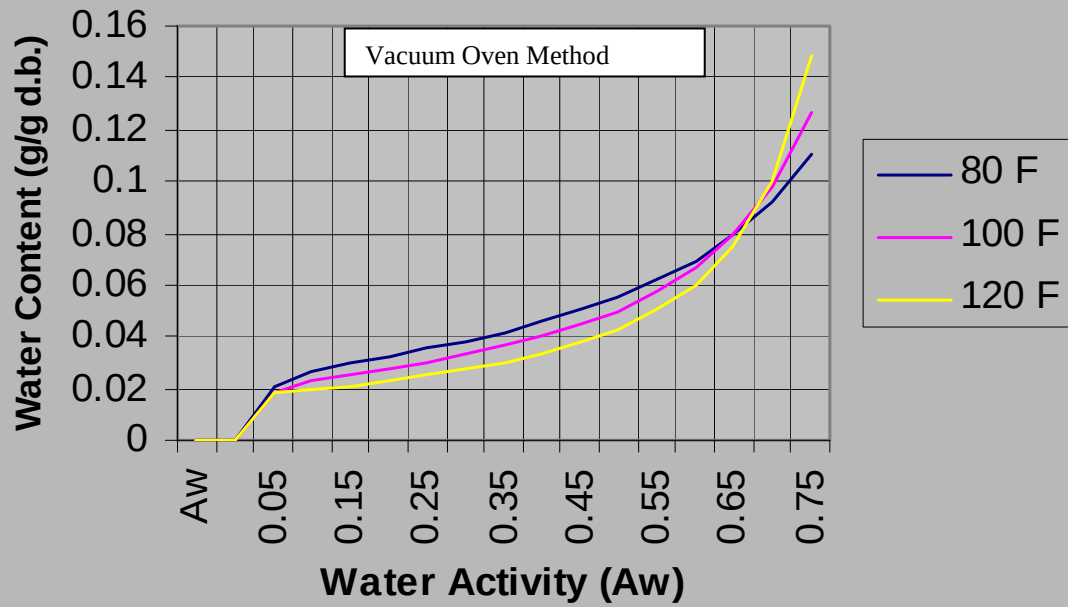
Sorption Isotherms for Shortbraed Cookies



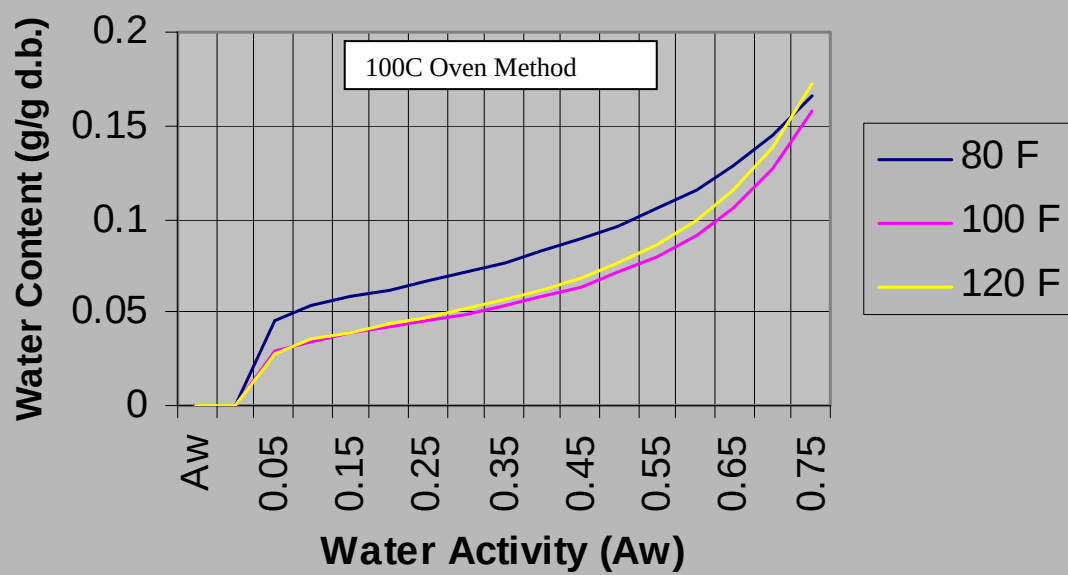
Sorption Isotherms for Oatmeal Cookies



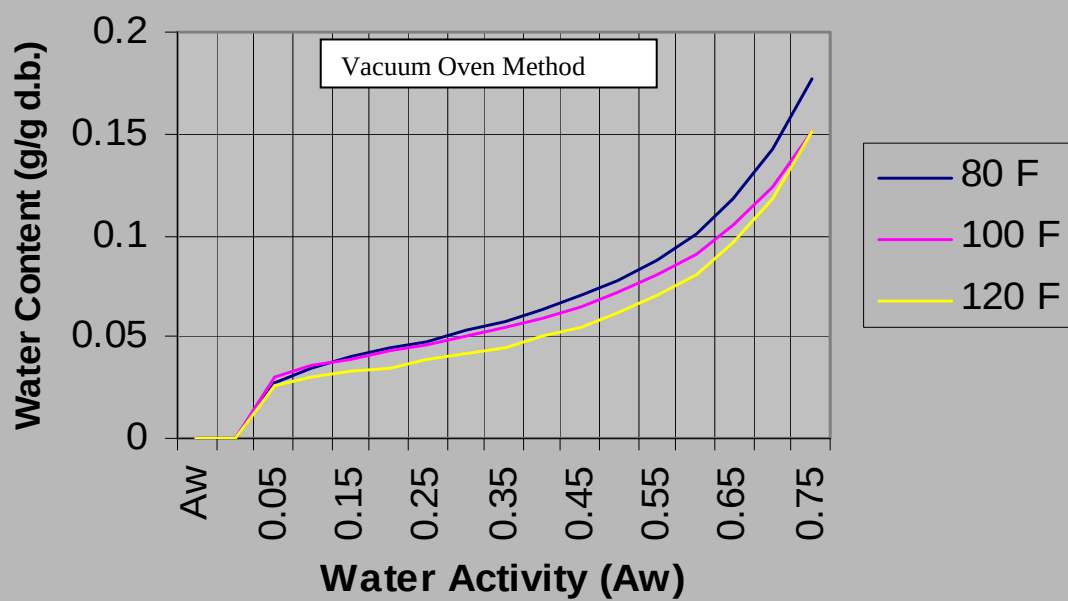
Sorption Isotherms for Oatmeal Cookies



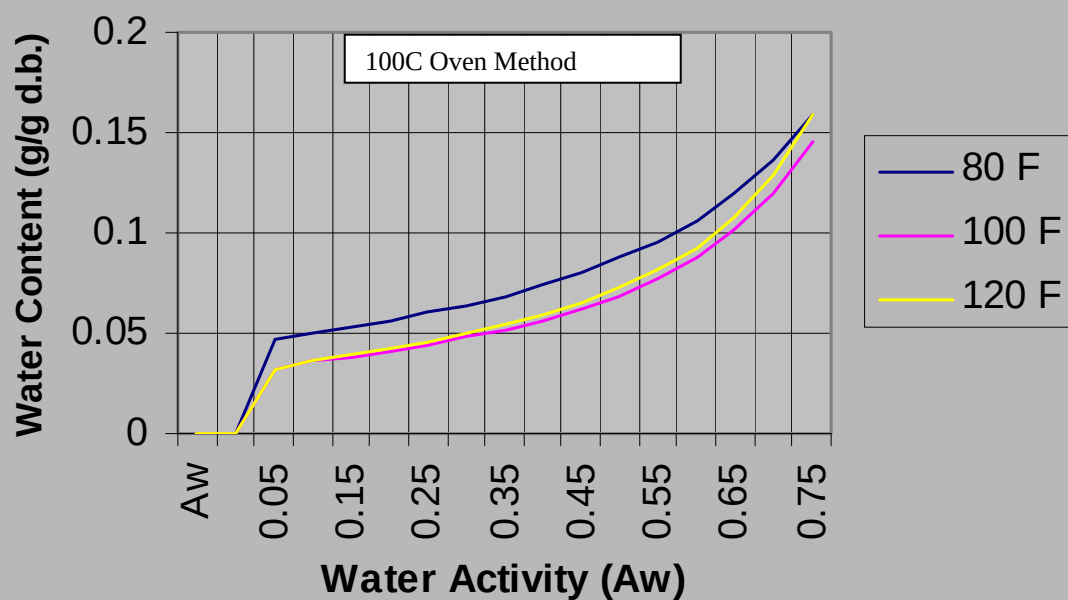
Sorption Isotherms for Cheese Combos-Shell Portion

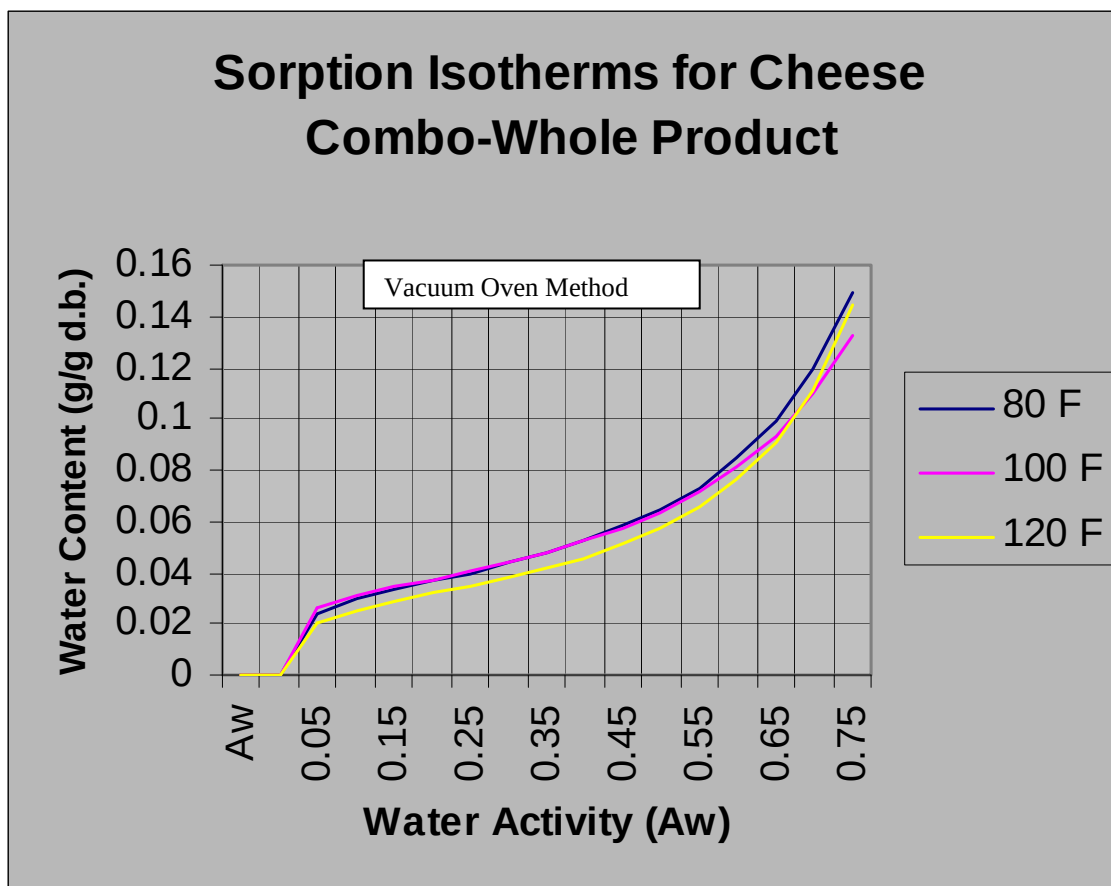


Sorption Isotherms for Cheese Combos-Shell Portion



Sorption Isotherms for Cheese Combos-Whole Product



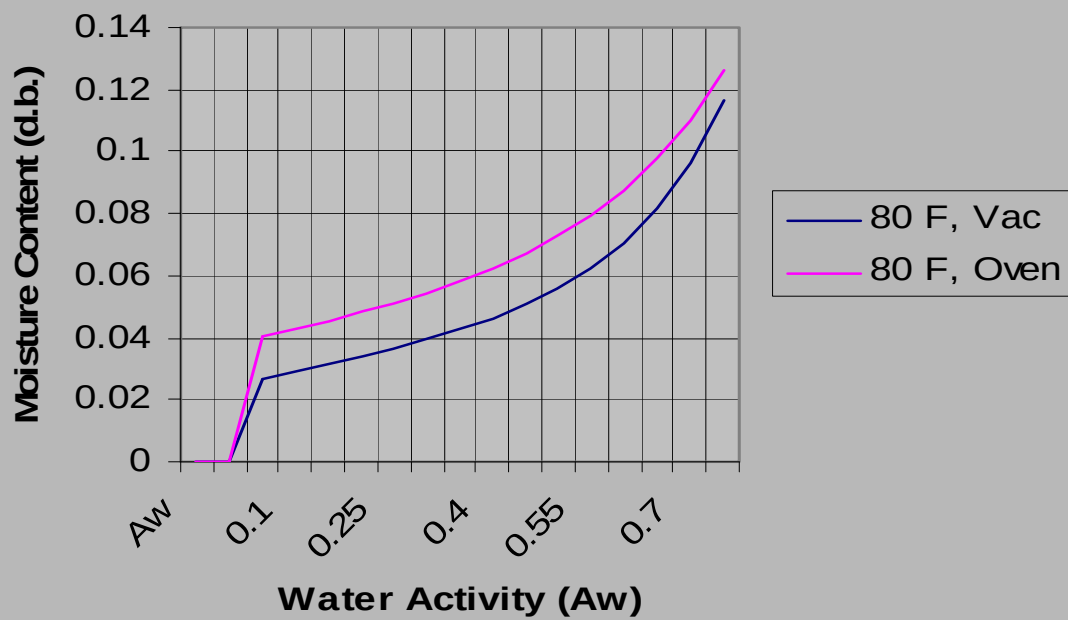


The following graph compares the sorption isotherms of Oatmeal Cookies as constructed using data from two different drying techniques. There is a substantial difference between the two methods with potentially, significant implication on product quality.

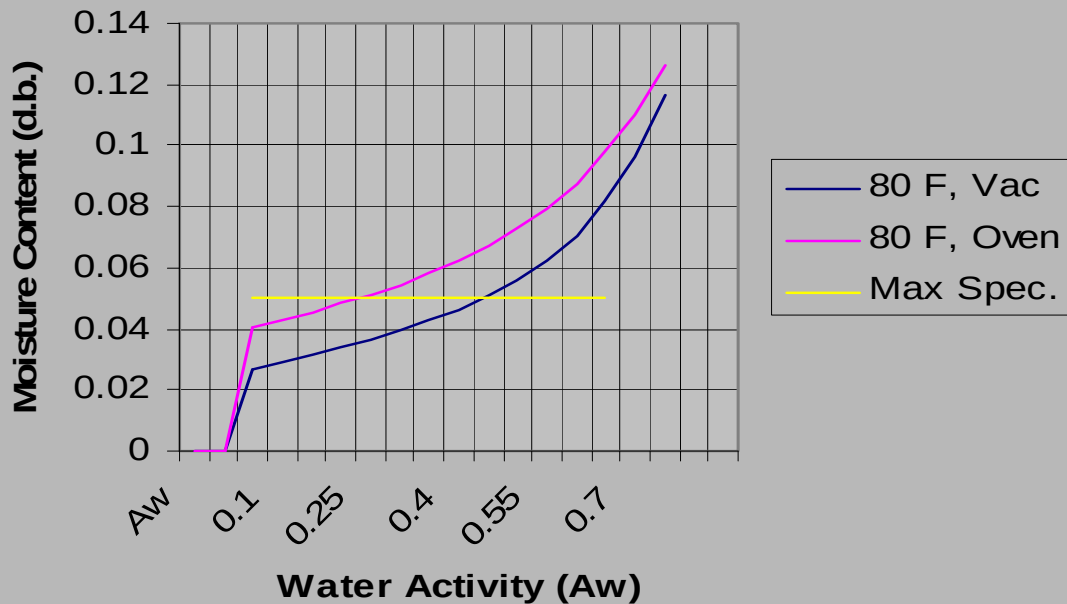
The graph with the yellow horizontal line shows the current moisture level specification for Oatmeal Cookies (at 5%). It is evident that using the vacuum method the level of 5% is associated with water activity of about 0.45 while with the oven method the spec is exceeded at water activity of about 0.30.

It is clear that the drying method is a critical variable in establishing and monitoring the moisture content spec. The site-to-site variability in executing these tests should be looked at as well. There are no “standard samples” for moisture content measurements. The only way to make sure that moisture measurements are done properly in different laboratories is through a round robin tests on samples tested by a “referee lab.” It is in part for this reason that we recommend the use of water activity measurements as the way to specify water in cookies and crackers.

Sorption Isotherm, Oatmeal Cookie, Vacuum vs Conventional Oven Method



Sorption Isotherm, Oatmeal Cookie, Vacuum vs Conventional Oven Method

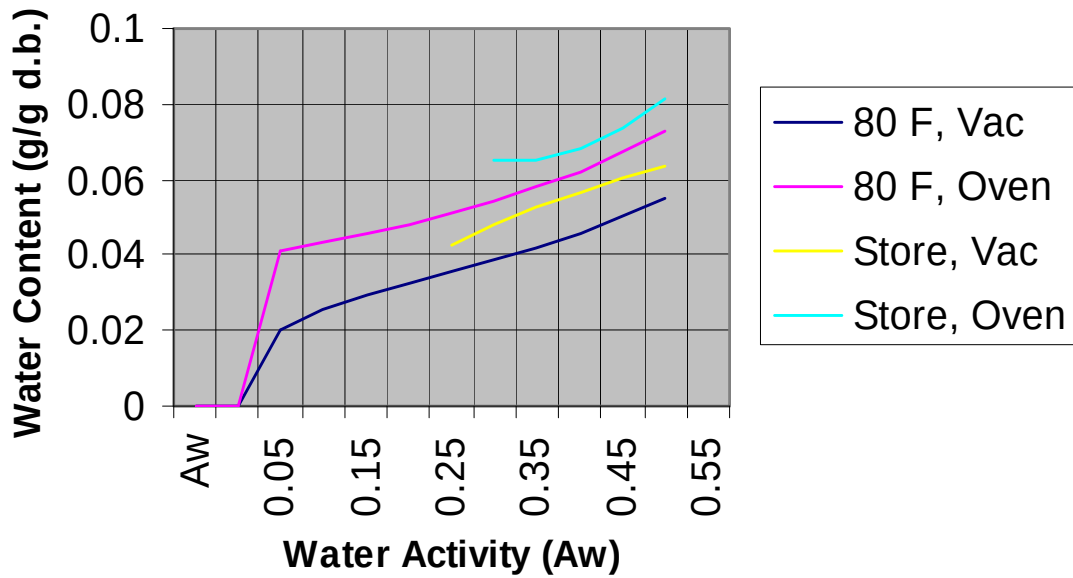


The following two graphs compare the moisture content data for Oatmeal Cookies and Vegetable Crackers from storage to the sorption isotherms data of the same products. It can be seen that the data falls in parallel lines (within experimental variation) to the isotherms.

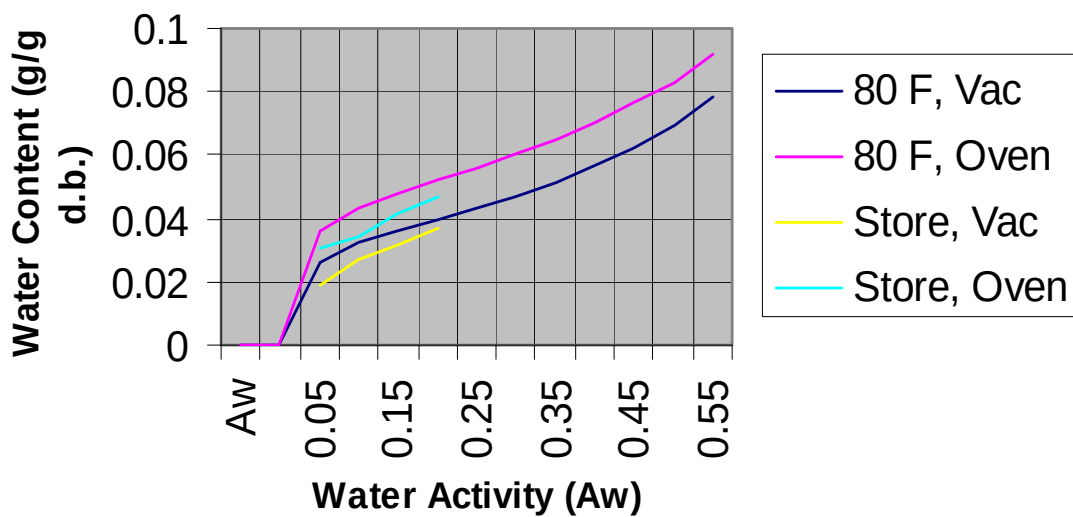
Variability is primarily due to the fact that the isotherms are for 80F and the product from storage is at slightly lower temperature (about 70F). Also, sorption isotherms are constructed on product in equilibrium, while product from storage, although close, is not at full equilibrium.

These graphs however show the value of sorption isotherms as tools for understanding moisture content behavior in a product, and as a tool for creating specifications for this parameter.

Oatmeal Cookies: Moisture and Aw Data from Sorption Isotherms and Storage



Vegetable Crackers: Moisture and Aw Data from Sorption Isotherms and Storage



6.3 Texture Measurements

6.3.1 Instrumental Texture Measurements

- A TA XT2 Texture Analyzer was used.
- A Three Point Bend Cell was used to measure texture changes with Vegetable Crackers, Oatmeal Cookies and Shortbread Cookies. A different Sheering Device (with a sharp edge) was used for Cheese Combos
- The testing equipment parameters were:
 - Distance between the “shoulders” of the two points bridge that held the sample
 - The speed at which pressure was applied to the sample by the plunger.
 - The distance the plunger traveled from point of contact with the sample.
- The following parameters were recorded:
 - Maximum Force to Breakage
 - Maximum Deflection at Breakage
 - Work Expended to Achieve Total Break

TA-XT2
Texture
Analyzer

with a

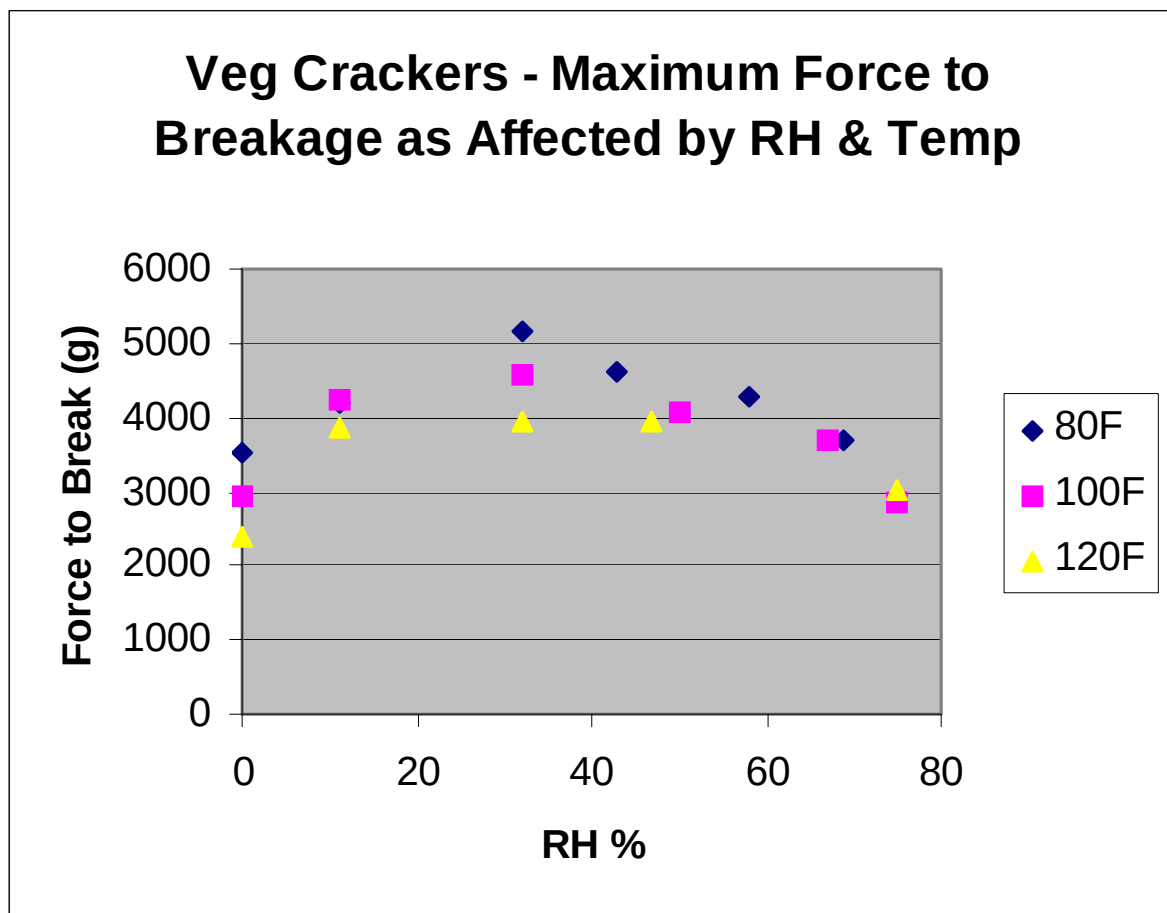
**3 Point Bend
Cell**



- 10 to 15 samples from each variable combination were used in order to document an average value for the lot. There is a large inherent variability in the cookies or crackers in the study.
- Average values were calculated. And data was summarized in tables and graphs (shown in next section).

6.3.1 Texture Measurements Results and Analysis:

The graph below illustrates the relationship between the relative humidity & temperature that a vegetable cracker is exposed to and the force required to break it in half. It is interesting to note that Too much water or too little water results in 'weakening' of the structure. However, in terms of sensory perception they might be very different.

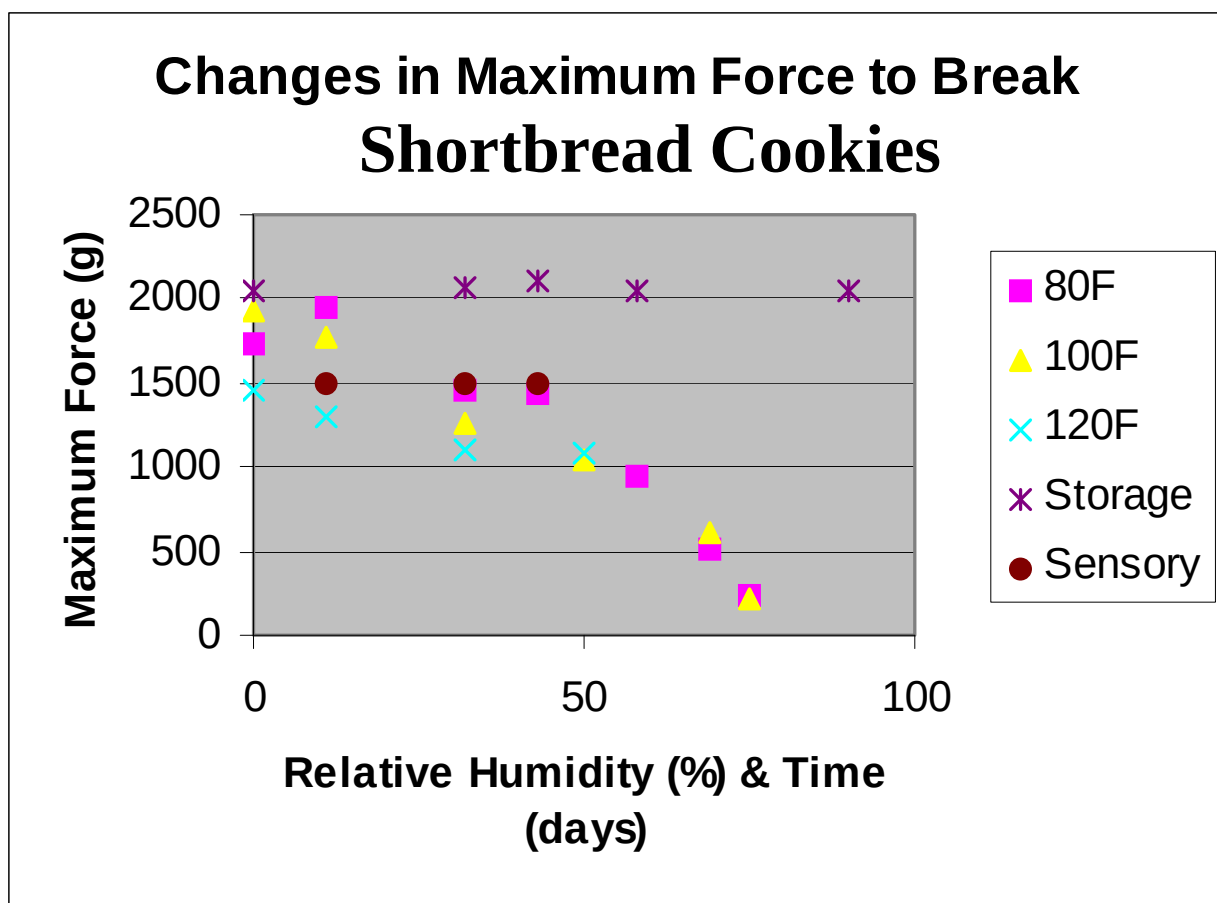


The next table & graph illustrate the effect of water activity and maximum force required to break a shortbread cookie. In this case increase in water activity results in reduction in force. The cookies become softer, but less desirable from a sensory satisfaction perspective. The maximum force measurements obtained from shortbread cookies retrieved from storage is also shown (the X axis is both %RH and Days of storage). The minimum force acceptable, as determined by correlating with a sensory panel is indicated as well at 1,500 g.

Texture Analysis of Shortbread Cookies

Stored at 80F, 100F, 120F & Various Aw

% RH or Days	80F Max Force g	100F Max Force g	120F Max Force g	Storage Max Force g	Sensory Max Force g
0	1,738	1,936	1,453	2,045	1,500
11	1,954	1,772	1,290		
32	1,464	1,251	1,107	2,074	1,500
43	1,434			2,115	1,500
50		1,046	1,091		
58	942			2,051	1,500
69	522	620			
75	239	215			
90				2,045	1,500



The texture measurements for Cheese Combos are summarized in the tables below. There are trends in instrumental measurement that correlate to sensory quality perceptions. In general the amount of force required to bend/break the sample goes down with increase in moisture and A_w . The product is more flexible and so it is tougher; requiring more energy and further travel of the plunger to affect a break.

Summary of Texture Measurements:
Cheese Combo
80F

Aw	Slop g/mm	Max Force g	Distance mm	Area g*mm
0.000	3,713	5,170	3.04	8,430
0.113	3,854	5,935	2.58	9,108
0.326	3,820	6,486	2.86	10,264
0.432	2,854	6,083	3.17	11,004
0.568	2,799	6,252	3.51	12,767
0.684	1,381	4,518	4.12	10,528
0.752	608	3,671	4.78	8,735
Std Div	220 - 980	650 - 1,525	0.4 - 1.0	1,925 - 5,150

Summary of Texture Measurements:
Cheese Combo
100F

Aw	Slop g/mm	Max Force g	Distance mm	Area g*mm
0.000	3,311	5,033	2.34	7,353
0.112	3,547	5,490	2.50	7,831
0.318	3,262	5,902	3.05	9,859
0.492	2,661	5,954	3.41	11,426
0.665	2,078	6,128	4.22	14,397
0.748	657	4,206	4.73	9,789
Std Div	370 - 1,050	1015 - 1,730	0.4 - 0.95	3,020 - 4,500

Summary of Texture Measurements: Cheese Combo 120F

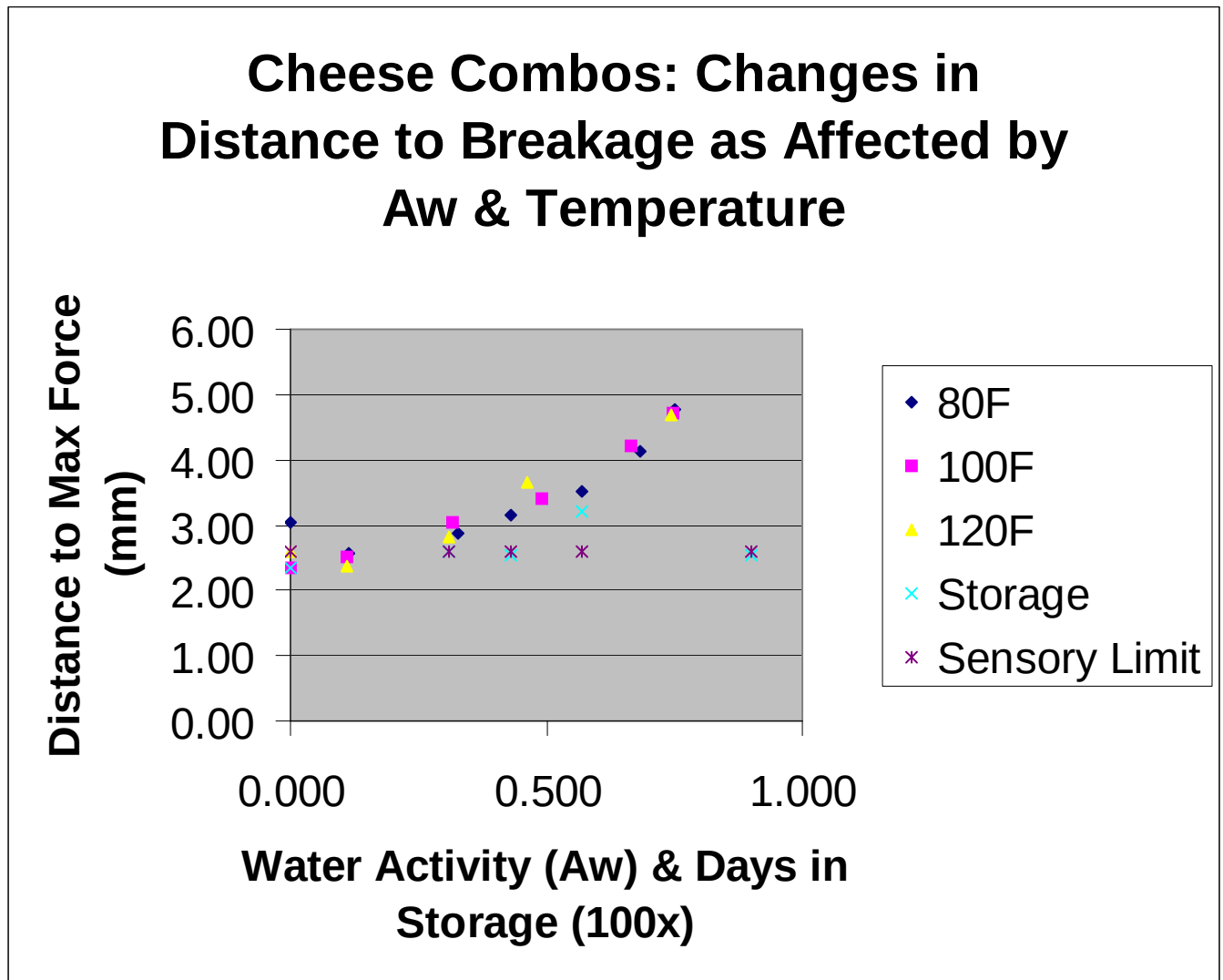
Aw	Slop g/mm	Max Force g	Distance mm	Area g*mm
0.000	3,373	5,091	2.60	7,313
0.111	3,817	5,132	2.36	6,945
0.308	2,983	5,943	2.83	9,814
0.462	2,288	6,559	3.65	12,939
0.745	1,014	5,276	4.70	12,642
Std Div	410 - 1,120	1,035 - 1,635	0.4 - 0.9	3,200 - 4,210

The Cheese Combos stored at an assembler's plant for 90 days remained in good quality, as measured by the TA XT2. Sensory evaluations indicated that product was judged to be crisp and liked overall when the force required for deflection of 1 mm was greater than 3350 g*mm, but the distance for breakage was less than 2.6 mm (see graphs below).

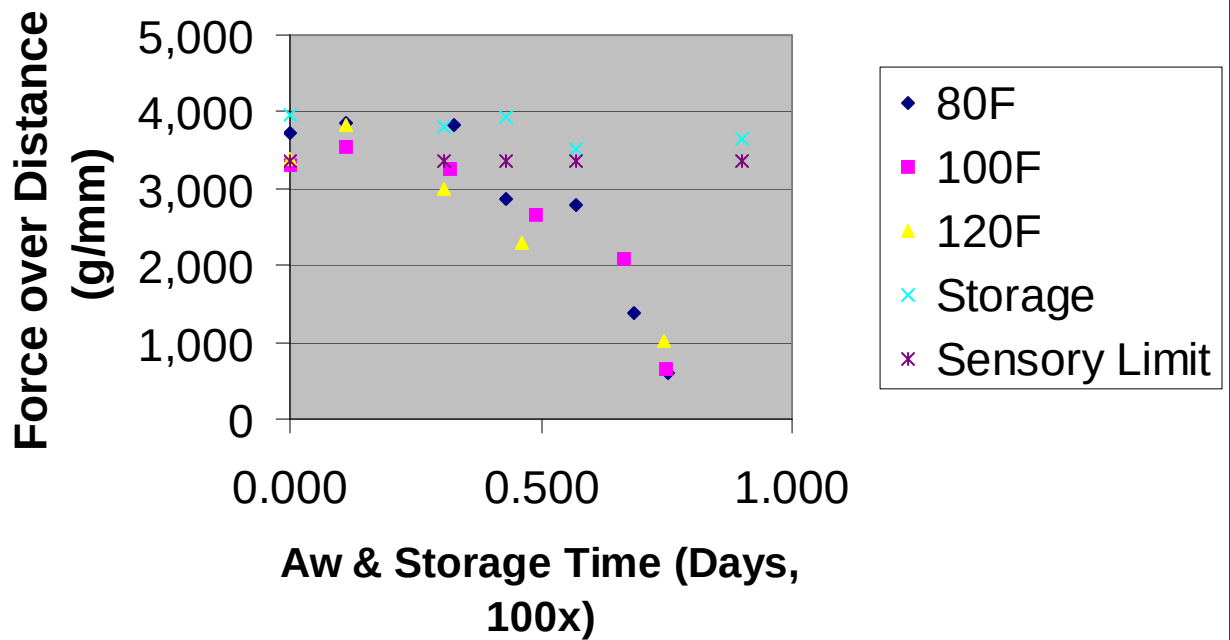
Summary of Texture Measurements: Cheese Combo Storage Test

Time Days	Slop g/mm	Max Force g	Distance mm	Area g*mm
0	3,962	4,894	2.34	6,290
30	3,799	5,287	2.59	7,713
45	3,934	5,534	2.53	8,078
60	3,513	5,611	3.20	10,359
90	3,651	5,174	2.53	7,564
Std Div	860 - 1,410	1,040 - 1,295	0.75 - 0.95	2,990 - 4,240

The graphs below illustrate the relationship between the force and penetration distance required for breakage of Cheese Combos. The graphs also superimpose the evaluation of product from storage and how it falls within the quality parameters.



Cheese Combos: Changes in Force/Distance behavior as affected by Aw and Temperature



The texture measurements for Oatmeal Cookies are summarized in the tables below. There are trends in instrumental measurement that correlate to sensory quality perceptions. In general the amount of force required to break the sample goes down with increase in moisture and Aw. This behavior correlates well with sensory evaluation.

Oatmeal Cookies were judged to be crisp and liked overall when maximum force for breakage was at least 6,000g.

Summary of Texture Measurements: Oatmeal Cookies 80F

Aw	Max Force g	Distance mm	Area g*mm	Tot. Area g*mm
0.000	6,033	1.09	2,356	2,762
0.113	7,427	0.81	2,636	3,233
0.326	7,671	1.12	3,820	4,491
0.432	7,171	1.18	3,499	4,279
0.568	6,290	1.21	3,496	4,931
0.684	1,634	1.59	1,255	2,842
0.752	425	1.65	450	1,523
Std Div	36 - 1,200	0.15 - 0.65	65 - 1,035	165 - 980

Summary of Texture Measurements: Oatmeal Cookies 100F

Aw	Max Force g	Distance mm	Area g*mm	Tot. Area g*mm
0.000	6,790	1.11	3,044	3,666
0.112	7,064	1.31	3,088	3,538
0.318	7,348	1.13	3,412	4,087
0.492	7,185	1.17	3,810	4,899
0.665	2,038	1.48	1,397	2,847
0.748	273	2.23	393	1,405
Std Div	35 - 1,230	0.1 - 0.8	60 - 1,230	145 - 1,245

Summary of Texture Measurements: Oatmeal Cookies 120F

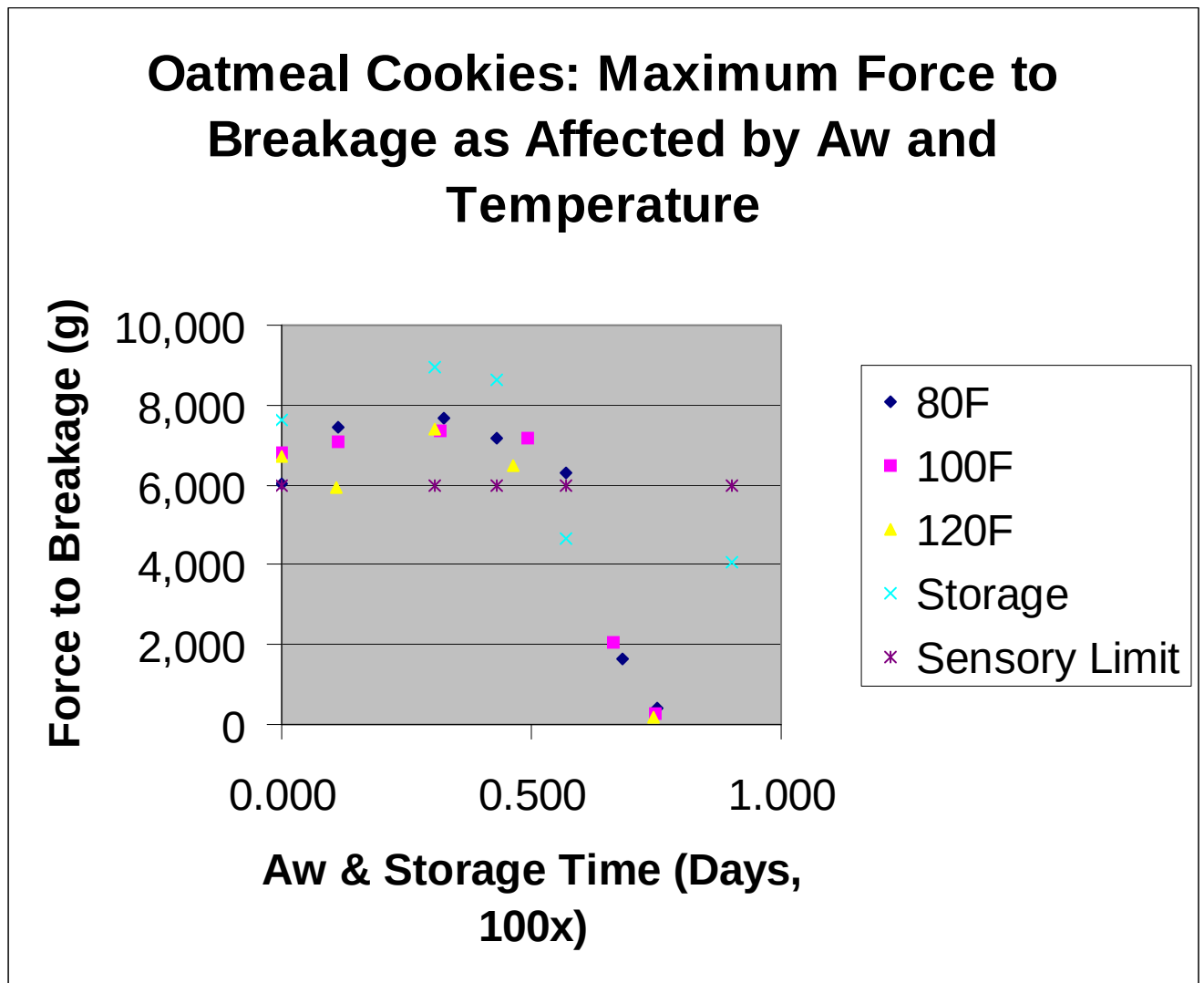
Aw	Max Force g	Distance mm	Area g*mm	Tot. Area g*mm
0.000	6,716	0.99	2,750	3,307
0.111	5,955	0.87	2,110	2,803
0.308	7,404	1.10	3,024	3,565
0.462	6,497	1.16	3,092	3,840
0.745	169	3.18	381	1,030
Std Div	5 - 1,470	0.15 - 0.5	60 - 910	115 - 875

The Oatmeal Cookies stored at an assembler's plant for 90 days deteriorated in quality, as measured by the TA XT2. Product after 60 and 90 days storage fell below 6,000g maximum force for breakage. Indeed a sensory panel found that Oatmeal Cookies retrieved from the assembler after 90 day were much less crispy than control and much less liked overall (see sensory evaluation section).

Summary of Texture Measurements: Oatmeal Cookies Storage Test

Time days	Max Force g	Distance mm	Area g*mm	Tot. Area g*mm
0	7,633	1.32	4,347	5,002
30	8,970	1.70	7,788	12,886
45	8,621	1.98	8,816	16,922
60	4,671	1.37	3,404	9,463
90	4,066	1.20	2,486	7,320
Std Div	365 - 1,120	0.15 - 0.25	480 - 1,080	850 - 3,080

The graph below illustrates the relationship between the maximum force required for breakage of Oatmeal Cookies. The graph also superimposes the evaluation of product from storage and how it falls within, or outside the quality parameters.



6.3.1 Texture Measurements Conclusions:

Correlation between instrumental texture measurements and sensory perceptions on the cookies and crackers have been established. The shortcoming of using the technology for QA purposes is the large variability that exist in the “normal” product. It makes the ability to spot small changes very difficult and it requires the use of a relatively large sample size to have any confidence in the results. Where the changes are large, such as the case with the Oatmeal Cookies from storage, the instrumental evaluation clearly spotted the reduction in sensory quality with product that was stored for 60 to 90 days.

6.4 Surface Color Measurements

6.4.1 Sampling for Color Measurements

Cookies and crackers from both Storage and Sorption Isotherm studies were selected arbitrarily for color measurements. Since the color measurements are non destructive in cases where the available sample pool was small that product was used later for measuring other parameters (such as moisture content). 10 to 12 samples were used for each measurement 'batch.'

6.4.1 Instrumental Color Measurements

- A Hunter Lab Color Meter was used.
- Standard white ceramic tile was used to calibrate the equipment
- The specimens (cookie or cracker) were placed on a regular white paper to provide a uniform background. Pre-test method development measurements showed that there was no/negligible effect of background on readings. The Cheese Combos, because of there small size and cylindrical shape were benefited from standardization.
- The sensor/camera unit was placed on the product; touching it lightly, and a reading was taken. 10 to 12 duplicate measurements of each variable were taken to obtain reliable average figures.
- Since coloration on the top and back sides of the cookies and crackers were different to begin with, we measured both throughout the study. Cheese Combos were the exception, we only took top side color.
- The following parameters were recorded:
 - 'L' Brightness
 - 'a' a Yellow to Red Scale
 - 'b' a Blue to Green

Color Meter shown with Calibration Tile & Shortbread Cookie being Tested



6.4.2 Color Measurements Results

The tables below contain summary of the 'L', 'a' and 'b' values describing the color of the Cheese Combos' shell after storage at various temperature and relative humidity conditions. There are trends that one can infer from the data, particularly the 'a' value scale (see chart below). However, the initial high variability in color among the cheese combo pieces makes it hard to attach significance to changes over the Aw range of 0.00 to 0.50.

Summary of Color Measurements:

Cheese Combo

80F

Aw	L	a	b
0.000	51.34	17.49	37.36
0.113	51.81	17.24	36.13
0.326	55.16	16.01	38.49
0.432	54.66	15.39	36.49
0.568	56.52	15.17	38.11
0.684	53.08	14.92	33.74
0.752	53.86	13.83	32.59
Std Div	1.6 to 3.0	0.7 to 1.9	1.45 to 3.3

Summary of Color Measurements:

Cheese Combo

100F

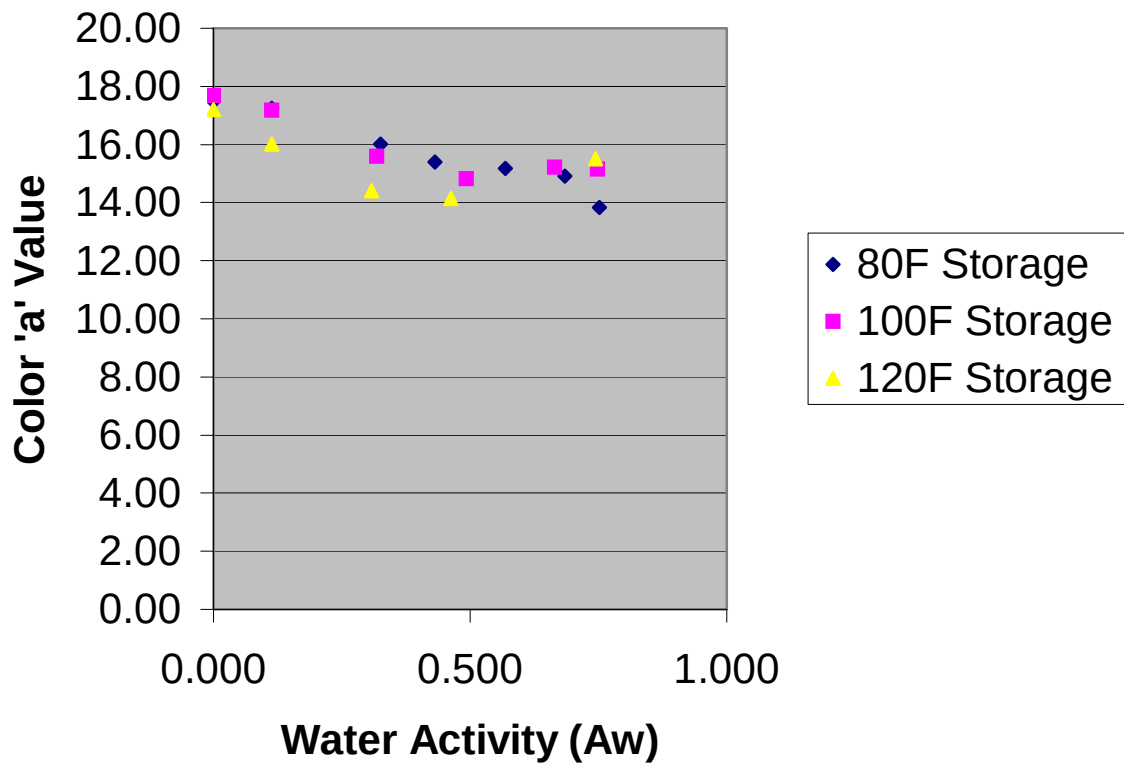
Aw	L	a	b
0.000	50.01	17.69	35.15
0.112	54.19	17.19	39.70
0.318	56.83	15.60	40.03
0.492	57.42	14.82	38.91
0.665	54.60	15.23	35.68
0.748	52.37	15.16	32.87
Std Div	1.35 to 2.55	0.7 to 1.75	1.3 to 2.7

Summary of Color Measurements:

Cheese Combo 120F

Aw	L	a	b
0.000	52.23	17.21	37.43
0.111	55.57	16.02	39.98
0.308	59.03	14.41	40.89
0.462	59.17	14.14	38.88
0.745	50.97	15.50	31.71
Std Div	2.0 to 3.0	0.7 to 1.7	1.6 to 2.15

Cheese Combos: Color 'a' Values Changes with Changes in Aw at Different Temperatures



The following table summarizes the color measurements data obtained from Cheese Combos samples stored at one of the assemblers. The product did not change color during the 90 days storage. This product's bulk pack is very good, and the findings are in line with what was expected. The 'L' 'a' and 'b' readings are similar to those observed in the tables above for Cheese Combos stored at 0.0% to 11% RH. Indeed the Aw of Cheese Combos from storage was at the low end of less than 0.065.

Summary of Color Measurements: Cheese Combo Storage Test

	L	a	b
0	49.24	18.19	34.35
30	50.94	17.49	34.46
45	52.30	17.87	36.56
60	50.37	17.99	35.09
90	52.58	17.50	36.27
Std Div	1.6 to 3.3	1.25 to 1.45	1.4 to 2.55

The tables below contain summary of the 'L', 'a' and 'b' values describing the color of Oatmeal Cookies after storage at various temperature and relative humidity conditions.

There is a large difference in initial color between the top-center and the top-side parts of the cookie (see 'a' and 'b' values below). For this reason we took measurements of both center and side to see which one, if any will provide a good corollary tool for product quality.

There are trends that one can infer from the data, in the 'a' and 'b' value scale (particularly 'b'). However, the "natural" high variability in color among the oatmeal cookies makes it hard to attach significance to changes over the Aw range of 0.00 to 0.50. Differences in 'a' and 'b' values are significant between very dry and moist samples, but it is not useful over the practical range of humidity conditions most likely to be encountered.

Summary of Color Measurements:

Oatmeal Cookies

80F

Front Center

Aw	L	a	b
----	---	---	---

0.000	50.73	7.70	33.07
0.113	47.70	10.53	34.29
0.326	51.13	8.29	34.15
0.432	52.64	7.09	32.92
0.568	53.86	6.73	31.40
0.684	55.94	5.85	29.22
0.752	49.94	8.35	29.60
Std Div	1.5 to 2.5	0.75 to 2.0	0.75 to 1.50

Summary of Color Measurements:

Oatmeal Cookies

80F

Front Edge

Aw	L	a	b
----	---	---	---

0.000	51.32	12.25	37.79
0.113	46.85	13.52	35.93
0.326	50.92	12.83	38.17
0.432	52.33	11.47	37.66
0.568	54.66	10.89	36.83
0.684	55.73	9.43	33.89
0.752	50.10	11.51	32.99
Std Div	1.5 to 2.5	0.75 to 2.0	0.75 to 1.50

Summary of Color Measurements:

Oatmeal Cookies

80F

Back Center

Aw	L	a	b
----	---	---	---

0.000	40.67	16.04	30.91
0.113	39.33	15.12	29.09
0.326	40.66	15.44	30.51
0.432	42.06	15.79	32.38
0.568	44.60	14.78	32.99
0.684	46.97	13.28	31.85
0.752	41.85	14.12	28.67
Std Div	0.5 to 2.5	0.3 to 1.0	1.0 to 2.0

Summary of Color Measurements:

Oatmeal Cookies

80F

Back Edge

Aw	L	a	b
----	---	---	---

0.000	41.48	15.24	29.94
0.113	38.42	15.03	26.78
0.326	40.64	15.32	29.21
0.432	42.75	15.48	31.07
0.568	43.85	14.76	30.83
0.684	46.51	13.26	30.92
0.752	40.30	14.23	26.67
Std Div	0.5 to 2.5	0.3 to 1.0	1.0 to 2.0

Summary of Color Measurements:

Oatmeal Cookies

120F

Front Center

Aw	L	a	b
----	---	---	---

0.000	50.74	7.92	33.83
0.111	49.66	10.91	35.84
0.308	51.23	8.67	34.49
0.462	51.49	9.67	33.87
0.745	34.93	12.52	23.10
Std Div	1.2 to 2.4	0.5 to 1.35	0.55 to 1.9

Summary of Color Measurements:

Oatmeal Cookies

120F

Front Edge

Aw	L	a	b
----	---	---	---

0.000	49.58	12.95	37.29
0.111	47.15	14.89	36.11
0.308	51.33	12.10	37.32
0.462	51.83	12.84	35.94
0.745	35.84	13.98	23.64
Std Div	1.2 to 2.15	0.45 to 1.45	0.8 to 1.7

Summary of Color Measurements:

Oatmeal Cookies

120F Back Center

Aw	L	a	b
----	---	---	---

0.000	40.55	15.81	31.01
0.111	40.09	15.93	29.70
0.308	43.77	15.73	33.22
0.462	43.46	15.42	32.03
0.745	33.82	14.57	23.24
Std Div	07 to 2.35	0.35 to 1.1	0.7 to 1.5

Summary of Color Measurements:

Oatmeal Cookies

120F Back Edge

Aw	L	a	b
----	---	---	---

0.000	40.17	15.90	29.27
0.111	39.21	16.06	27.55
0.308	43.51	15.69	31.81
0.462	43.30	15.37	30.73
0.745	33.12	14.50	20.92
Std Div	1.2 to 2.9	0.3 to 0.7	1.3 to 2.05

The following tables summarize the color measurements data obtained from Oatmeal Cookies samples stored at one of the assemblers over a 90 days period. The product color during the 90 days storage did not change significantly. This product's bulk pack is very poor and moisture pick up by the product was detected. The color measurement methodology, however, is not sensitive enough to determine color differences over narrow Aw changes

Summary of Color Measurements:

Oatmeal Cookies

Storage Front Center

Days	L	a	b
------	---	---	---

0	50.42	6.71	31.98
30	51.78	6.28	32.24
45	52.48	6.35	32.55
60	53.71	6.20	32.18
90	53.96	6.62	33.31
Std Div	1.35 to 3.7	0.25 to 1.45	0.8 to 3.3

Summary of Color Measurements:

Oatmeal Cookies

Storage Front Edge

Days	L	a	b
------	---	---	---

0	51.42	12.33	38.21
30	50.08	9.98	36.99
45	51.93	12.17	38.66
60	52.99	11.39	37.61
90	53.55	11.75	38.55
Std Div	1.4 to 2.15	1.2 to 1.5	0.9 to 1.7

Summary of Color Measurements:

Oatmeal Cookies

Storage

Back Edge

Days	L	a	b
0	41.40	15.50	29.75
30	42.85	15.57	31.49
45	41.53	15.97	30.73
60	43.82	15.40	32.14
90	43.21	15.34	32.20
Std Div	0.95 to 2.25	0.4 to 1.15	0.45 to 1.4

The tables below contain summary of the 'L', 'a' and 'b' values describing the color of Vegetable Crackers after storage at various temperature and relative humidity conditions.

There is a large difference in initial color between the top and the back sides of the crackers (see 'a' and 'b' values below). For this reason we took measurements of both sides to see which one, if any will provide a good corollary tool for product quality.

There are trends that one can infer from the data, in the 'a' and 'b' value scale (particularly 'b'). This trend is more evident in data obtained for the back-side of the cracker. There is a lowering trend in the 'b' value and an accompanying increase trend in the 'a' value (particularly at the higher storage temperatures) with increase in Aw. However, in this case as well the high variability in the population makes it difficult to assign significance to small shifts over small ranges of temperature and relative humidity conditions.

Summary of Color Measurements:

Vegetable Crackers

80F

Front Center

Aw	L	a	b
0.000	67.64	6.85	34.69
0.113	67.98	7.21	34.63
0.326	69.31	6.08	35.28
0.432			
0.568			
0.684	69.32	6.06	34.07
0.752	68.71	6.50	34.15
Std Div	0.7 to 1.2	0.6 to 0.9	0.75 to 1.3

Summary of Color Measurements:

Vegetable Crackers

80F

Back Center

Aw	L	a	b
0.000	65.79	7.88	36.08
0.113	67.56	7.21	36.31
0.326	67.91	7.70	36.58
0.432			
0.568			
0.684	67.76	7.32	34.36
0.752	65.93	8.25	33.47
Std Div	1.15 to 2.1	0.75 to 1.25	0.6 to 0.95

Summary of Color Measurements:

Vegetable Crackers

100F Front Center

Aw	L	a	b
0.000	66.79	7.05	37.39
0.112	67.16	7.26	37.11
0.318			
0.492	69.06	6.45	37.88
0.665	67.24	7.18	36.40
0.748	65.35	7.94	35.79
Std Div	0.5 to 0.9	0.5 to 0.7	0.45 to 0.85

Summary of Color Measurements:

Vegetable Crackers

100F Back Center

Aw	L	a	b
0.000	65.82	8.01	38.53
0.112	65.99	8.00	38.32
0.318			
0.492	66.41	8.59	38.62
0.665	64.58	9.38	36.73
0.748	61.27	10.01	34.73
Std Div	1.25 to 2.45	0.95 to 1.45	0.4 to 0.9

Summary of Color Measurements:

Vegetable Crackers

120F Front Center

Aw	L	a	b
0.000	66.56	7.68	37.69
0.111	67.98	6.93	37.96
0.308	68.65	6.64	38.10
0.462	67.95	6.73	38.04
0.745	61.98	9.43	35.46
Std Div	0.4 to 1.1	0.35 to 0.7	0.5 to 0.75

Summary of Color Measurements:

Vegetable Crackers

120F Back Center

Aw	L	a	b
0.000	66.48	7.64	38.01
0.111	65.89	8.76	38.80
0.308	67.01	8.05	39.16
0.462	66.00	8.86	38.68
0.745	59.56	10.48	35.02
Std Div	1.1 to 2.75	0.75 to 2.05	0.45 to 1.00

The following tables summarize the color measurements data obtained from Vegetable Crackers samples stored at one of the assemblers over a 90 days period. The product color during the 90 days storage did not change significantly. This product's bulk pack is relatively good and moisture pick up by the product was small.

Summary of Color Measurements:

Vegetable Crackers

Storage Front Center

	L	a	b
0	67.47	7.64	34.98
30	67.02	7.74	35.05
45	67.86	7.11	35.20
60	67.12	7.66	35.16
90	68.17	6.95	35.57
Std Div	0.75 to 1.25	0.5 to 0.8	0.4 to 0.8

Summary of Color Measurements:

Vegetable Crackers

Storage Back Center

	L	a	b
0	66.08	8.31	36.15
30	66.25	7.90	34.96
45	66.52	7.72	35.11
60	66.56	7.87	34.01
90	68.99	6.46	35.81
Std Div	1.5 to 2.7	1.0 to 1.5	0.6 to 1.2

The tables below contain summary of the 'L', 'a' and 'b' values describing the color of Shortbread Cookies after storage at various temperature and relative humidity conditions.

We took measurements of both top and back sides to see which one, if any will provide a good corollary tool for product quality.

There are trends that one can infer from the data. The 'a' and 'b' values decrease in value and the 'L' values increase as Aw increases. However, the high variability in the population makes it difficult to assign significance to small shifts over small ranges of temperature and relative humidity conditions.

Summary of Color Measurements:

Shortbread Cookies

80F Front Center

Aw	L	a	b
0.000	63.86	8.13	32.80
0.113	63.96	8.22	32.60
0.326	66.57	6.90	32.53
0.432	66.77	6.79	32.58
0.568	67.91	6.49	32.07
0.684	67.17	6.61	31.22
0.752	67.23	6.79	30.25
Std Div	0.65 to 1.15	0.5 to 1.15	0.25 to 0.75

Summary of Color Measurements:

Shortbread Cookies

80F Back Center

Aw	L	a	b
0.000	70.99	5.39	33.98
0.113	71.76	4.96	33.85
0.326	73.07	4.58	33.21
0.432	73.33	4.02	32.99
0.568	72.42	5.09	33.77
0.684	73.94	4.14	32.27
0.752	73.79	4.48	31.49
Std Div	1.95 to 3.35	1.65 to 2.95	0.75 to 1.95

Summary of Color Measurements:

Shortbread Cookies

100F Front Center

Aw	L	a	b
----	---	---	---

0.000			
0.112	62.42	8.66	33.96
0.318			
0.492	64.62	7.55	35.02
0.665	63.37	8.07	34.55
0.748	64.32	7.62	32.25
Std Div	1.0 to 2.1	0.6 to 1.7	0.5 to 0.75

Summary of Color Measurements:

Shortbread Cookies

100F Back Center

Aw	L	a	b
----	---	---	---

0.000			
0.112	69.17	6.45	35.81
0.318			
0.492	70.60	5.57	36.01
0.665	71.78	4.28	34.06
0.748	71.26	5.12	33.49
Std Div	1.7 to 2.8	1.2 to 2.55	0.85 to 1.6

Summary of Color Measurements:

Shortbread Cookies

120F Front Center

Aw	L	a	b
----	---	---	---

0.000			
0.111	62.39	8.55	34.80
0.308	64.63	6.91	35.75
0.462	63.81	8.00	35.97
0.745	62.96	9.09	35.23
Std Div	0.65 to 1.95	0.5 to 1.3	0.45 to 0.65

Summary of Color Measurements:

Shortbread Cookies

120F Back Center

Aw	L	a	b
----	---	---	---

0.000			
0.111	70.00	5.28	35.19
0.308	71.81	4.39	35.79
0.462	69.36	6.27	36.95
0.745	69.76	6.25	36.24
Std Div	1.45 to 2.80	1.15 to 2.65	0.85 to 1.8

The following tables summarize the color measurements data obtained from Shortbread Cookies samples stored at one of the assemblers over a 90 days period. The product color during the 90 days storage did not change significantly. This product's bulk pack is excellent and moisture pick up by the product was negligible.

Summary of Color Measurements:

Shortbread Cookies

Storage Front Center

	L	a	b
--	---	---	---

0	64.38	8.92	32.40
30	64.04	8.46	32.17
45	64.98	8.19	32.22
60	63.71	9.11	35.30
90	64.83	8.20	32.56
Std Div	0.8 to 1.3	0.6 to 1.0	0.45 to 0.7

Summary of Color Measurements:

Shortbread Cookies

Storage Back Center

	L	a	b
--	---	---	---

0	72.56	5.01	33.69
30	72.91	4.64	33.69
45	72.83	4.73	34.15
60	72.13	5.18	34.56
90	73.25	4.35	33.71
Std Div	0.45 to 2.7	0.6 to 2.3	0.75 to 1.15

6.4.3 Color Measurements Conclusions:

Instrumental color measurements of cookies and crackers proved to be an insensitive tool for monitoring quality changes. The measurements are easy and the software provides basic statistics of the tested lot immediately. However, color is not the sensory quality affected most by Aw and temperature changes; thus might be a poor choice as indicator. Also, the large inherent differences between specimens of the same batch make it difficult to have confidence in small value changes.

6.5 Sensory Tests

6.5.1 MATERIALS AND METHODS:

A consumer panel evaluated four bakery items included in military MREs that have been stored under varying temperature, humidity and length of storage conditions. There were a total of 5 sessions, where the same panelists returned each time to evaluate these products under a specific condition. The products consisted of a vegetable cracker, an oatmeal cookie, a shortbread cookie and a cheese filled pretzel snack. Each sample was presented in pairs comparing a specific storage condition to a control sample. Panelists evaluated the following attributes: hardness, brittleness, crispiness, and overall liking.

Selection of panelists:

Panelists were recruited through E-Mail notification on the Cook College campus. The panelists for this test consisted of healthy men and women aged 18-55 years of age. A total of 30 panelists participated in the study.

Sample Preparation:

Samples: Each treated product was paired with a control sample

1. Vegetable cracker
2. Oatmeal cookie

3. Lorna Doone shortbread cookie
4. Cheese Combos pretzel snack

Five Sessions (testing occurred during the period of March-September 2003):

- Control vs. storage to equilibrium at 80F/32% relative humidity
- Control vs. storage to equilibrium at 100F/32% relative humidity
- Control vs. storage to equilibrium at 80F/43% relative humidity
- Control vs. 90-days of storage at an assembler site
- MRE samples storage for 6 months at 80F vs. 100F temperature

Note: Control is product of the same lot as the sample, but that was sent to Rutgers shortly after arrival at the participating assembler. The product was packed well and stored at “cool” temperatures, to minimize moisture gain or loss.

The samples were stored under the specified conditions until the day of the taste test. For sessions 1-4, the treated samples were delivered in special plastic containers and the controls were store packaged as is. For session 5, all the samples were packaged as meal ready to eat (MRE) packs.

Panel Procedures:

Each taste panel session was conducted in the Sensory Evaluation Lab in the Food Science Building on the Cook College Campus. Each session panel ran from 11:30 –2:00pm. Each panelist was given general instructions on how the taste panel would run before the samples were distributed.

Approximately 1 piece of the vegetable cracker, oatmeal and shortbread cookie sample along with 2 pretzel snacks were placed into separate standard 2oz soufflé cups placed on a foam tray. The samples were served in pairs, the order of which was randomized across panelists. Instructions on how to correctly complete the ballots were given. After the panelist evaluated the first pair, the unused portion of the samples were removed and the next pair of samples was served. Panelists were provided with water and instructed to rinse between samples. After completing the test, the panelists were compensated for their participation.

Ballot:

RATING SCALES:

A 15cm line scale anchored with either “very soft, very crumbly or very soggy” to the far left and either “very hard, very brittle or very crispy” to the far right was used to measure four attributes (hardness, brittleness and crispiness). An additional 15cm line scale anchored with “dislike extremely” to the far left and “like extremely” to the far right was used to measure overall liking.

Demographic information:

Data was collected on age and gender at each taste panel session.

DATA ANALYSIS:

The test sessions were completed and analyzed using the FIZZ (Statex, Inc. Montreal, Canada) sensory analysis program. Statistical tests included the Student’s t-test and Analysis of Variance (ANOVA) followed by the LSD test to probe for mean differences. $P \leq 0.05$ was used as the statistical cutoff criterion.

Data from the temperature/humidity sessions were analyzed together to compare ratings across all three conditions. Prior to this analysis, ANOVA was used to establish if the

ratings for the control samples were consistent across sessions. If so, the control ratings would be pooled for further analysis. A small but significant loss of crispiness was noted for the oatmeal cookie across test sessions. Since this loss did not affect liking ratings of the oatmeal cookies, this finding was not considered meaningful and the control data was pooled as planned.

ANOVA was used to compare overall mean differences in the ratings among the pooled control and each of the treatments (80° F/32% humidity, 100° F/32% humidity, and 80° F/43% humidity). ANOVA was performed for all attributes and all products. If the ANOVA results were significant, then the LSD test was performed to determine which samples were different from each other.

Data from each of the two remaining sessions were analyzed separately. The Student's t-test was used to determine mean differences between treatments and control for each attribute across all products.

Significance was set at $p \leq 0.05$ for all tests.

6.5.2 RESULTS:

Demographics:

Of the 30 panelists participating, 91% were women. The majority of respondents (70%) were between 18-34 years of age.

Observations/Attribute Ratings:

Initial screening of the data revealed no significant differences in brittleness for any product in any test condition. It was assumed that the panelists did not understand this attribute since texture changes in the products were clearly captured in the hardness and crispiness attributes. Thus data for brittleness are omitted from this report.

Preliminary General Interpretation:

Control vs. 90-day storage. Storage time had an effect on oatmeal cookies but not the other products.

MRE - 6 month storage (80F vs. 100F)

Oatmeal cookies stored at higher temperature were harder & crispier, but no effect on liking.

Temp-humidity variations vs. control

The "control" samples here represent the mean of the 4 sessions which included a control. We ran a statistical test on the controls. There were no significant differences across all the attributes and products except for crispiness of oatmeal cookies (which tended to decrease slightly chronologically across sessions).

We only saw this one significant effect in all these comparisons and it did not seem to have an undue influence on comparisons of crispiness as a function of temperature & humidity. In other words, this shift does not 'threaten' the validity of the analysis.

The general trends are quite clear. Higher temp reduced hardness, crispiness and overall liking. But high humidity had the greatest affect.

The sensory score and indication of significant differences are illustrated below in a table and graph forms.

When interpreting the sensory results it is important to know the condition of the ‘control’ product verses the tested variables. The table below summarizes the water activity and water content of the ‘control’ product.

Water Activity of “Control”

<u>Product Name</u>	<u>Aw</u>	<u>% Water Content</u>	<u>% Water Specs</u>
Cheese Combo	0.06	1.5	2.6
Shortbread Cookies	0.15	2.4	4.0
Vegetable Crackers	0.17	3.4	1.5 to 4.0
Oatmeal Cookies	0.32	4.7	5.0

Sensory Evaluation of Selected Baked Goods

Packed in MRE Pouches and Stored at 80F and 100F for 6 Months

CRACKER

	Hardness	Crispiness	Liking
80 F	9.6	9.3	8.4
100F	9.6	9.2	7.7

OATMEAL COOKIE

	Hardness	Crispiness	Liking
80 F	8.4	7.6	8.9
100 F	9.7	10.7	8.9
	*	**	

SHORTBREAD

	Hardness	Crispiness	Liking
80 F	7.3	9.3	10.5
100 F	6.5	8.6	10.0

COMBO

	Hardness	Crispiness	Liking
80 F	8.6	10.2	10.3
100 F	8.9	10.6	10.1

*p<0.05; **p<0.01

Sensory Evaluation of Selected Baked Goods Packed in bulk and Stored at Assembler's Plant Warehouse

CRACKER

	Hardness	Crispiness	Liking
Control	9.8	9.3	7.2
90 days	9.2	9.7	8.4
			*

OATMEAL COOKIE

	Hardness	Crispiness	Liking
Control	10.8	9.7	8.8
90 days	4.2	4.1	6.7
	**	**	**

SHORTBREAD

	Hardness	Crispiness	Liking
Control	6.7	8.7	10.6
90 days	6.1	7.9	9.8

COMBO

	Hardness	Crispiness	Liking
Control	8.9	10.4	10.5
90 days	8.6	10.5	10.5

*p<0.05; **p<0.01

Sensory Evaluation of Selected Baked Goods

As Influenced by Temp & Humidity Conditions

VEGETABLE CRACKER

	Hardness		Crispiness		Liking
Control	9.6	ns	9.1	a	7.9
80F/32H	9.7	ns	7.9	a,b	6.1
100F/32H	9.2	ns	6.8	b	6.0
80F/43H	9.0	ns	6.8	b	4.8

OATMEAL COOKIE

	Hardness		Crispiness		Liking
Control	11.1	a	10.3	a	9.1
80F/32H	10.6	a	10.3	a	8.2
100F/32H	10.0	a	10.9	a	9.8
80F/43H	8.2	b	8.4	b	8.7

SHORTBREAD

	Hardness		Crispiness		Liking
Control	6.0	a	8.9	a	11.2
80F/32H	5.8	a	7.8	a	10.4
100F/32H	5.6	a,b	7.3	a,b	9.0
80F/43H	4.0	b	5.8	b	8.0

CHEESE COMBO

	Hardness		Crispiness		Liking
Control	8.8	a	10.6	a	10.9
80F/32H	7.9	a,b	6.4	b	6.7
100F/32H	8.2	a,b	6.4	b	5.8
80F/43H	6.5	b	4.5	c	4.5

Temperature-Humidity Variations

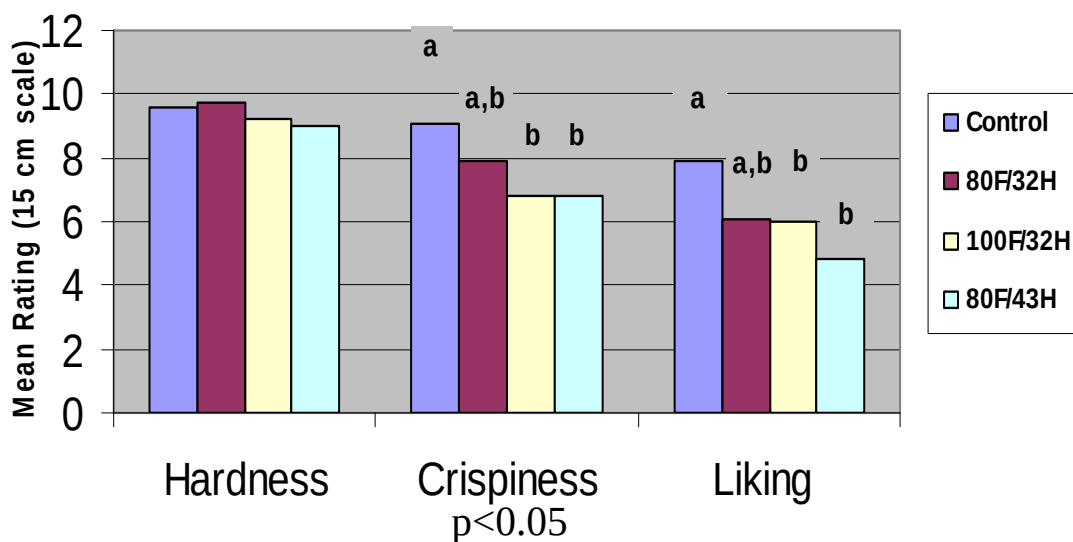
(Control vs. storage for 6+ weeks at 80F/32H, 100F/32H or 80F/43H)

Graphs showing the mean ratings for the three attributes (hardness, crispiness, overall liking) for each product are shown in four Figures below.

Comparisons across the treatments showed that storage at high humidity (80F/43H) reduced the crispiness more than storage at low humidity (80F/32H or 100F/32H). Liking showed a similar pattern but differences were significant only between the sample stored at 80F/43H and 80F/32H.

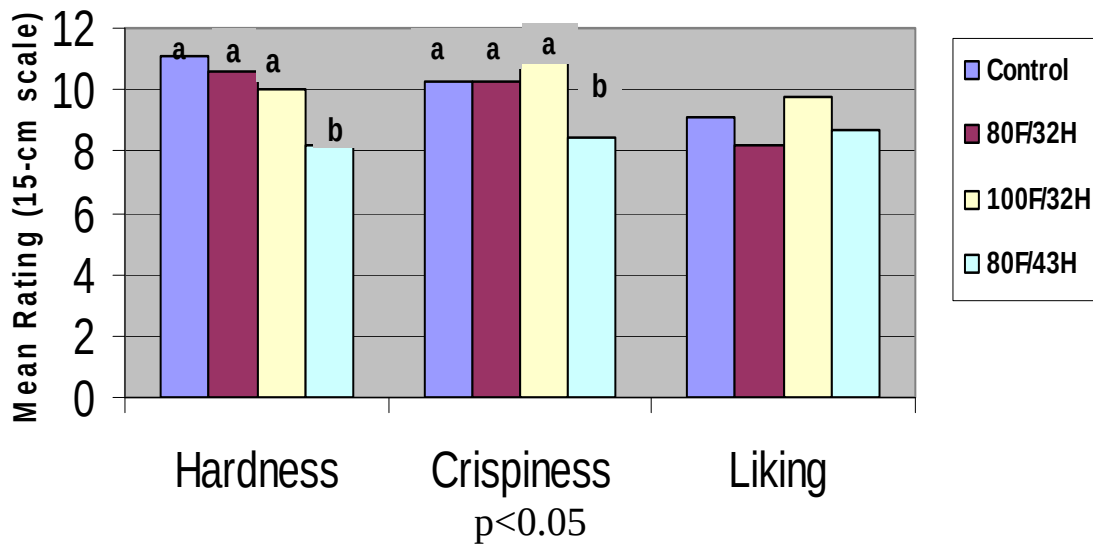
Vegetable cracker: There were no differences among the treatments for hardness. Significant differences were found among the samples for crispiness ($p=0.01$) and overall liking ($p=0.001$). Post-hoc tests showed that samples stored at either high temperature (100F/32H) or high humidity (80F/43H) were different from control. Samples stored at 80F/32H were not different from control or the other treatments.

Sensory Attributes Changes as Affected by Storage Temperature and RH Cracker



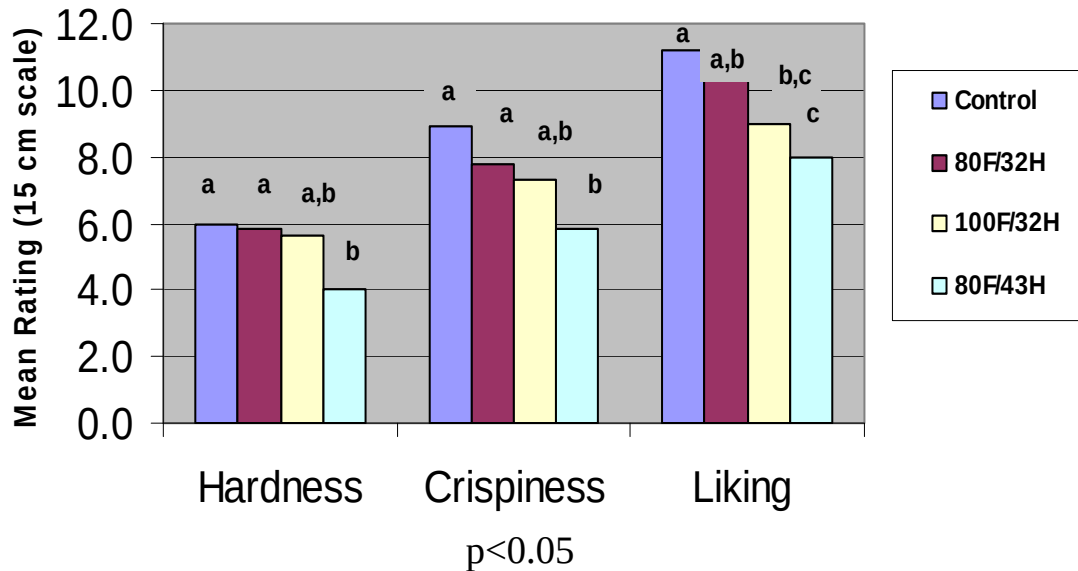
Oatmeal cookie: Significant differences were found among the samples for hardness ($p=0.001$) and crispiness ($p=0.01$). Post-hoc tests showed that samples stored at high humidity (80F/43H) were rated less hard and less crisp than all other treatments and control. These differences did not influence overall liking which was not different across samples.

Sensory Attributes Changes as Affected by Storage Temperature and RH Oatmeal Cookie



Shortbread cookie: Significant differences were found among the samples for hardness ($p=0.01$), crispiness ($p=0.001$) and overall liking ($p=0.001$). Post hoc tests showed that high humidity had the greatest effect on the ratings. Samples stored at high humidity (80F/43H) were rated less hard, less crisp and were less well liked than either control or the samples stored at the same temperature at lower humidity (80F/32H). Although the sample stored at 100F/32H was less well liked than control, the crispiness and hardness of this sample was not different than the sample stored at 80F/32H.

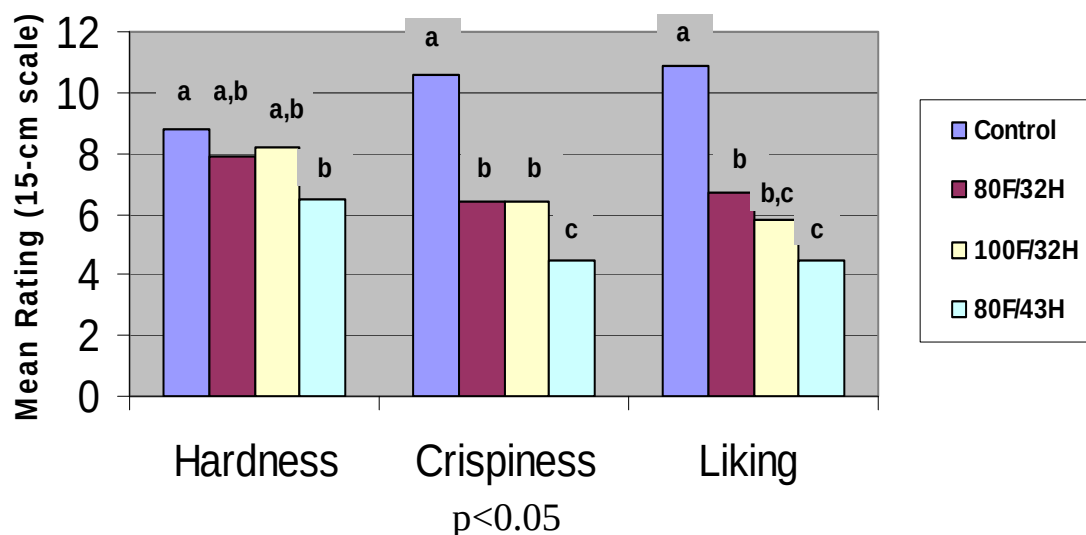
Sensory Attributes Changes as Affected by Storage Temperature and RH Shortbread



Combo snack pretzels: Significant differences were found for hardness ($p=0.02$), crispiness ($p=0.001$) and overall liking (0.001). Post hoc tests show that high humidity had a strong influence on the ratings. Samples stored at 80F/43H were rated lower than control for all attributes. The other treatments also reduced the ratings for crispiness and overall liking relative to control.

Sensory Attributes Changes as Affected by Storage Temperature and RH

Combo

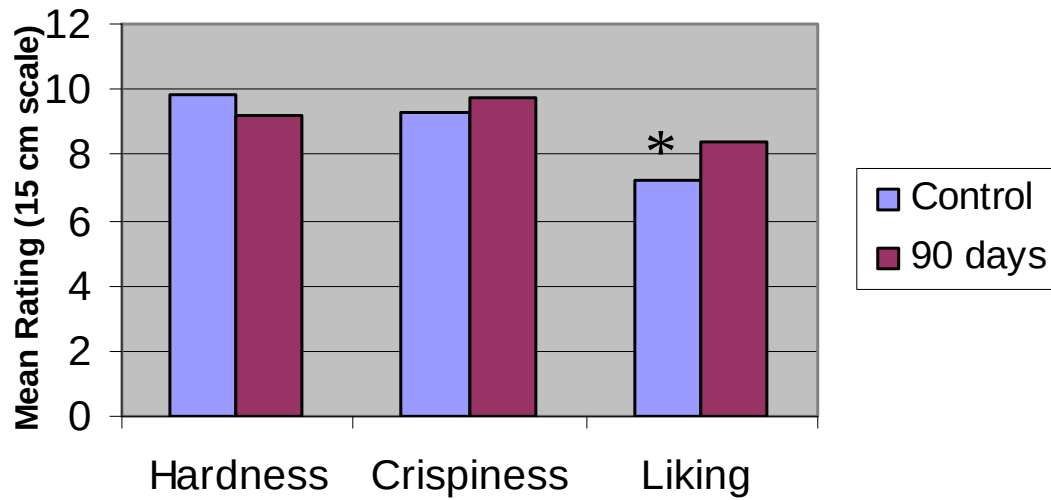


Control vs. 90-day Bulk Storage at Assembler

Graphs showing the mean ratings for the attributes (hardness, crispiness, overall liking) for each product are shown in four Figures below. Results showed that 90 days of bulk storage had a strong influence on the ratings of the oatmeal cookie but not the other products. After 90 days of storage, the oatmeal cookie was rated lower in hardness ($p=0.001$), crispiness ($p=0.001$) and overall liking ($p=0.01$) as compared to control. A small but significant increase was observed in liking of the vegetable cracker after storage. However, this difference could not be linked to changes in the texture attributes

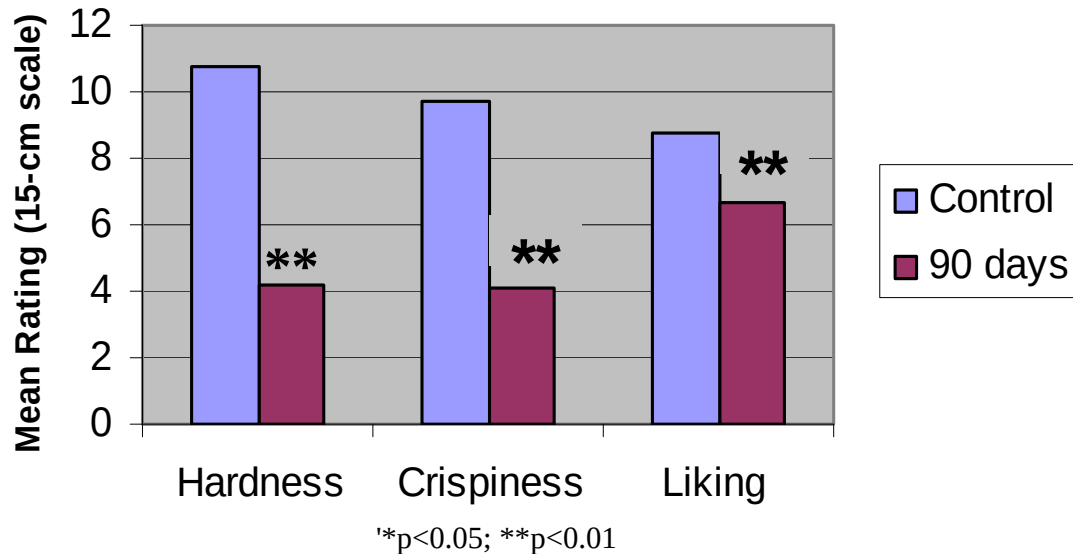
Sensory Attributes Changes as Affected by Storage Time at Assembler's Warehouse

Cracker

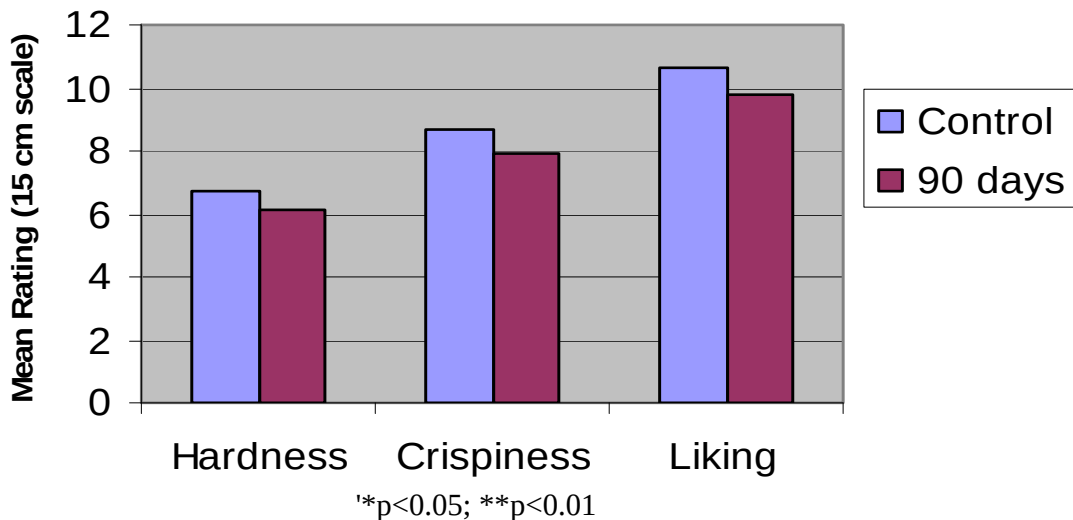


* $p < 0.05$; ** $p < 0.01$

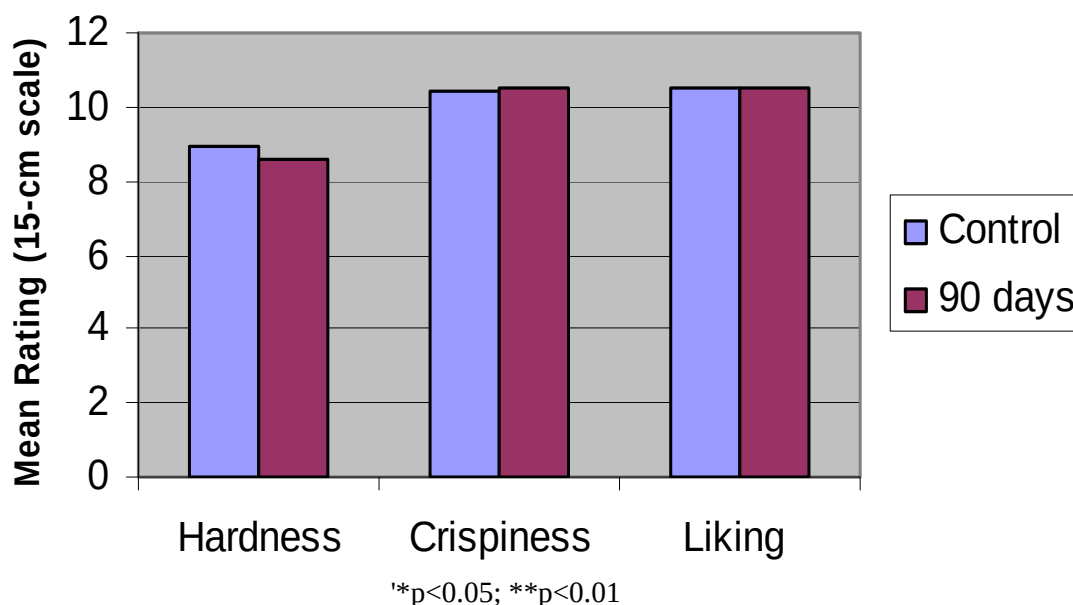
Sensory Attributes Changes as Affected by Storage Time at Assembler's Warehouse Oatmeal Cookie



Sensory Attributes Changes as Affected by Storage Time at Assembler's Warehouse Shortbread



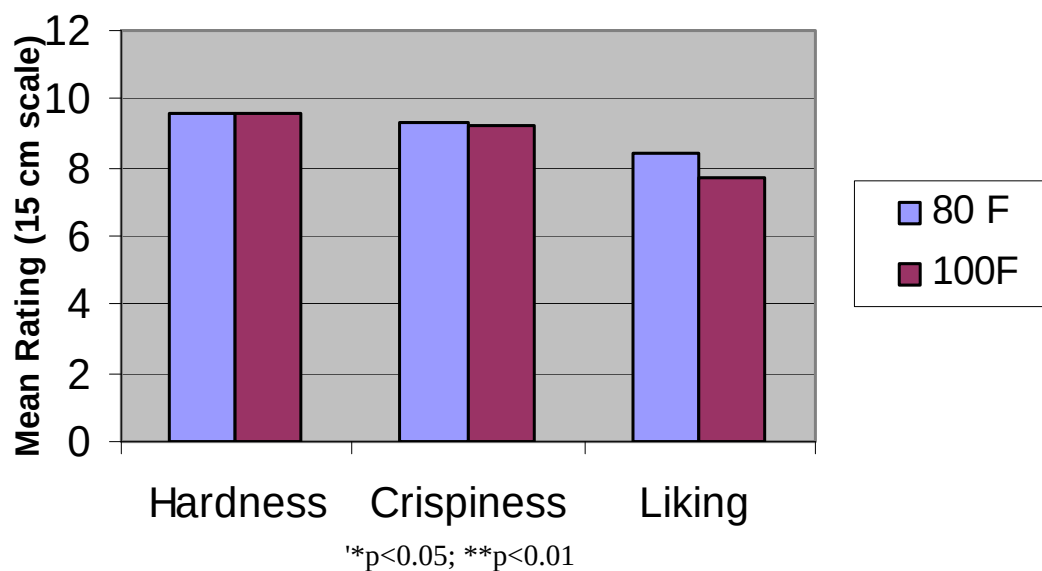
Sensory Attributes Changes as Affected by Storage Time at Assembler's Warehouse Combo



Standard storage at 80°F vs. storage for 6 months at 100°F (MRE foil packs)

Graphs showing the mean ratings for the attributes (hardness, crispiness, overall liking) for each product are shown in four Figures below. Results showed that storage for 6 months at 100°F influenced ratings of the oatmeal cookie but not the other products. After 6 months of storage at 100°F the oatmeal cookie was rated lower in hardness ($p=0.02$) and crispiness ($p=0.001$) than control. Although these differences were noticeable to panelists they had not effect on liking of the product.

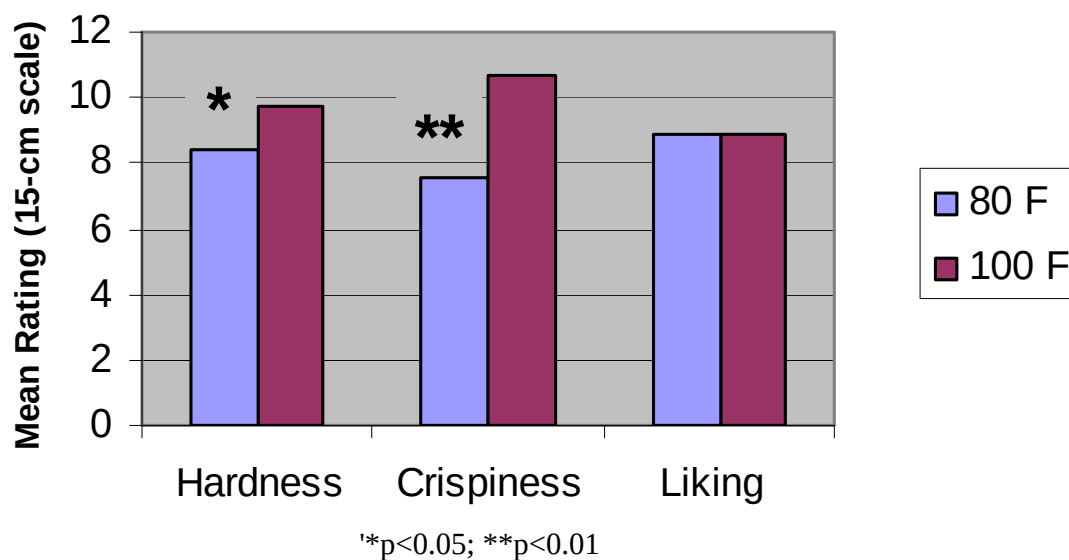
Sensory Attributes Changes MRE - 6 Month Storage 80F vs. 100F Cracker



Sensory Attributes Changes

MRE - 6 Month Storage 80F vs. 100F

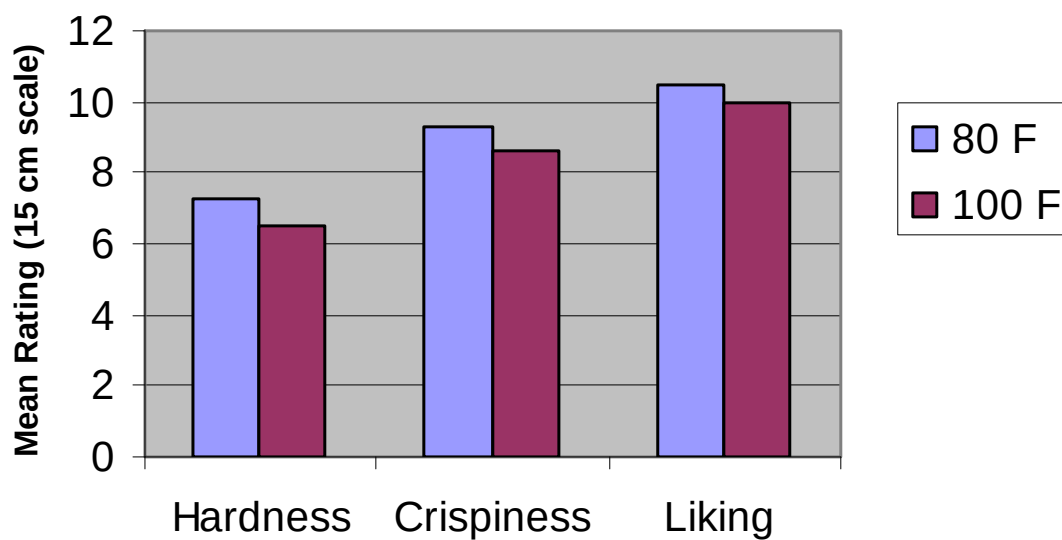
Oatmeal Cookie



Sensory Attributes Changes

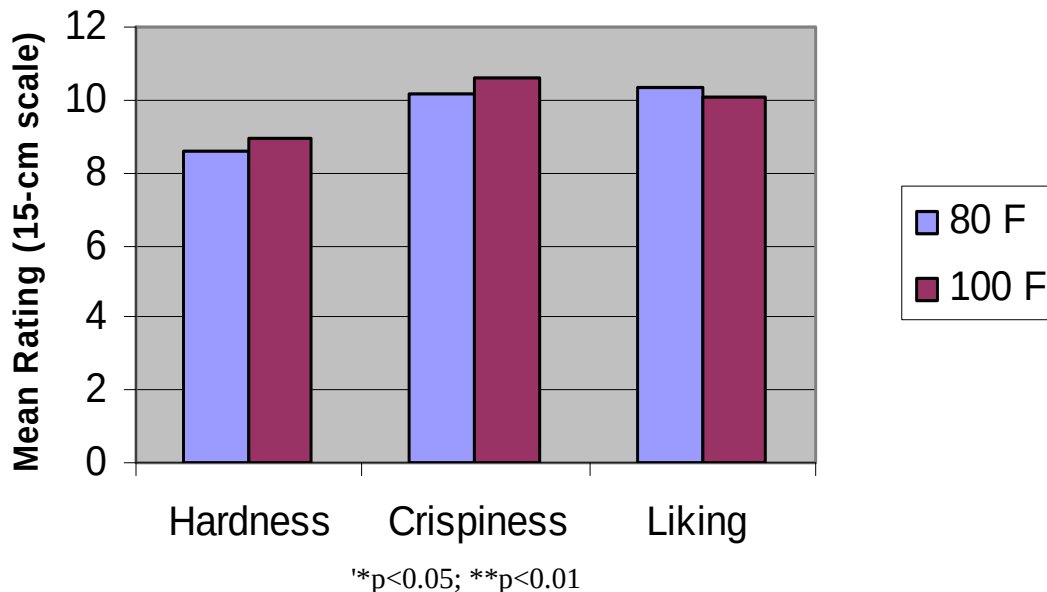
MRE - 6 Month Storage 80F vs. 100F

Shortbread



*p<0.05; **p<0.01

Sensory Attributes Changes MRE - 6 Month Storage 80F vs. 100F Combo



6.5.3 SUMMARY AND CONCLUSIONS:

A consumer study was conducted to assess the acceptance of four bakery items included in military MREs held under varying conditions of temperature, humidity and length of storage. Samples were evaluated for intensity of hardness, brittleness and crispiness and overall liking.

Temperature-humidity variations: High humidity (80F/43H) had a strong effect on reducing the hardness, crispiness and overall liking of the products. In general, storage at 80F/32H did not reduce the ratings relative to control. In some cases, storage at high temperature (100F/32H) led to lower ratings relative to control, but this effect was not uniform across products. The pretzel snack was the most vulnerable to both heat and humidity treatments, whereas the oatmeal cookie was the most resistant to these treatments.

90-day bulk storage test and 6-month storage at 100^o F: In both tests, differences were observed for the oatmeal cookie, but not the other products. Following 90 days of storage, the oatmeal cookie was rated lower in all attributes. Oatmeal cookies were also rated higher in hardness and crispiness after 6-months of storage at 100^o F, but no differences in liking were observed.

Conclusions: Under short-term storage conditions, high humidity rather than elevated temperature had a greater influence on perceived texture and consumer acceptance of snack products. However, the individual effects of temperature and humidity varied across products. 90 days of bulk storage negatively affected the texture and acceptance of the oatmeal cookie, but not any of the other products.

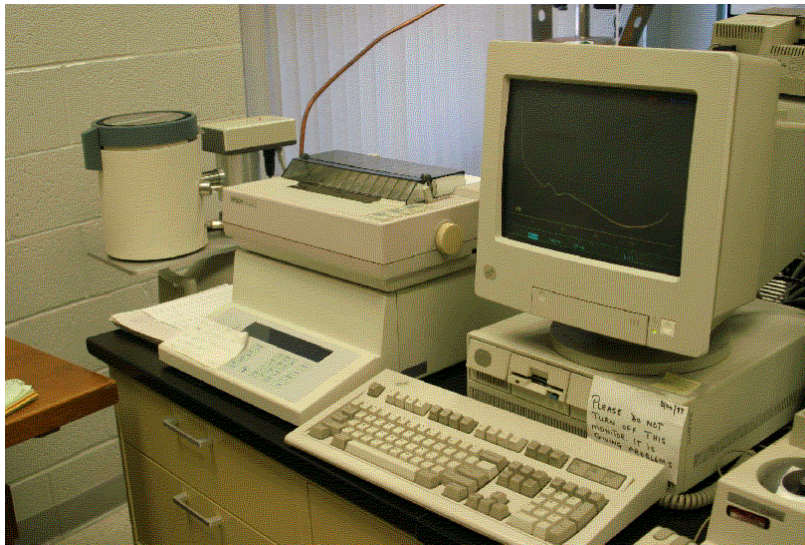
7.0 Bakery Item Matrix Structure

7.1 Phase Transitions Measurements Using DSC

Differential Scanning Calorimeter allows one to measure changes in the amount of energy a sample absorb as it increases in temperature by a set amount (i.e. degree centigrade). Matter absorbs or emits more energy in order to cause a change in temperature during phase changes. Using this technique can give insight to the structure or changes in the structure of polymers (and other elements). Starch is a class of polymers that were studied using this technique.

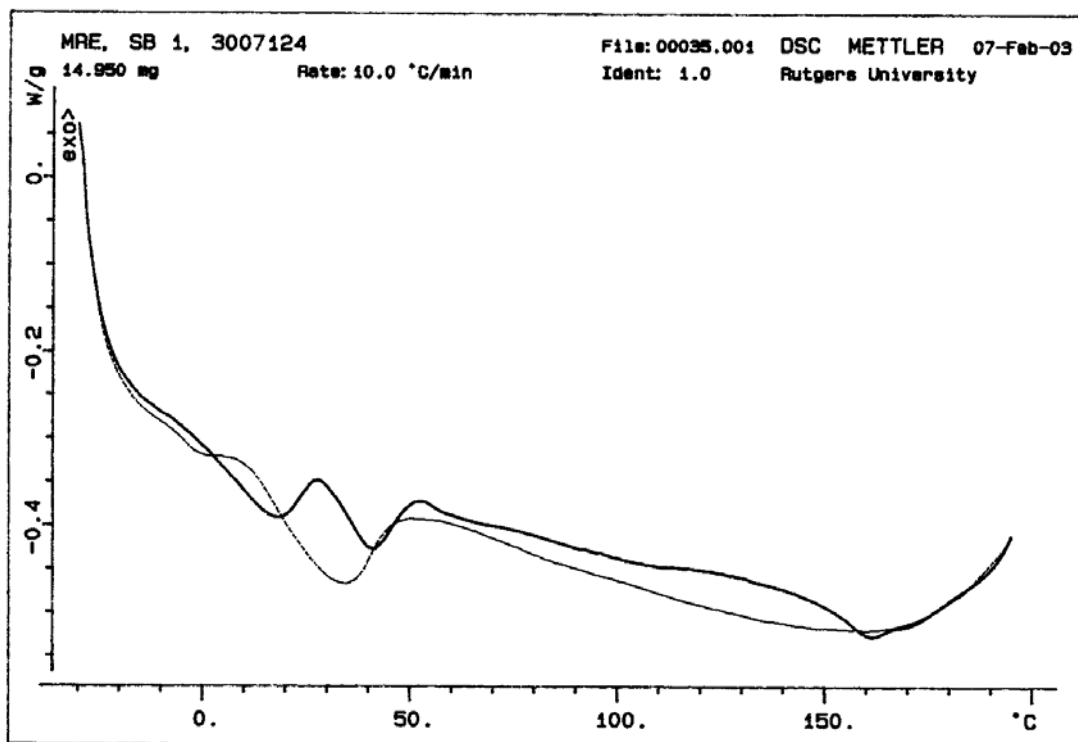
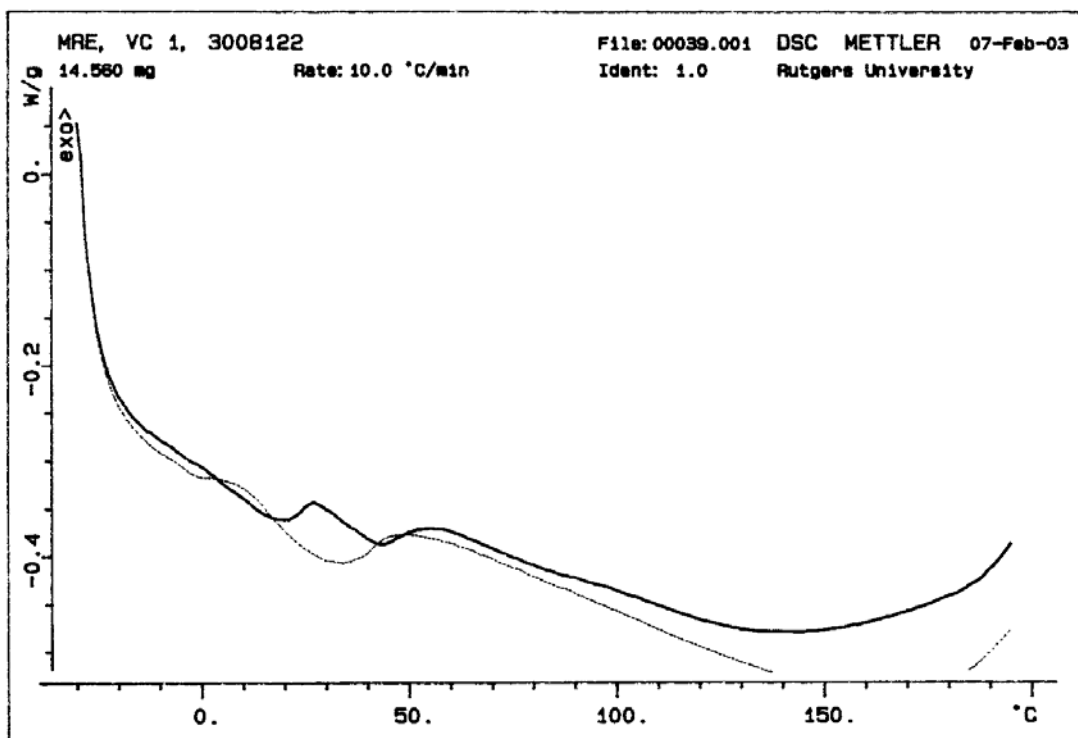
Using DSC in this study was proposed in order to understand the changes to the starch structure of the cookies and crackers as affected by moisture content and storage temperature conditions.

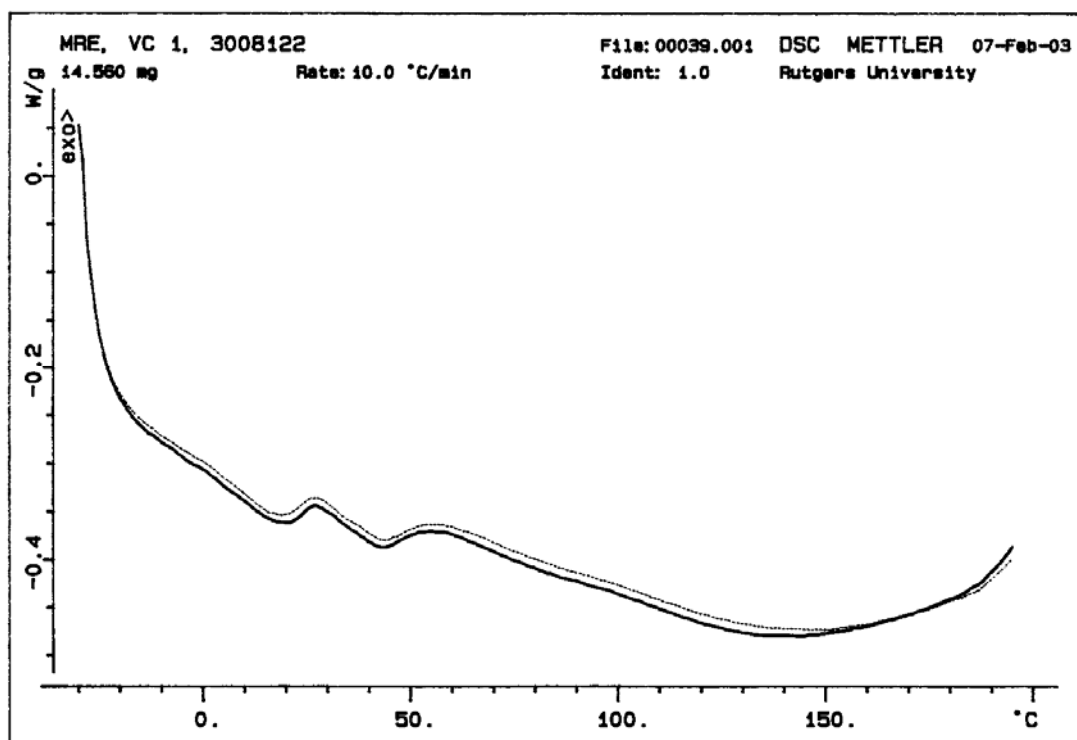
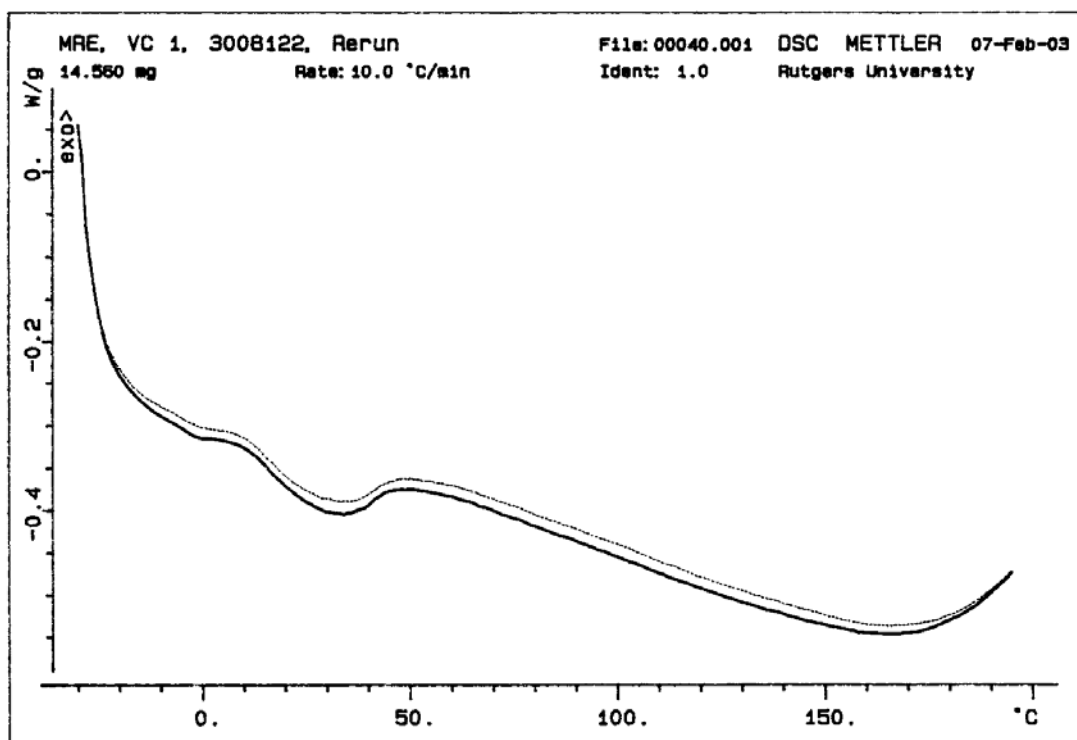
Differential Scanning Calorimeter



The following 4 charts provide two examples of DSC (Differential Scanning Calorimeter) scans, one for Vegetable Crackers and one for Shortbread Cookies. Each chart shows two scans one of the original sample (as is) and the other, a rerun of the sample which usually does not have the crystalline region any longer as it was “melted” in the first run.

The other two charts are given to show the good reproducibility of the method. The two scans on each chart are from duplicate samples of the same product and set of storage conditions.





The differential Scanning Calorimetry did not result in the insight we anticipated. Glass transition temperature was difficult to measure, because of interferences primarily from fat phase changes. Although the scans were highly reproducible within the same sample, the error in trying to determine the starting and end points of glass transition was large and subject to person-to-person interpretation. The differences between samples were not large enough to overcome the methodology error as applied to these products. Typically starch glass transition occurs in the range of 60C to 95C. One can see from the above scans that trying to find changes in slopes (changes in energy absorption per degree) are very difficult to “pin down.”

7.2 Crystallography

This portion of the study was carried out in cooperation with:

Thomas J. Emge, Ph.D.

Director of X-Ray Diffraction Facility

Department of Chemistry and Chemical Biology

Rutgers, The State University of New Jersey

Samples of cookies and crackers were provided from the storage and the sorption isotherms segments of the study. They were then analyzed by Dr Emge, deploying Wide-Angle X-ray Scattering (WAXS) technique using the HiStar Area Detector.

In the text below VC=Vegetable Crackers, CC=Cheese Combos, SB=Shortbread Cookies and OT=Oatmeal Cookies. Number pairs like 100/67 mean 100F storage temperature and 67% relative humidity environment.

7.2.1 Experimental

The wide-angle x-ray scattering (WAXS) patterns of several starch-containing cookie/snack samples were obtained by use of a Bruker HiStar area detector and an Enraf-Nonius FR571 rotating anode x-ray generator equipped with a graphite monochromator ($\text{Cu K}\alpha$; $\lambda = 1.5418 \text{ \AA}$) operating at 40 kV and 50 mA. Samples were stored at room temperature prior to examination, and, in all cases, were examined within a few minutes of being freshly removed from the packaging. All of the data were collected at room temperature over a period of 15 minutes. The sample to detector distance was 12 cm and the standard spatial calibration was performed at that distance. Scans were 179 degrees wide in ϕ with fixed detector, or Bragg, angle (2θ) of 20 deg, and fixed platform (ω and χ) angles of -90 and 45 deg, respectively. In all cases, the count rate for the area detector did not exceed 100,000 cps.

The samples were prepared by first cutting the cookie/snack in half and scraping crumbs from the innermost, lightest colored, core region with a razor blade. These crumbs were crushed to uniform size between two glass microscope slides. Finally, the fine powder was gathered to the outer surface of a previously oiled 1 mm special glass x-ray capillary. The oil used was Paratone-N, a viscosity-enhancing agent for motor oil (Exxon-Mobile). The center of the capillary was centered on the instrument.

The contribution to the scattering of the capillary (special glass) and oil (Paratone-N)

The scattering from the capillary and oil used to mount the samples is very weak.

Its component (lower, broken line) to the overall scattering, for example, of the SB-80/69 sample (solid line) is depicted in Figure A1 below:

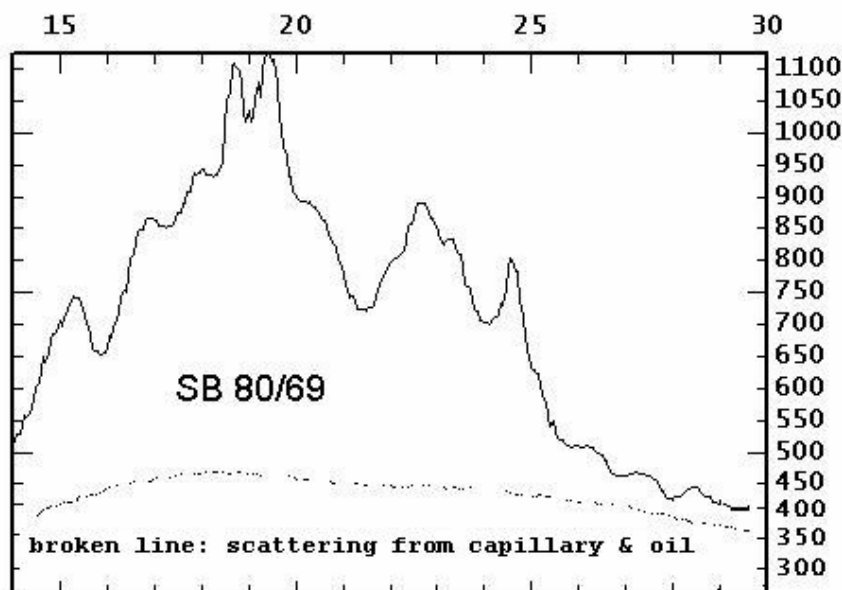


Figure A1. Contribution of capillary and oil (broken line) used for mounting sample, with respect to the overall scattering (solid line).

7.2.2 Methodology Explanation and Examples:

Figures 1 and 2 are the x-ray diffraction single frame (15 min) images of samples with high and low degrees of crystallinity, respectively. Line plots were made of the integration of all x-ray diffraction images, using the angular area defined by $14 < 2\theta < 30$ deg and $-160 < \chi < 20$ deg. The relative degree of crystallinity was assessed by the number and clarity of fine features (peaks) for a series of integration plots. These “peaks” observed in the raw images as x-ray diffraction rings which correspond to the strongest diffracting sets of crystalline (or nearly crystalline) planes in the sample (as in Figure 1, for example). In addition, diffraction spots from highly crystalline salt or sugar crystals were observed (superimposed on the main pattern) in several cases, and diffraction from these particles (large single crystals) is localized to spots, rather than rings, as shown in Figure 3.

Software used

GADDS v.4.1.02 (Bruker-AXS, Inc., 2000)

Routines:

“Collect>Scan>Single Run” for data collection;

“Peaks>Integrate>Chi” for integration plots.

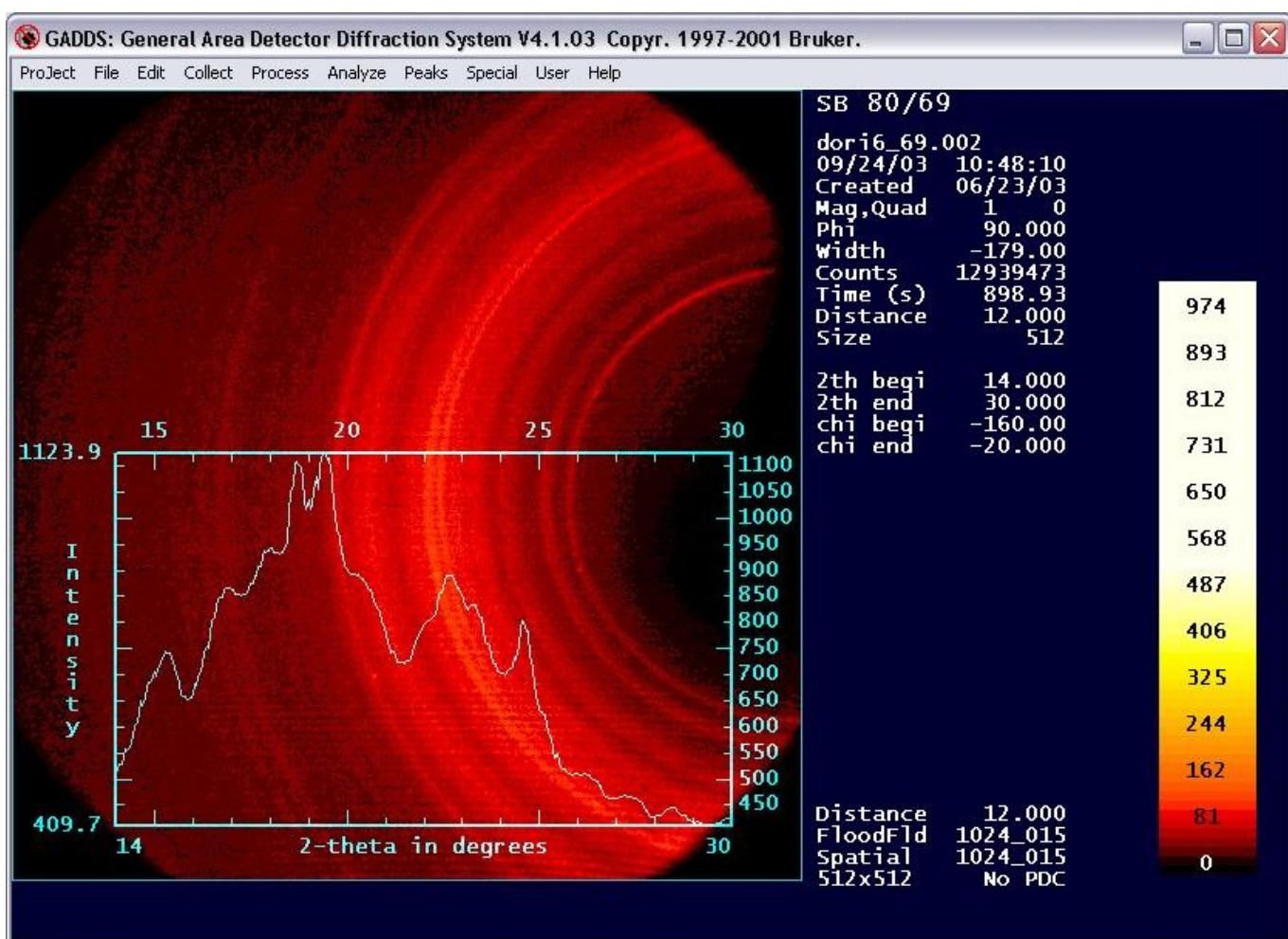


Figure 1. X-Ray Diffraction image of the highly crystalline SB80/69 sample, with superimposed line plot of the integrated area defined by $14 < 2\theta < 30$ and $-160 < \chi < 20$ deg.

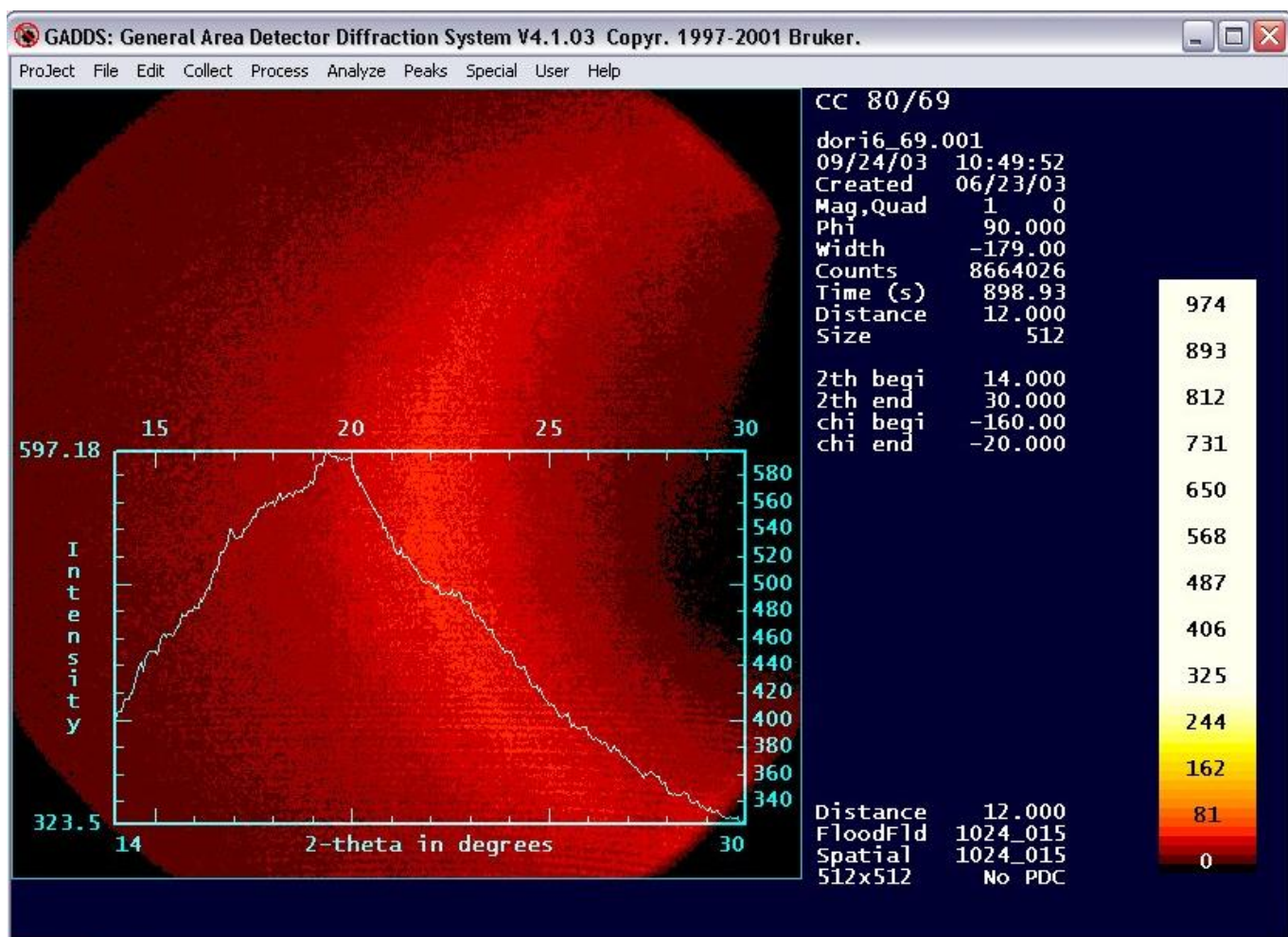


Figure 2. X-Ray Diffraction image of the poorly crystalline CC80/69 sample, with superimposed line plot of the integrated area defined by $14 < 2\theta < 30$ and $-160 < \chi < 20$ deg.

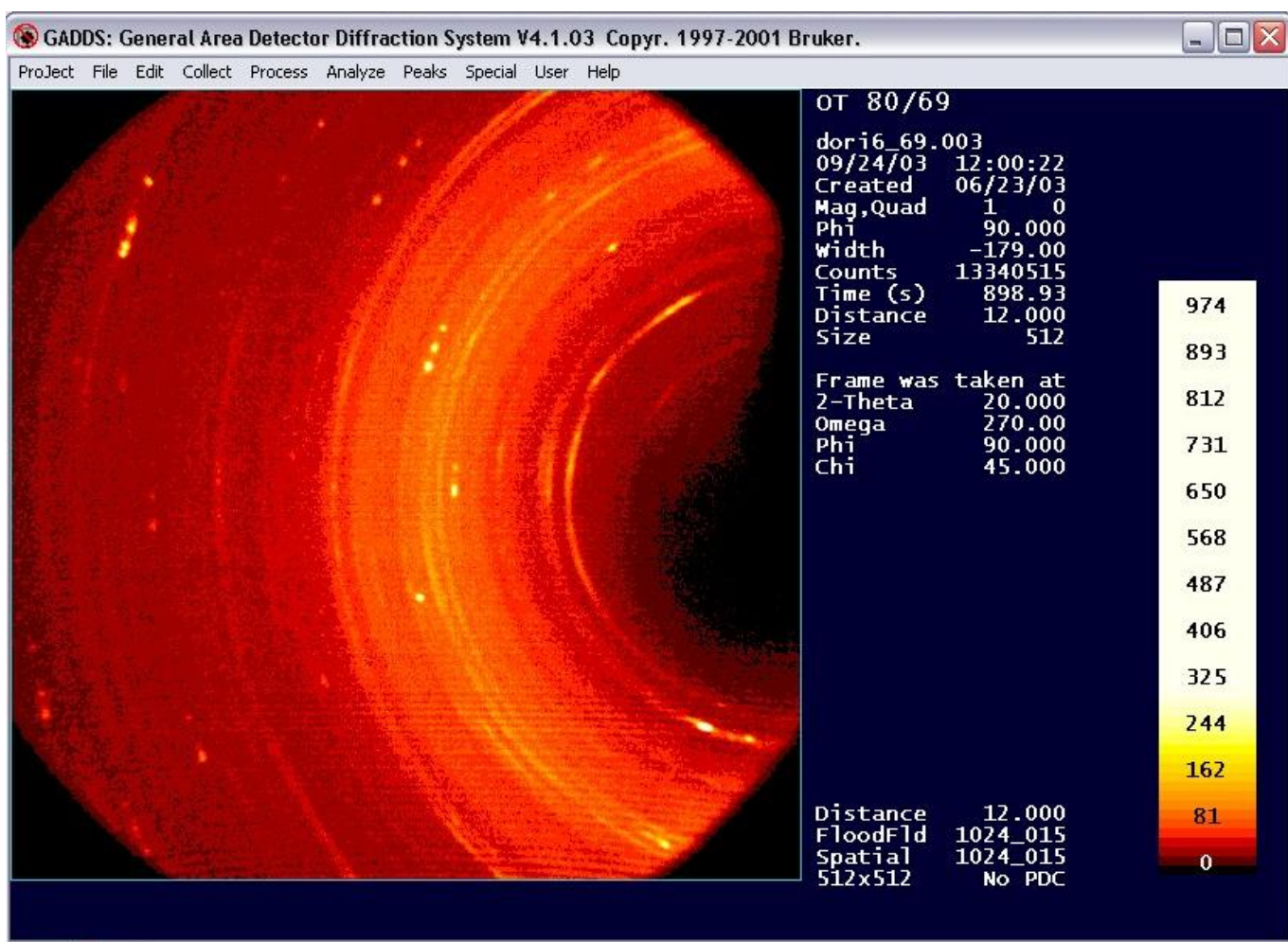


Figure 3. X-Ray Diffraction image of OT80/69, showing diffraction spots from single crystals of salt/sugar.

7.2.3. Results

The results are presented in a series of figures below. The scans of multiple samples are presented on one page to help in observing pattern changes with changes in Water activity/Relative Humidity and Temperatures. Some scans are shown in more than one figure to assist in the interpretation of the results.

To understand the origin of the scans here is a Key of Terms.

- VC = Vegetable Crackers
- OT = Oatmeal Cookies
- CC = Cheese Crackers
- SB = Shortbread Cookies

80/32, 120/75, 100/11 indicated storage conditions Temperature (F)/Relative Humidity (%)

The term MRE was sometimes used to described product received from storage in assembler's plant.

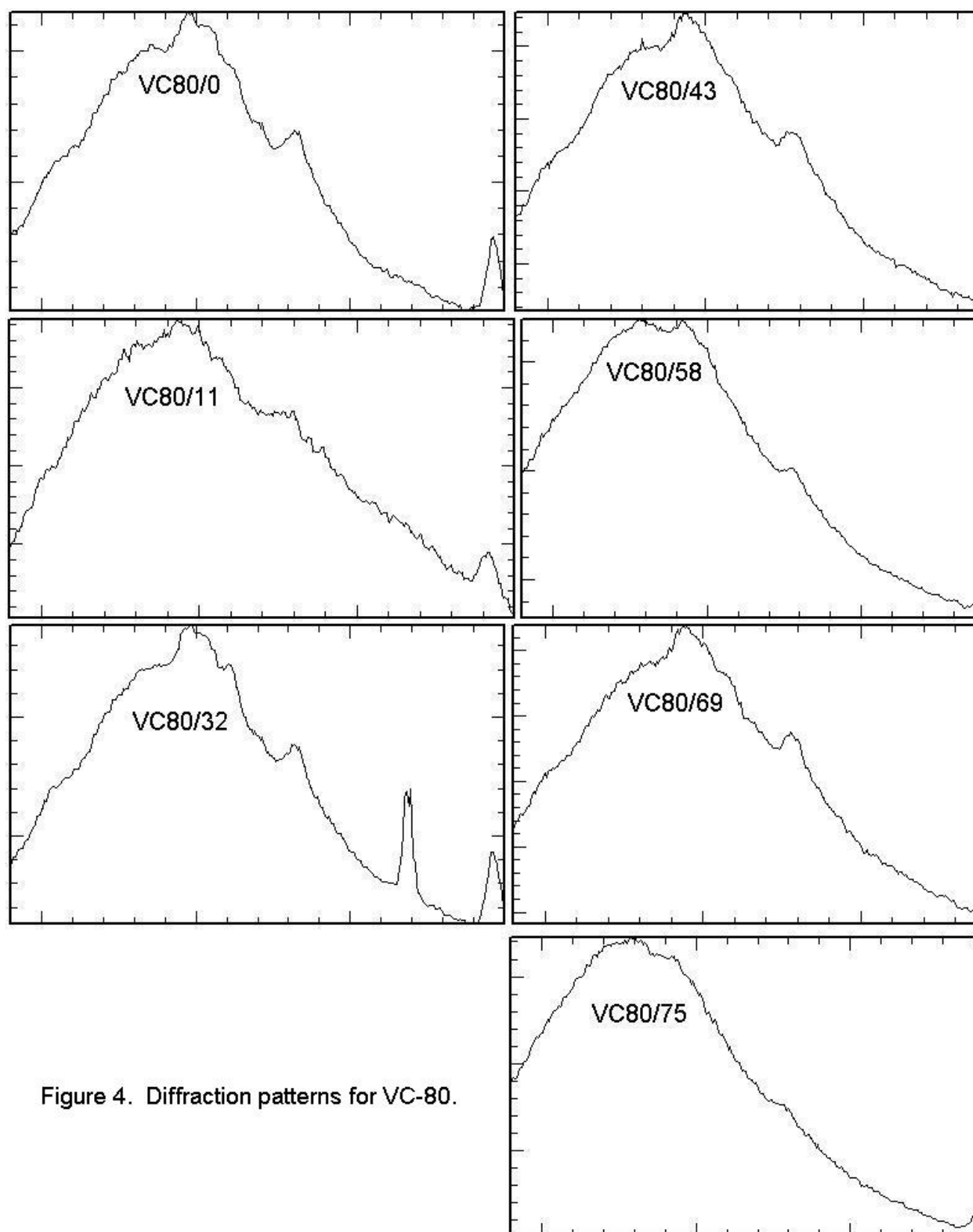


Figure 4. Diffraction patterns for VC-80.

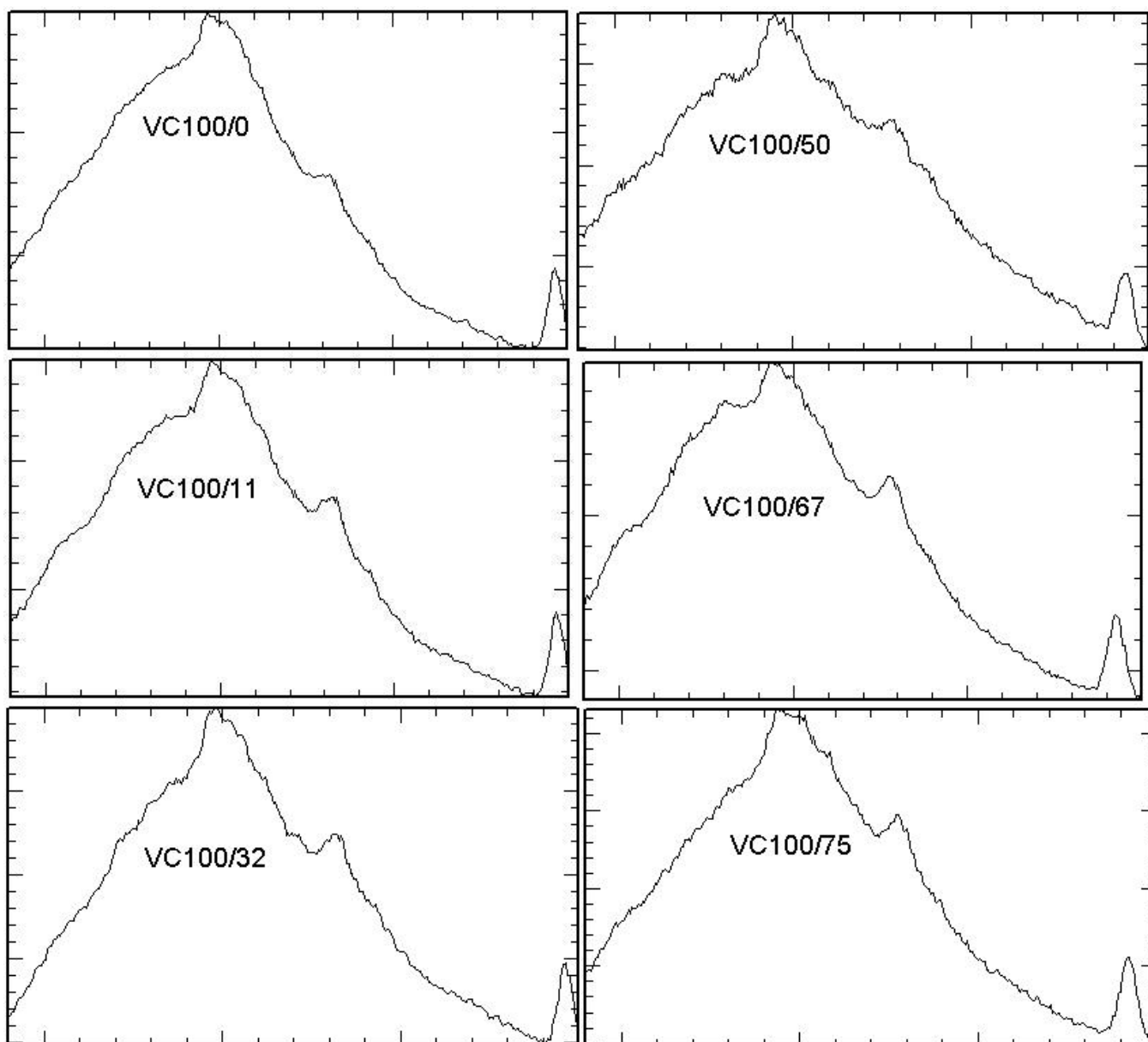


Figure 5. Diffraction patterns for VC-100.

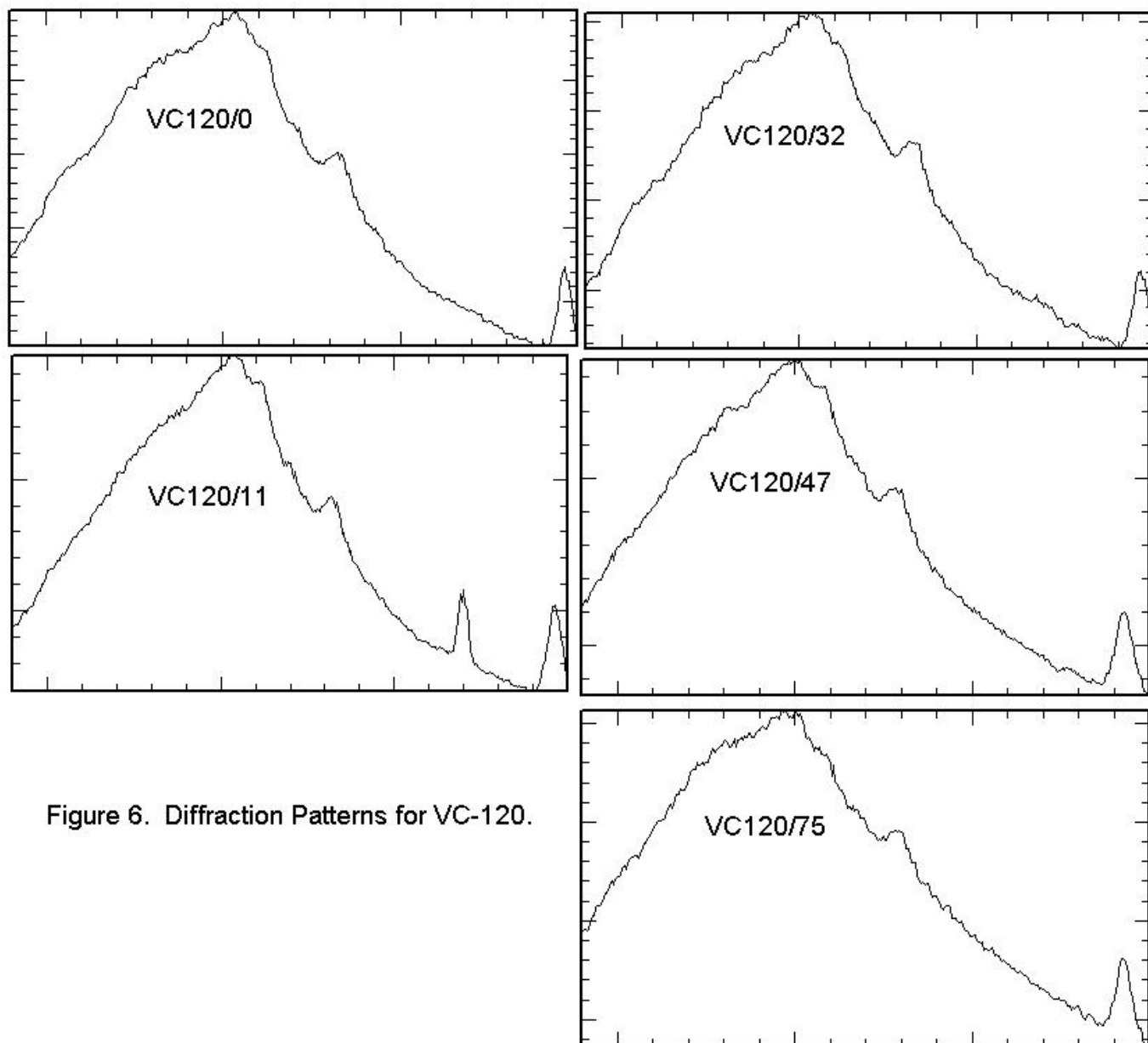


Figure 6. Diffraction Patterns for VC-120.

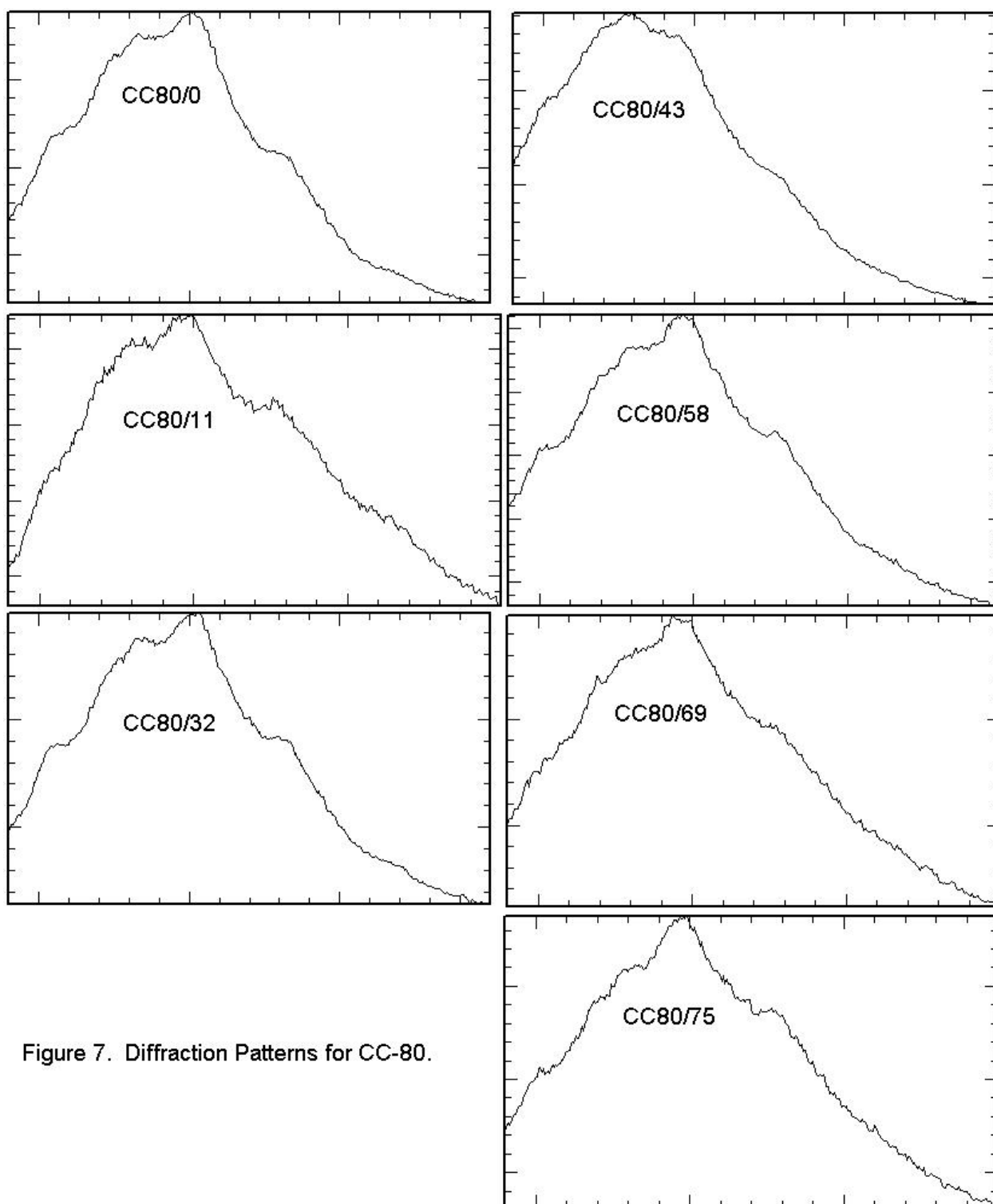


Figure 7. Diffraction Patterns for CC-80.

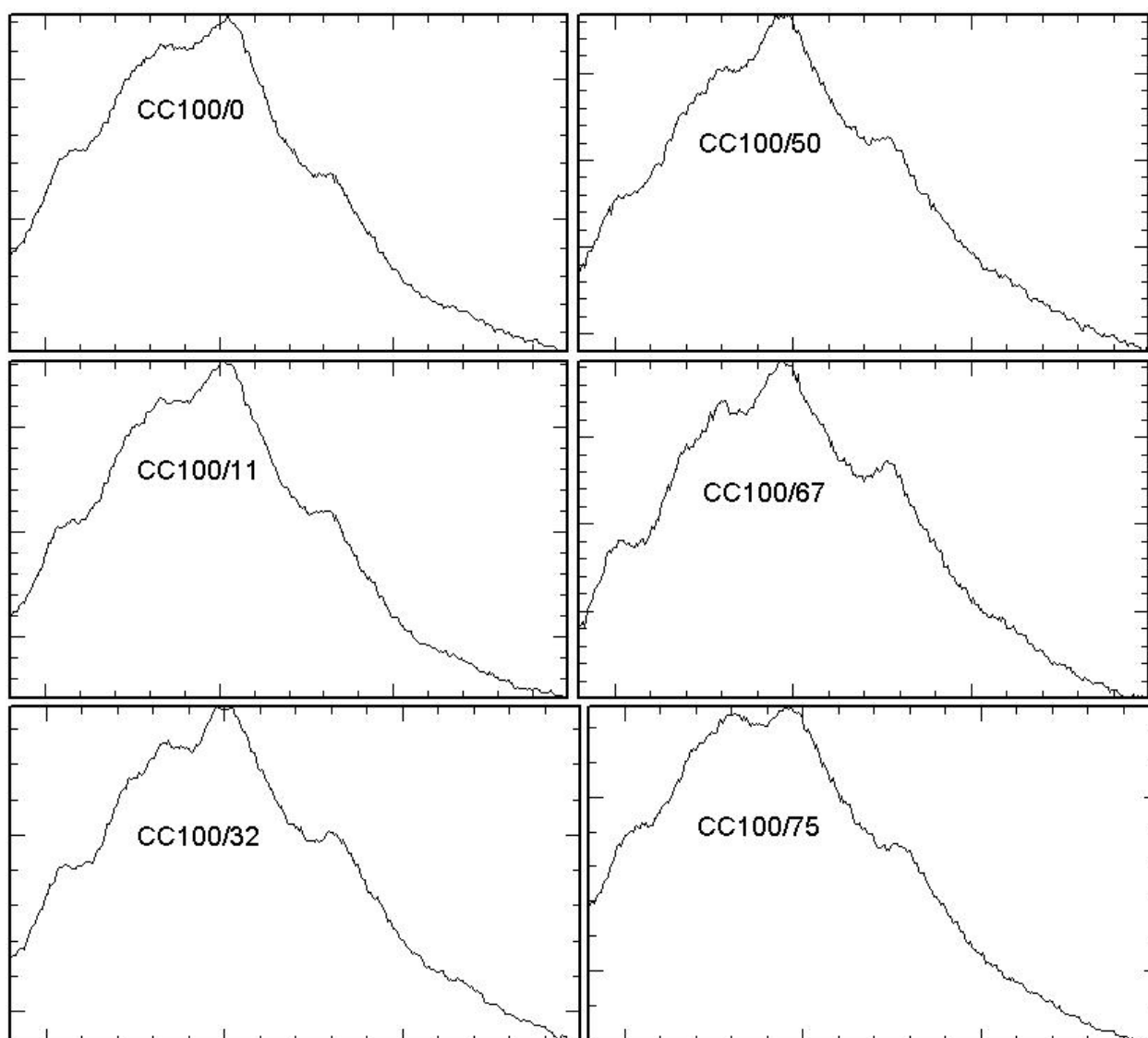


Figure 8. Diffraction Patterns for CC-100.

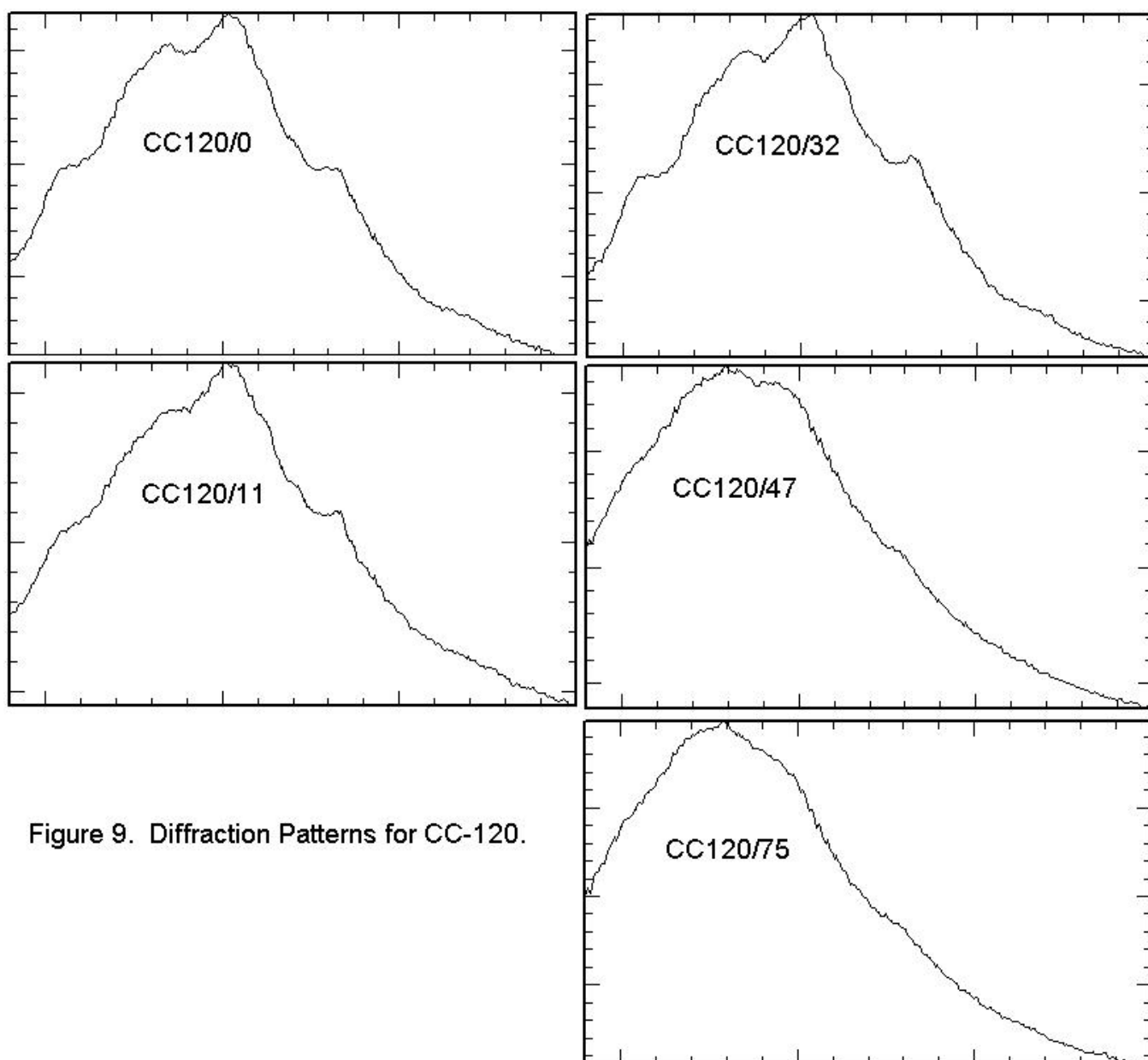


Figure 9. Diffraction Patterns for CC-120.

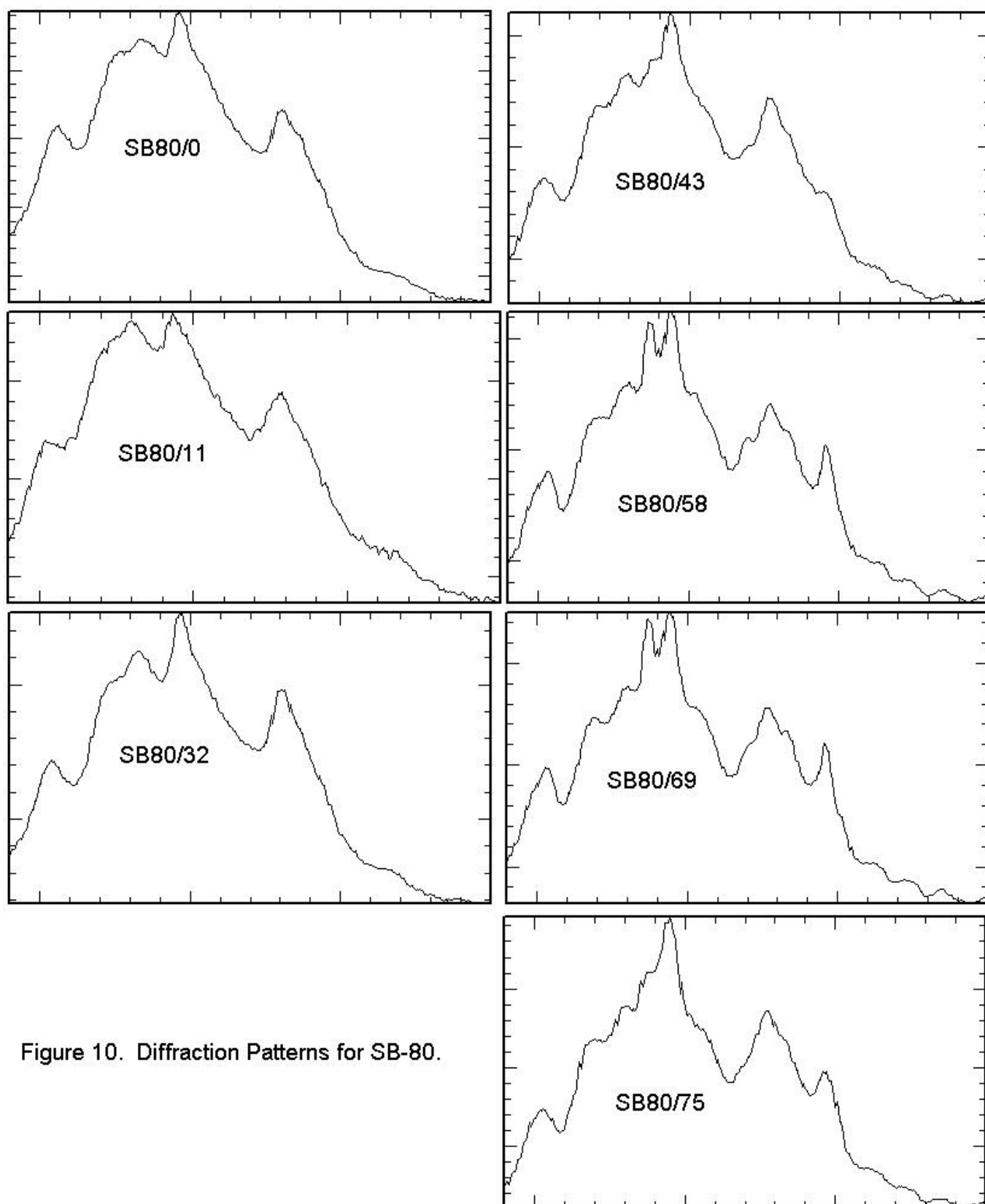


Figure 10. Diffraction Patterns for SB-80.

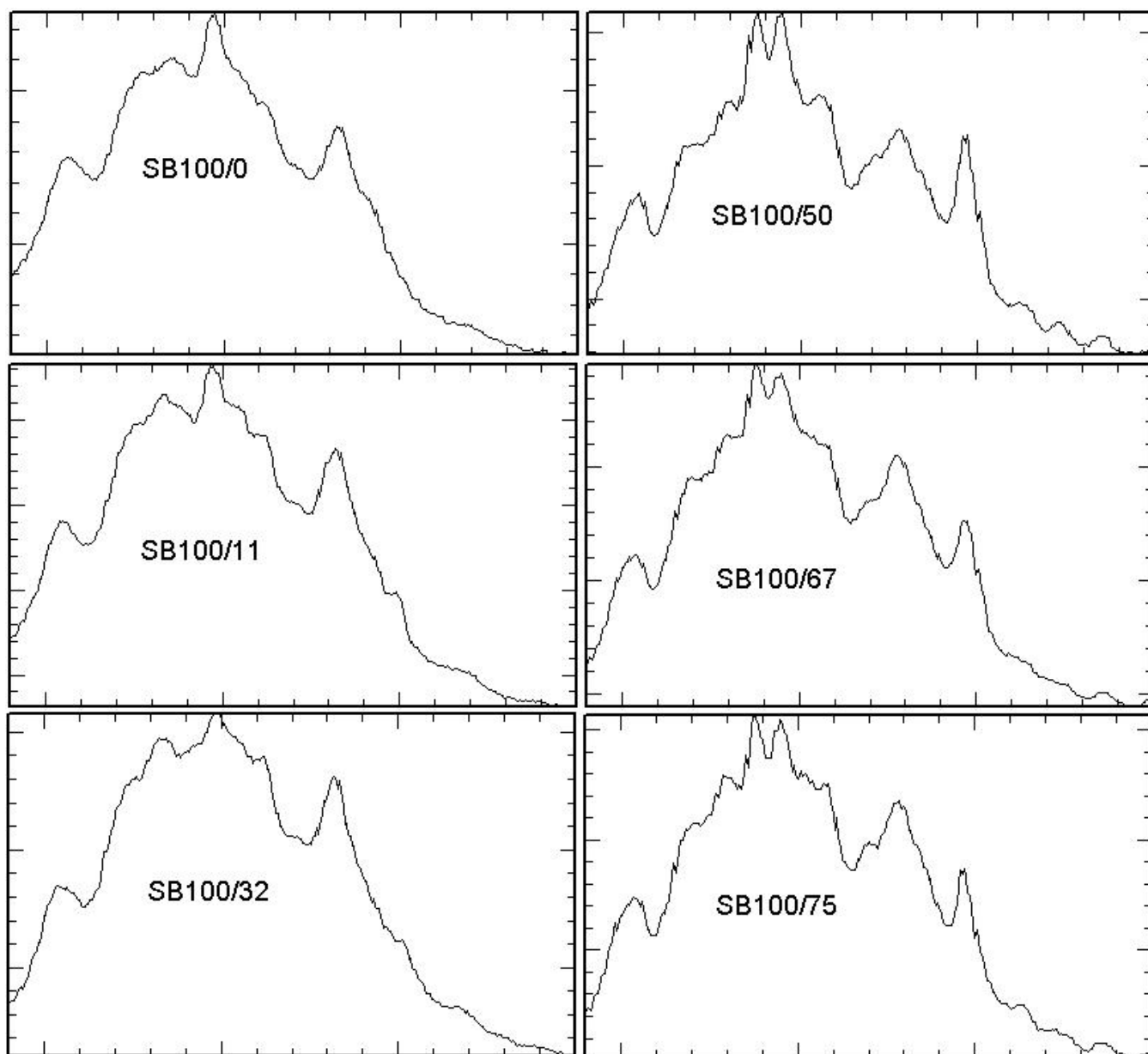


Figure 11. Diffraction Patterns for SB-100.

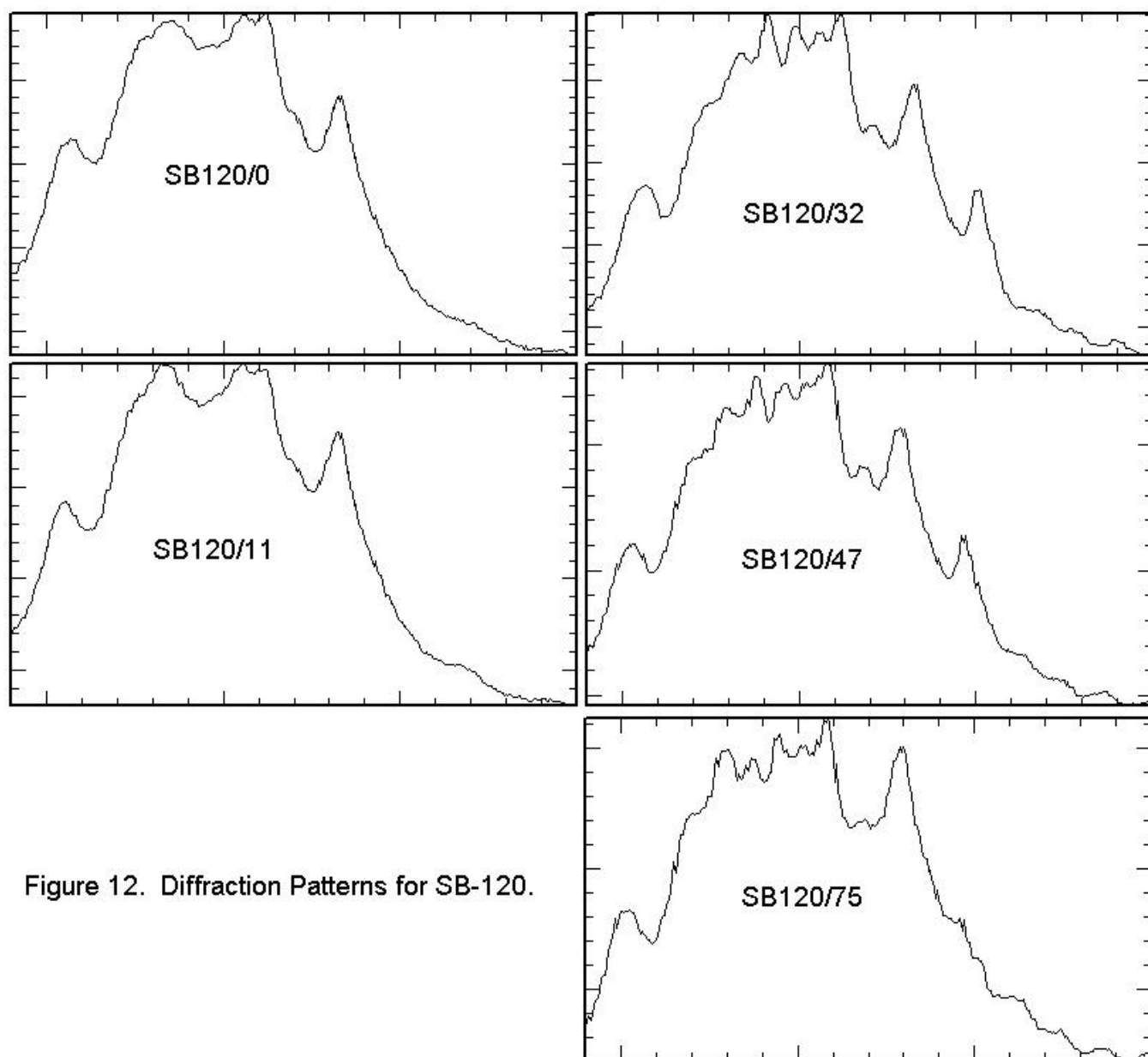


Figure 12. Diffraction Patterns for SB-120.

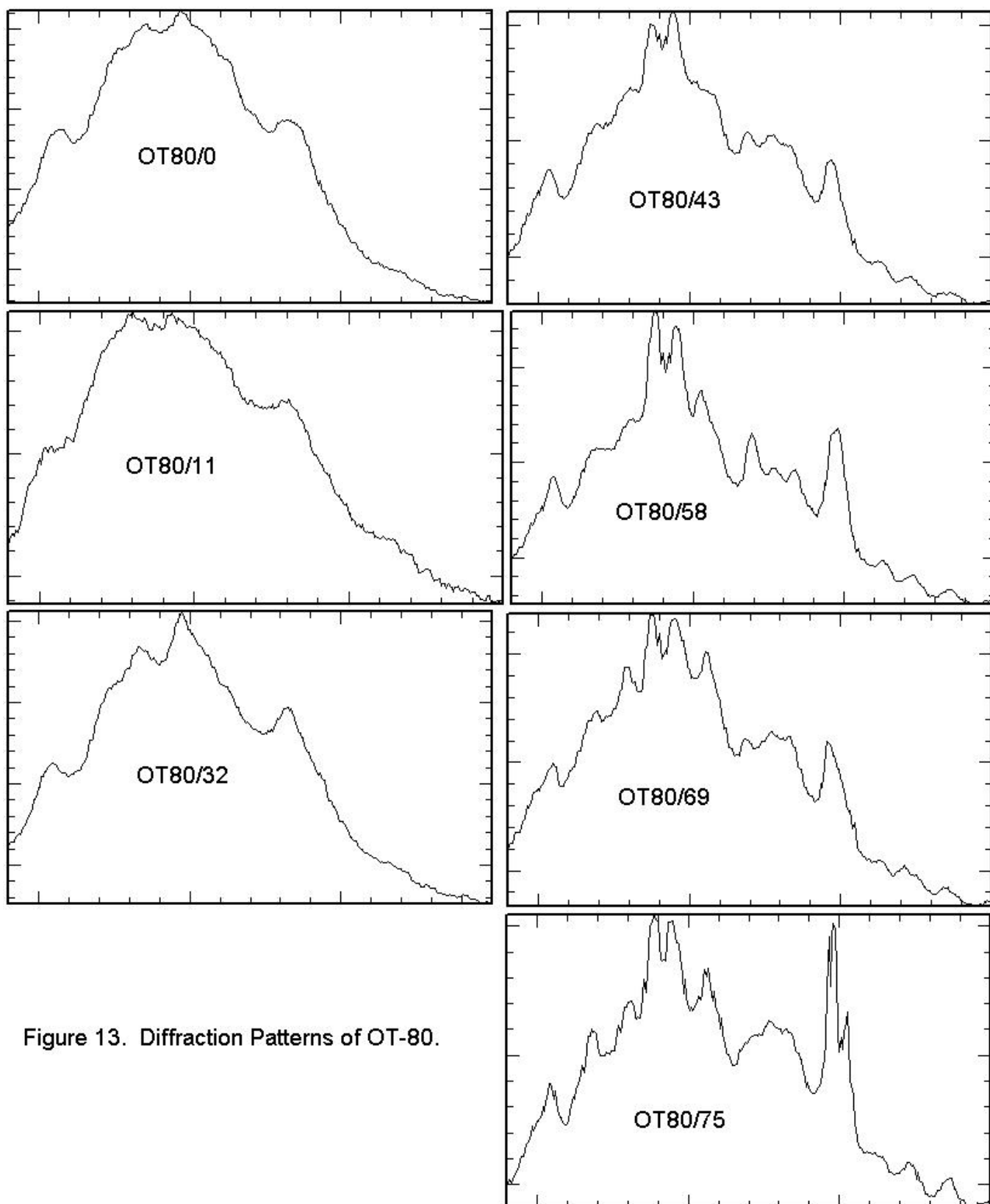


Figure 13. Diffraction Patterns of OT-80.

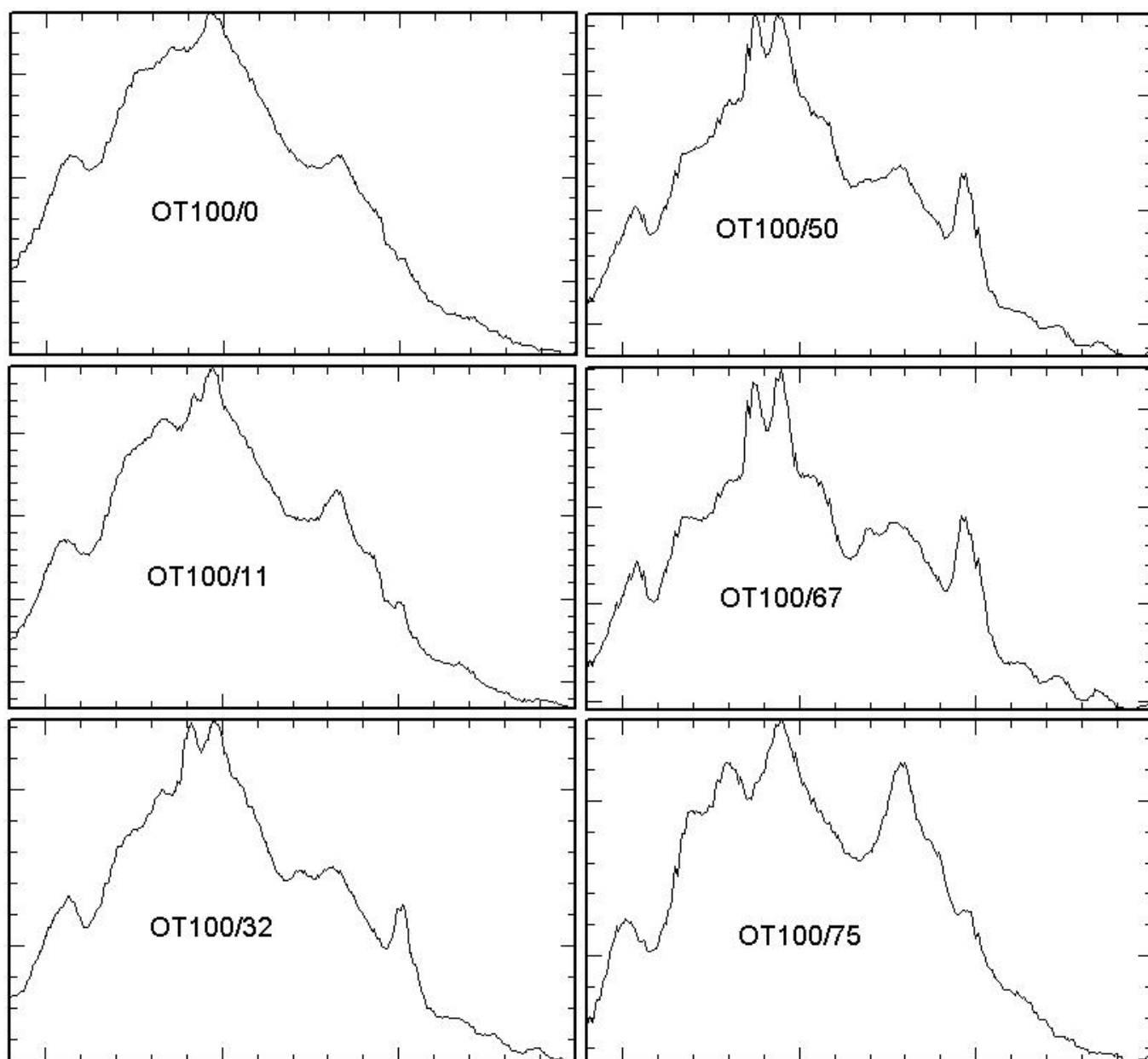


Figure 14. Diffraction Patterns for OT-100.

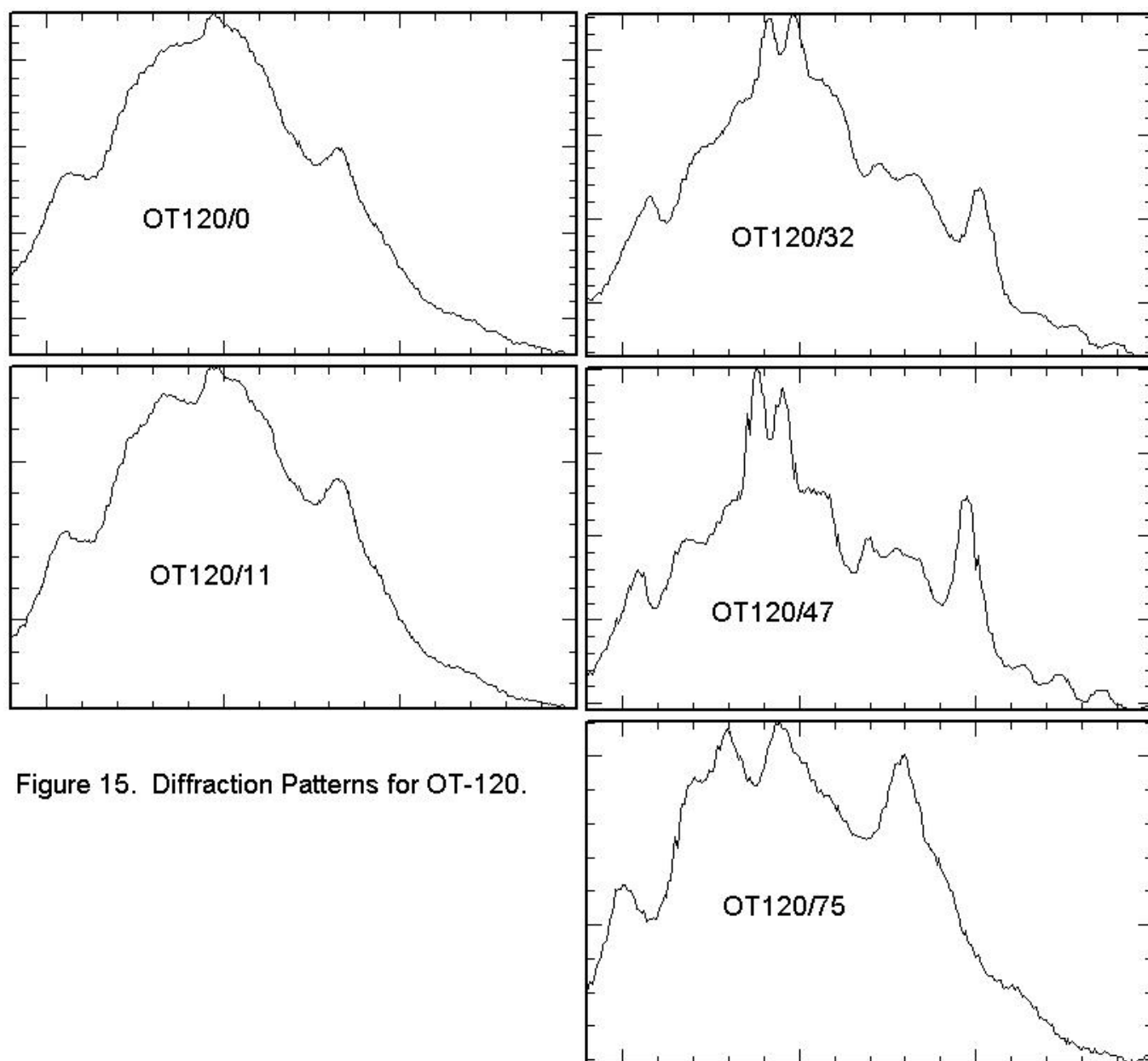


Figure 15. Diffraction Patterns for OT-120.

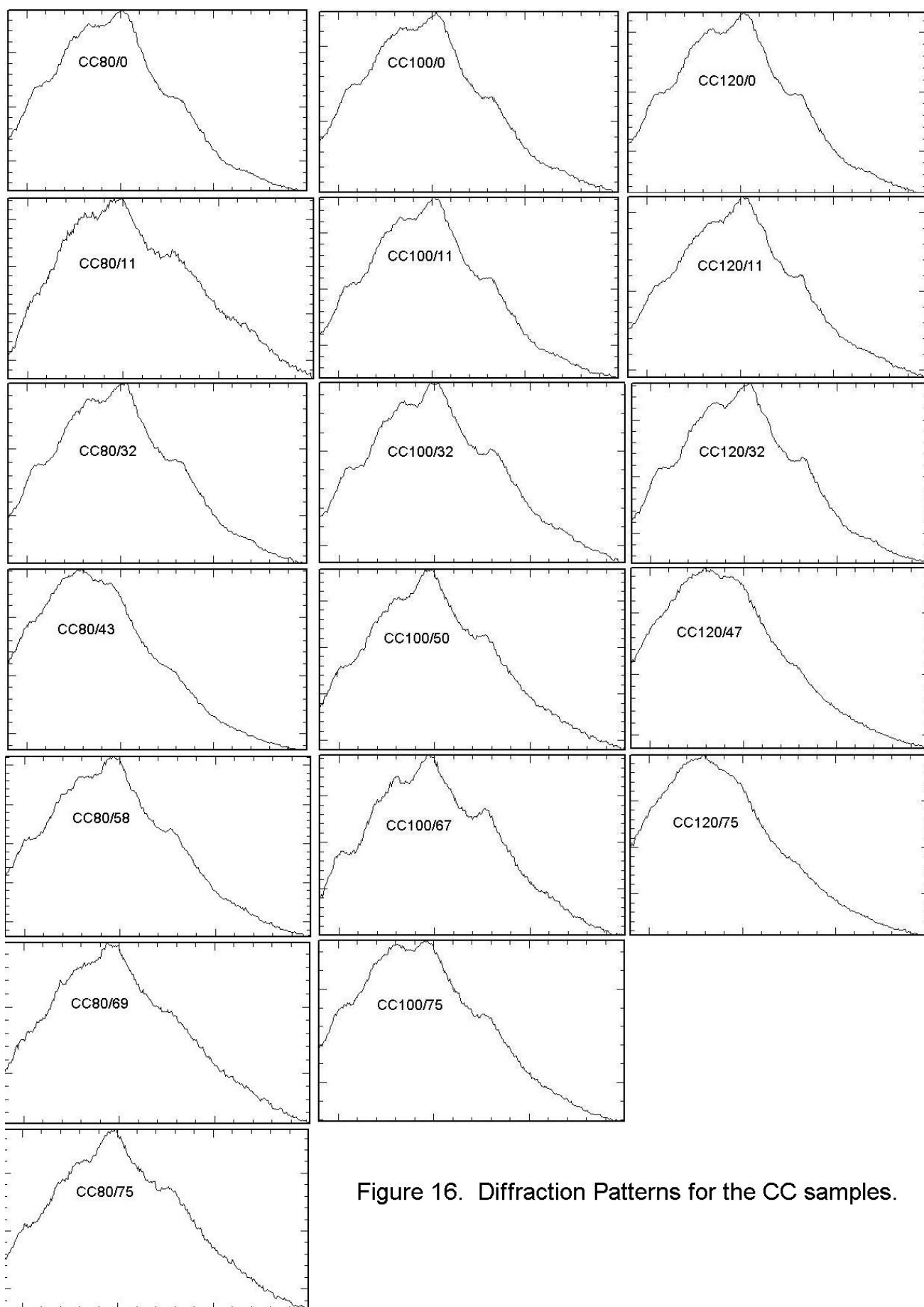


Figure 16. Diffraction Patterns for the CC samples.

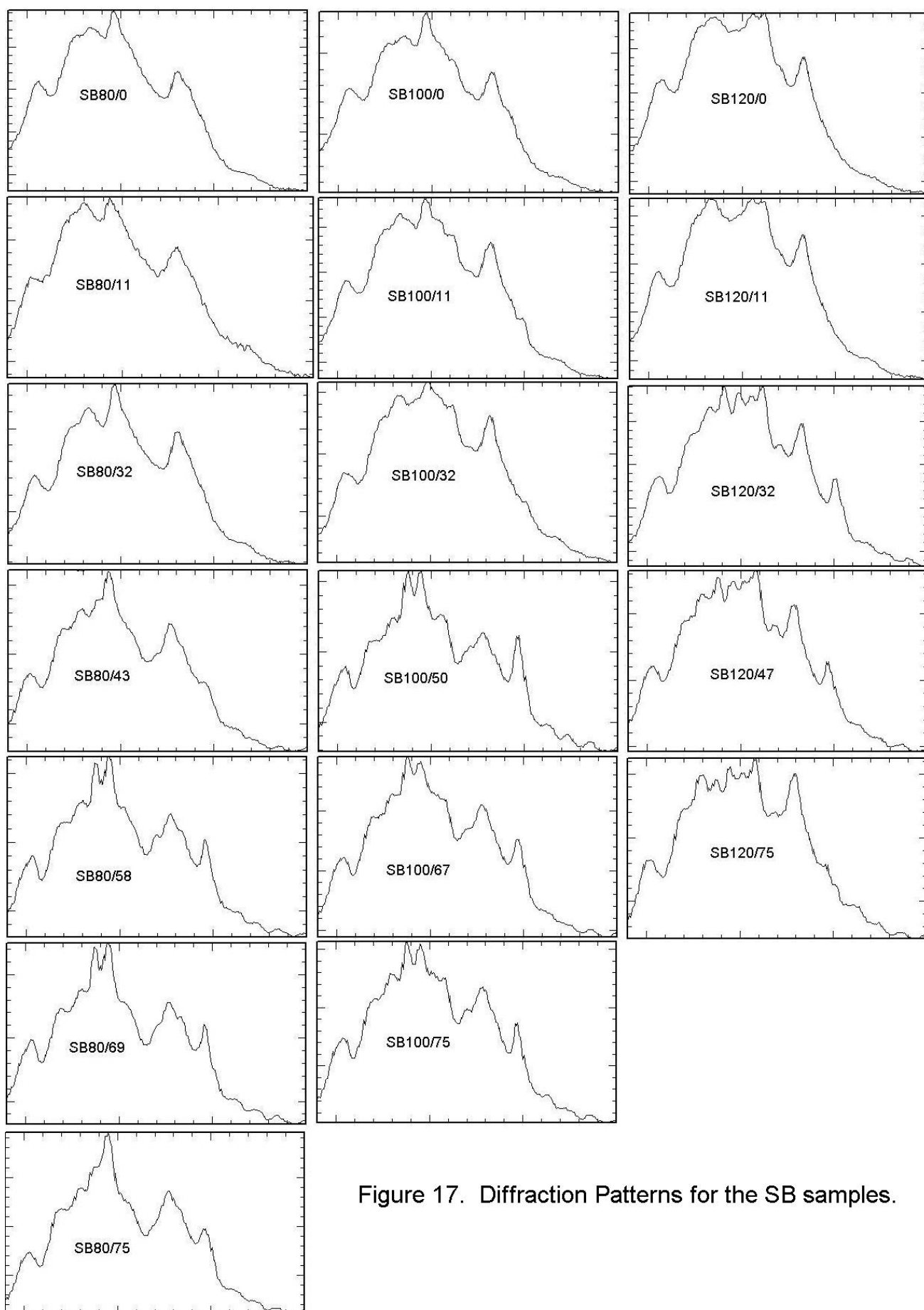


Figure 17. Diffraction Patterns for the SB samples.

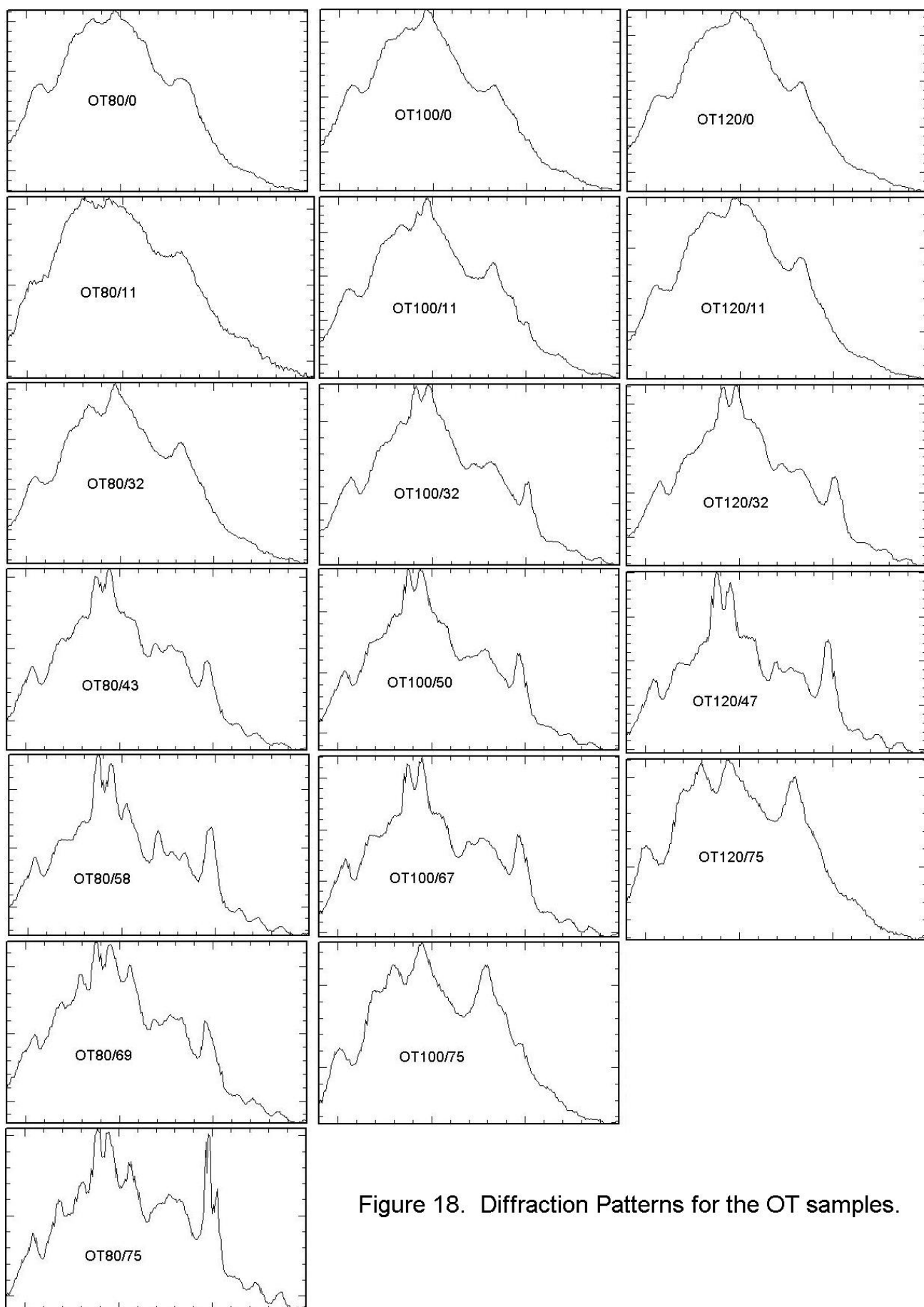


Figure 18. Diffraction Patterns for the OT samples.

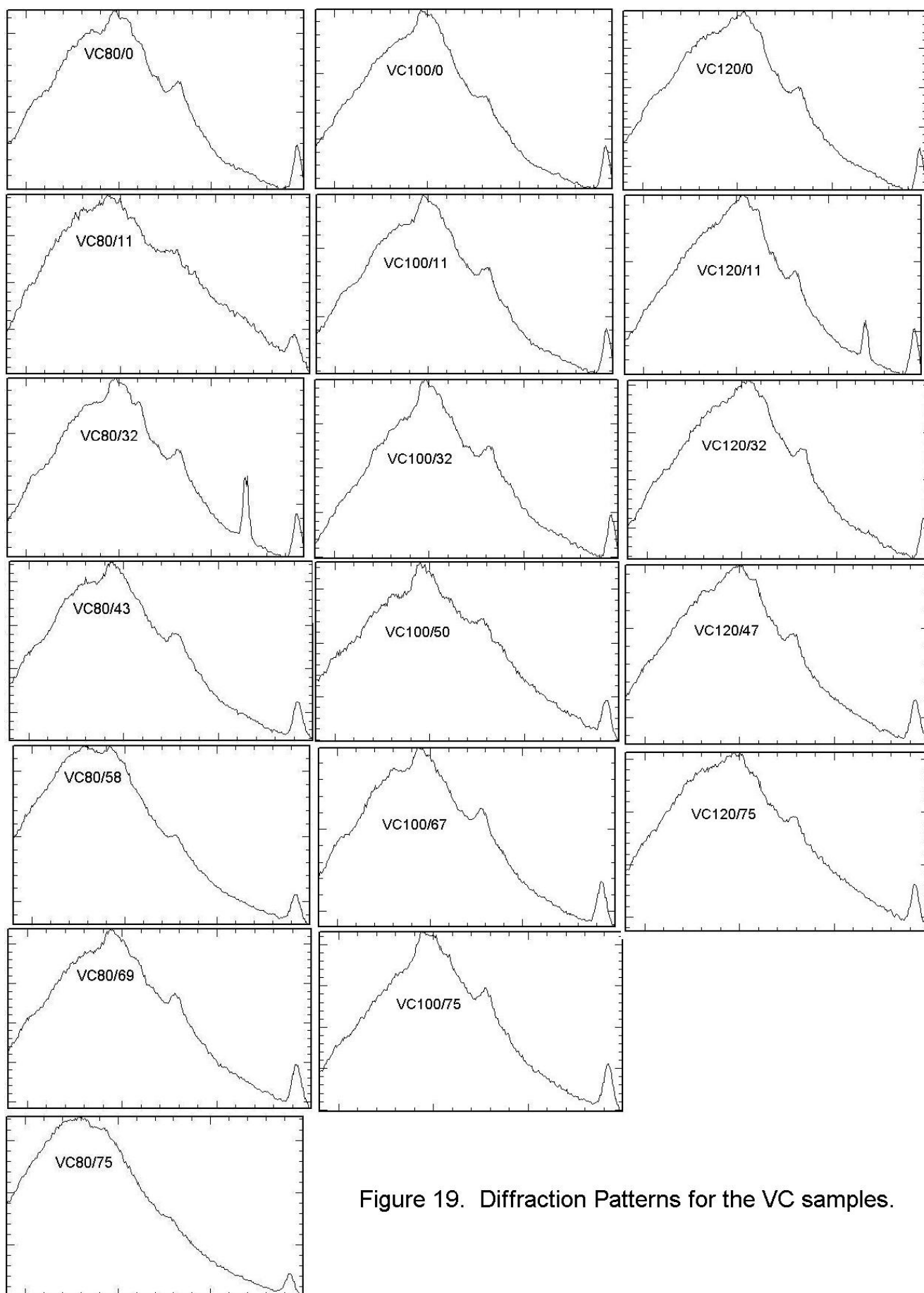


Figure 19. Diffraction Patterns for the VC samples.

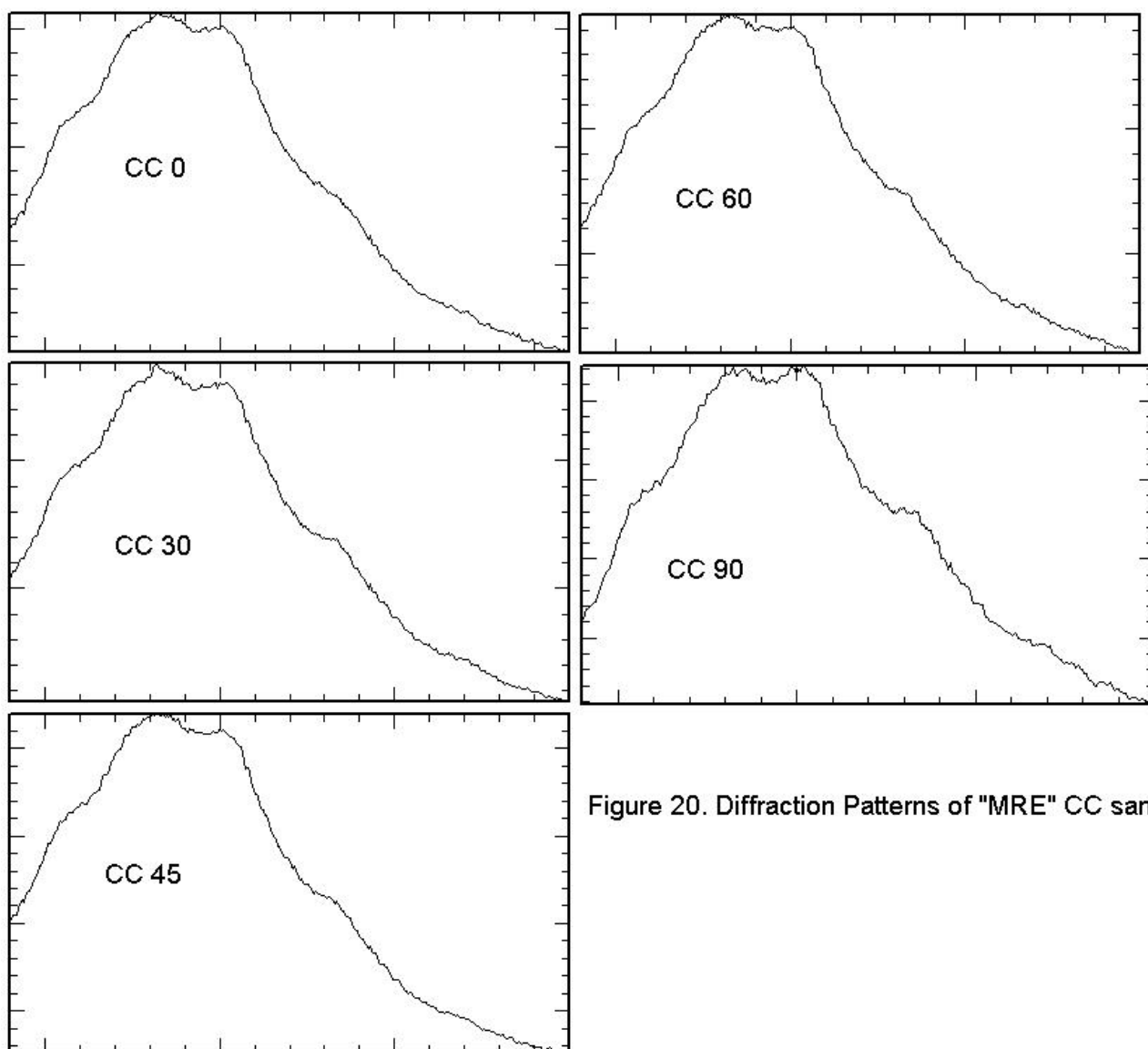


Figure 20. Diffraction Patterns of "MRE" CC samples.

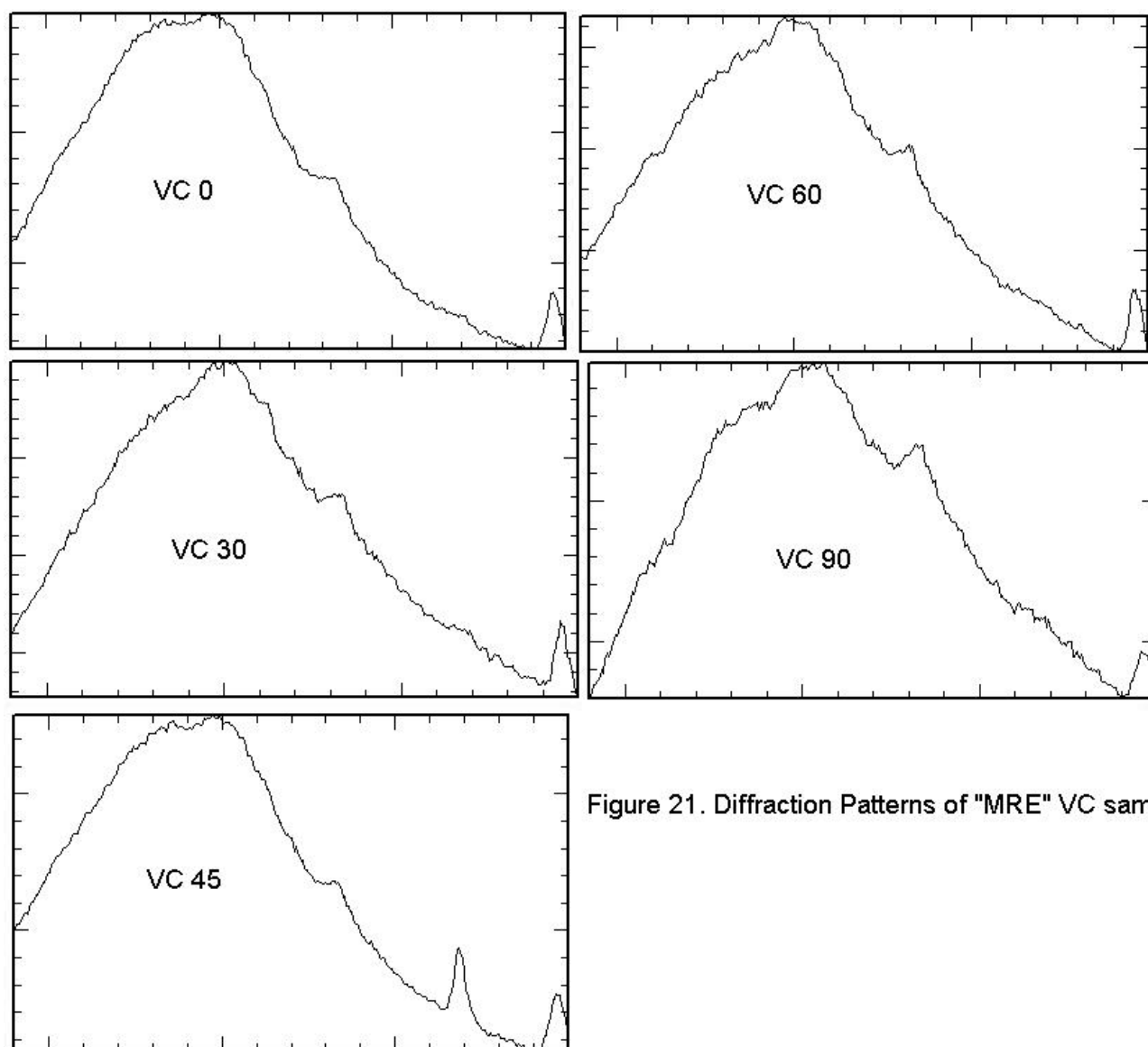


Figure 21. Diffraction Patterns of "MRE" VC samples.

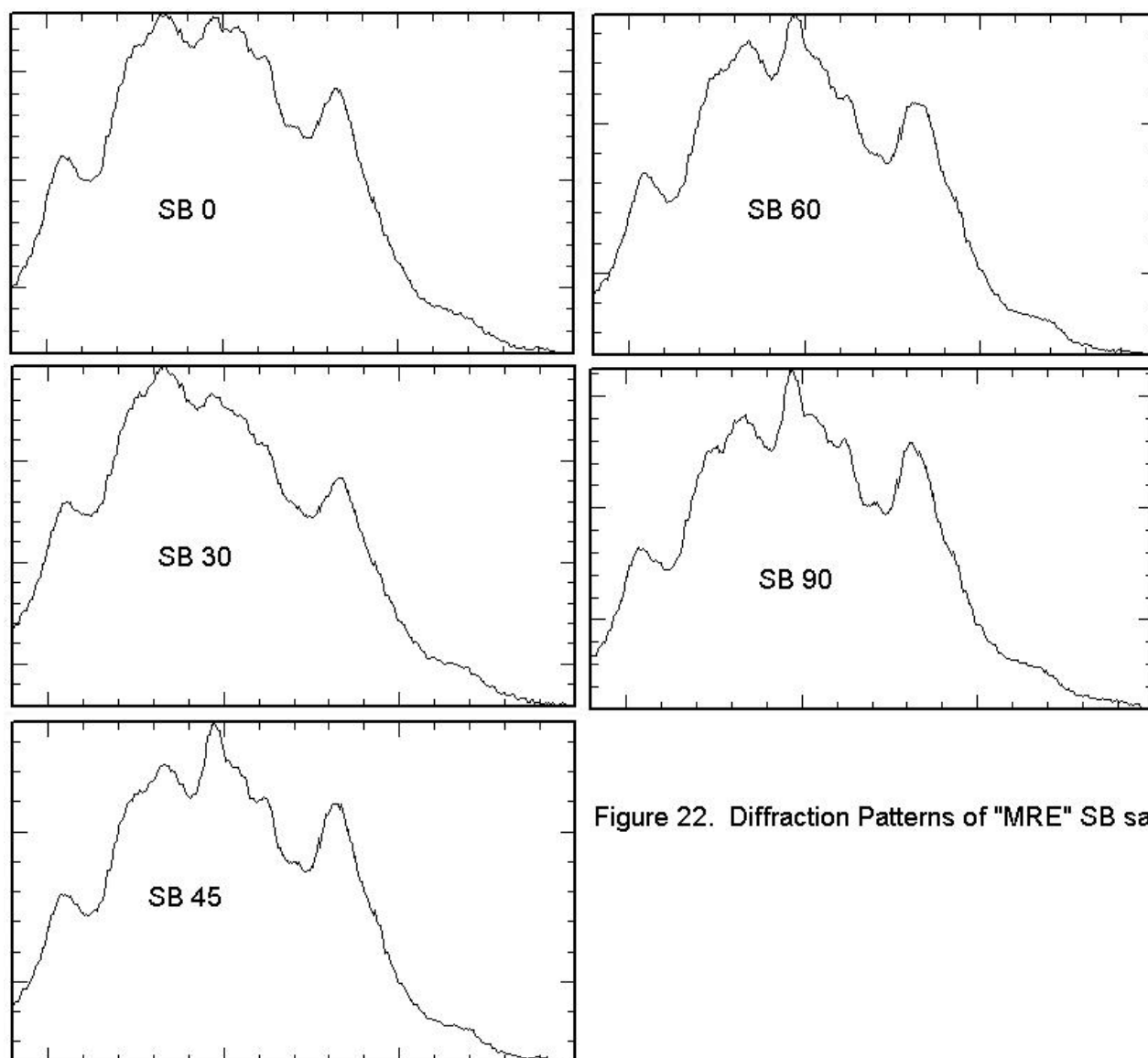


Figure 22. Diffraction Patterns of "MRE" SB samples.

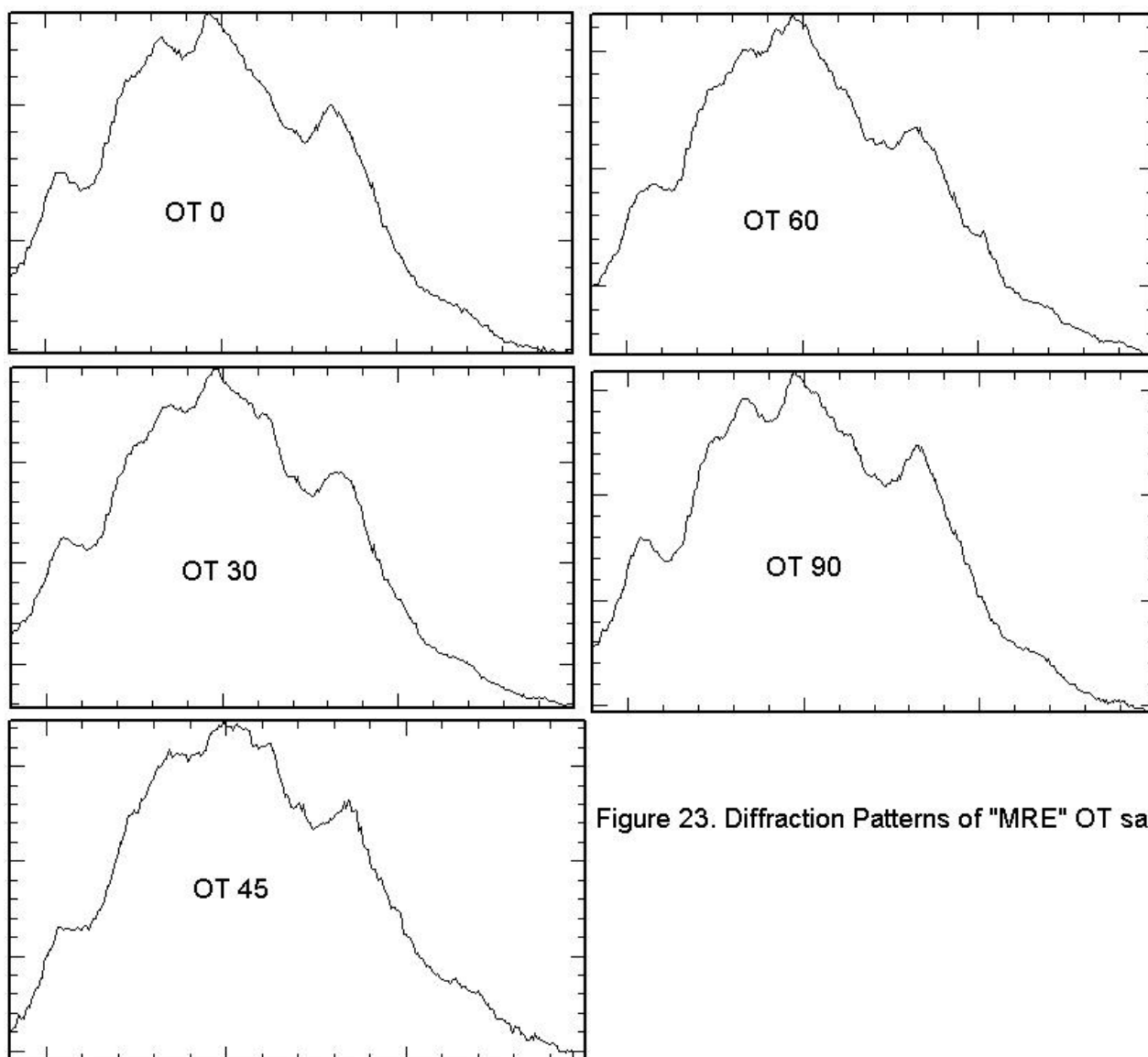


Figure 23. Diffraction Patterns of "MRE" OT samples.

7.2.4. Discussion

As is customary in qualitative x-ray diffraction analysis of polycrystalline samples and mixtures, estimation of relative degree of crystallinity is made by visual inspection of the plots in Figures 1-23, and is not quantified on an absolute scale here. A much more rigorous approach using careful calibration standards would be necessary for a quantitative study.

1. Analysis of samples stored at controlled RH and Temperature Conditions:

Vegetable Crackers Samples

The VC samples, although feeling more “granular” than the other samples, in general are not very crystalline (see Figures 4, 5 and 6). Sometimes, an additional peak is observed at 27 deg (2 θ), and this is attributed to the presence of small pieces of vegetable matter. These vegetable pieces were often brightly colored (orange or green) and were avoided. The relatively strong and isolated peak at 2 θ = 29 deg was found in all samples and may come from a triglyceride, rather than a starch, component. As T was increased from 80 $\rightarrow$ 100 $\rightarrow$ 120, the profiles (and hence degree of crystallinity) stay about the same (see Figure 19). Unlike all the other types of samples, VC samples remain at about the same degree of crystallinity for all RH values (e.g., 0 $\rightarrow$ 11 $\rightarrow$ 32 $\rightarrow$ 43 $\rightarrow$ 58 $\rightarrow$ 69 $\rightarrow$ 75), which is a relatively low degree of crystallinity. The VC samples seemed to retain their dryer “granular” feel for all RH values.

Cheese Combos Samples

The samples with the lowest degree of crystallinity (e.g., the most amorphous) were the CC samples (Figures 7, 8, 9). The degree of crystallinity increased only very slightly upon increase of Temperature and upon increase of RH (see Figure 16). The center “cheese-like” and outer shell “pretzel-like” regions of the sample were successfully avoided in all cases, as there were no diffraction peaks from the fats or inorganic salts contained in these two regions.

Oatmeal Cookies Samples

Only the OT samples were noticeably thicker and puffier with increase in RH. However, the degree of crystallinity increases dramatically with increase in RH (see Figure 18), from very low crystallinity at RH=0 to very crystallinity at RH=75 (Figures 13, 14, 15). Also, for all but the lowest (RH=0) RH level (e.g., see RH=32 row in Figure 18), the degree of crystallinity increases noticeably as Temperature increases from 80 $\rightarrow$ 100 $\rightarrow$ 120.

Shortbread Cookies Samples

Like the OT samples, the SB samples show an increase in relative degree of crystallinity with increase in RH or increase in Temperature (Figures 10, 11, 12). Unlike the OT samples, the texture and feel of the SB samples remained the same for all but the highest RH (RH=75) sample. At the RH=0 level, all SB samples (T=80,100,120) show a noticeably higher degree of crystallinity compared to any other sample at RH=0 (see Figure 17).

The relative degree of crystallinity for the four samples is: **CC < VC << SB, OT**

2. Analysis of samples from storage at assembler’s site.

The samples referred to in this section, as “MRE” are not from MRE packs, but rather samples from intermediate bulk storage at assembler’s location, waiting to be packed into MRE packs.

Vegetable Crackers Samples

Like the control VC samples in section 1., the “MRE” VC samples have very low degree of crystallinity (Figure 21). The degree of crystallinity may increase with RH, but only very slightly. This increase was not noticeable in the control VC samples.

Cheese Combos Samples

The CC “MRE” samples were the absolute lowest degree of crystallinity, even slightly lower than the CC control samples, and these five samples appear to be unchanged in degree of crystallinity for the entire storage range 0 to 90 days (Figure 20).

Oatmeal Cookies Samples

Only a small (relative) degree of crystallinity is observed in the “MRE” OT samples (Figure 23). It changes only slightly in the direction of more crystallinity as storage days 0 → 90. This contrasts the more dramatic changes in the OT samples, which were exposed to controlled conditions of high RH and temperatures.

Shortbread Cookies Samples

The “MRE” SB samples have a higher degree of crystallinity than the other “MRE” samples, and do slightly increase in relative degree of crystallinity as storage time increase 0 → 90 days (Figure 22). As is the case for the “MRE” OT sample at storage period 60 & 90 days, the degree of crystallinity of “MRE” SB samples, while greater than that for the “MRE” CC and “MRE” VC samples, is still noticeably less than that of the samples exposed to RH=58, 69 or 75 control SB.

3. The overall effect of Temperature (T=80 → 120) versus Relative Humidity (RH=0 → 75)

The overall effect of temperature for the range 80 → 120 on degree of crystallization (fat- or starch-based) is not as dramatic as that of relative humidity (see Figures 16 through 19). However, the downturn in crystallinity at the highest relative humidity occurs at different temperatures for the two “fat-crystalline” samples, SB (at T=80) versus OT (at T=120). The same can be roughly said for the “starch-crystalline” (or, rather, “not-fat-crystalline”) samples, VC (at T=80) versus CC (T=120).

4. The degree of crystallinity of the fat vs. starch component

The x-ray scattering (broad peaks) from the CC and VC samples (Figures 16 and 19 in the 9/24/03 report) were indicative of a major starch component and a very minor (if at all) fat component. The most “starch-crystalline” for the CC samples was 100/67 and for the VC samples was also 100/67. The least crystalline for the CC samples was the 120/75 and for the VC samples was 80/75. Thus, the intermediate relative humidity value of 67 was best for maintaining a more crystalline starch component CC or VC

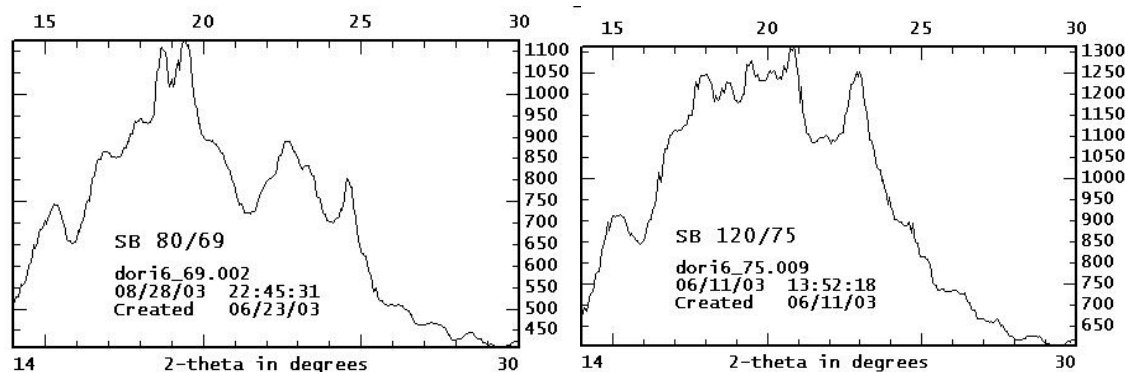
sample, and the high relative humidity value of 75 yielded a less crystalline starch component of the CC or VC sample.

For the SB and OT samples (Figures 17 and 18), there appears to be strong diffraction (sharp peaks) from the fat component as well as scattering (broad peaks) from the starch component. Although the more-coherent diffraction of the fat component dominates the overall x-ray pattern, the starch component is still the major component compositionally. Thus, both fat **and** starch components of the SB and OT samples can be treated as the major components that generate the x-ray diffraction profiles of Figures 17 and 18.

The least “fat-crystalline” for the SB samples was 80/0 and for the OT samples was 120/0. The unfavorable effect of low relative humidity on the crystallinity of the SB and OT samples may be due to significant interplay between the fat and starch components within these samples (e.g., a dryer starch component may not allow the fat component to form crystalline species). This idea needs more research...

The most “fat-crystalline” for the SB samples was 80/69 and for the OT samples was also 80/69. Thus, just as in the starch-dominated CC and VC samples, the intermediate relative humidity value of about 69 was best for maintaining a more crystalline sample, even though the SB and OT samples are “high-fat-containing” samples.

The x-ray scattering (e.g., broad peak from the starch component) or diffraction (e.g., sharper peak from the fat component) in the $22 < 2\theta < 24$ deg region best indicates the “starch-crystallinity” of any of the samples. In this region, there appears to be a sharp singlet if only the fat component is crystalline, and a broad doublet or triplet if both the starch and fat components are crystalline. For example, for the SB samples, the most “starch-crystalline” are the 80/69 (shown below) and 100/67 samples. The T=120 SB samples did not appear to have a significant crystalline starch component, but the fat component that is most crystalline for the T=120 SB series is 120/75 (also shown below).



Thus, the low relative humidity SB and OT samples 80/0, 80/11, 100/0, 120/0 (see Figures 17 and 18) exemplify poor fat crystallinity and unknown (but assumed significant, like those of the CC and VC samples) starch crystallinity. In contrast, the higher relative humidity SB samples 80/43, 80/58, 80/69, 100/50, 100/67, 100/75, 120/32, 120/47 and 120/75 show marked fat crystallinity and significant starch crystallinity, except for the T=120 samples. For the OT samples, the corresponding samples with optimal fat crystallinity are 80/43, 80/58, 80/69, 80/75, 100/50, 100/67, 120/32 and 120/47. The fat crystallinity fades a bit for the SB 80/75 (e.g., highest relative humidity) and for the OT 100/75 and 120/75.

8.0 Extended Storage Life (Phase III)

Although sufficient time existed within the scope of Phase II to allow 90-day interim storage of the as-received bakery items, behavior of the item once over-wrapped with its attendant storage time of 3 years was not possible. Obtaining this later extended storage behavior was the reason for defining a separate Phase III as well as locating it at the U.S. Army Laboratories, Natick.

Two types of testing will be conducted in Phase III: Sensory and Thermal-Mechanical. Items for Sensory Quality evaluation will be stored at a benchmark temperature of 80°F for a total of 24 months (sampled at time zero, 3 months, 6 months, 12 months and 24 months) and an accelerated condition of 100°F for a total

of 6 months (sampled at zero, 3 months and 6 months). For the examination of changes in mechanical properties (using the U.S. Natick Labs “Dynamic Mechanical Analyzer”) only the 80°F temperature storage will be employed with the same sample schedule as given earlier for sensory tests.

Rather than await the Phase II results regarding the impact of interim storage conditions on overall storage life, the decision was made to include that variable in the Phase III protocol. Accordingly, both the Sensory and Mechanical tests will be conducted on bakery items from a “zero time” repack or interim storage as well as a 90 day repack or interim storage.

Appendix A

The tables in Appendix A contain the data collected and the data calculated for the Sorption Isotherms.

Sorption Isotherms for Vegetable Crackers

Actual Data Collected

Water Content Determined Using 100C Oven Method

Aw	80F	100F	120F
M (kg Water/kg Product d.b.)			
0.000	0.00820	0.01018	0.00524
0.111			0.03209
0.112		0.03342	
0.113	0.03459		
0.308			0.05201
0.318		0.05388	
0.326	0.07087		
0.432	0.07182		
0.462			0.06842
0.492		0.07612	
0.568	0.09383		
0.665		0.10989	
0.684	0.12356		
0.745			0.14577
0.748		0.14080	
0.752	0.15104		

Sorption Isotherms for Vegetable Crackers

Actual Data Collected

Water Content Determined Using Vacuum Oven Method

Aw	80F	100F	120F
M (kg Water/kg Product d.b.)			
0.000	0.00287	0.00253	0.00052
0.111			0.01622
0.112		0.02338	
0.113	0.02667		
0.308			0.04774
0.318		0.05165	
0.326	0.04620		

0.432	0.06585		
0.462			0.05769
0.492		0.06648	
0.568	0.08861		
0.665		0.09632	
0.684	0.11202		
0.745			0.13882
0.748		0.13006	
0.752	0.15000		

Sorption Isotherms for Vegetable Crackers

Calculated data based on Iglesias and Chirife, 1982

Water Content Determined Using 100C Oven Method

Aw	80 F	100 F	120 F
Kg Water/Kg Product d.b.			
0.00	0.00000	0.00000	0.00000
0.05	0.03592	0.03252	0.03153
0.10	0.04323	0.03805	0.03652
0.15	0.04789	0.04178	0.03999
0.20	0.05195	0.04520	0.04326
0.25	0.05599	0.04872	0.04668
0.30	0.06027	0.05253	0.05044
0.35	0.06495	0.05680	0.05469
0.40	0.07020	0.06168	0.05960
0.45	0.07620	0.06736	0.06538
0.50	0.08319	0.07409	0.07231
0.55	0.09146	0.08224	0.08081
0.60	0.10144	0.09231	0.09150
0.65	0.11376	0.10511	0.10537
0.70	0.12936	0.12194	0.12411
0.75	0.14981	0.14510	0.15086
0.80	0.17780	0.17900	0.19220
0.85	0.21848	0.23338	0.26453
0.90	0.28306	0.33494	0.42371
R ²	0.96130	0.98600	0.98730

Sorption Isotherms for Vegetable Crackers

Calculated data based on Iglesias and Chirife, 1982

Water Content Determined Using Vacuum Oven Method

Aw	80 F	100 F	120 F
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Kg Water/Kg Product d.b.

0.00	0.00000	0.00000	0.00000
0.05	0.02574	0.02437	0.01793
0.10	0.03204	0.03093	0.01968
0.15	0.03614	0.03511	0.02128
0.20	0.03975	0.03868	0.02303
0.25	0.04339	0.04218	0.02501
0.30	0.04728	0.04586	0.02733
0.35	0.05164	0.04990	0.03009
0.40	0.05664	0.05445	0.03346
0.45	0.06253	0.05972	0.03765
0.50	0.06961	0.06593	0.04302
0.55	0.07835	0.07343	0.05016
0.60	0.08946	0.08270	0.06013
0.65	0.10407	0.09450	0.07503
0.70	0.12422	0.11007	0.09970
0.75	0.15384	0.13160	0.14850
0.80	0.20168	0.16335	0.29070
0.85	0.29222	0.21498	0.76515

R ²	0.94300	0.92010	0.75970
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Sorption Isotherms for Oatmeal Cookies

Actual Data Collected

Water Content Determined Using 100C Oven Method

Aw	80F	100F	120F
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M (kg Water/kg Product d.b.)

0.000	0.01741	0.01316	0.00978
0.111			0.02899
0.112		0.03212	
0.113	0.03696		
0.308			0.03922
0.318		0.04723	
0.326	0.07200		
0.432	0.06413		
0.462			0.05172
0.492		0.06054	
0.568	0.07171		
0.665		0.09524	

0.684	0.09959		
0.745			0.16541
0.748		0.15341	
0.752	0.14522		

Sorption Isotherms for Oatmeal Cookies

Actual Data Collected

Water Content Determined Using Vacuum Oven Method

Aw	80F	100F	120F
M (kg Water/kg Product d.b.)			
0.000	0.00050	0.00021	0.00192
0.111			0.01807
0.112		0.01815	
0.113	0.02006		
0.308			0.03086
0.318		0.03636	
0.326	0.04182		
0.432	0.04960		
0.462			0.03627
0.492		0.05102	
0.568	0.06658		
0.665		0.07838	
0.684	0.08828		
0.745			0.14551
0.748		0.12948	
0.752	0.10626		

Sorption Isotherms for Oatmeal Cookies

Calculated data based on Iglesias and Chirife, 1982

Water Content Determined Using 100C Oven Method

Aw	80 F	100 F	120 F
Kg Water/Kg Product d.b.			
0.00	0.00000	0.00000	0.00000
0.05	0.04074	0.03118	0.02701
0.10	0.04313	0.03304	0.02843
0.15	0.04555	0.03513	0.03027
0.20	0.04817	0.03750	0.03244
0.25	0.05108	0.04021	0.03498
0.30	0.05434	0.04335	0.03798

0.35	0.05803	0.04702	0.04155
0.40	0.06226	0.05137	0.04587
0.45	0.06713	0.05661	0.05121
0.50	0.07284	0.06303	0.05795
0.55	0.07959	0.07110	0.06676
0.60	0.08773	0.08154	0.07872
0.65	0.09771	0.09556	0.09592
0.70	0.11024	0.11542	0.12276
0.75	0.12647	0.14570	0.17045
0.80	0.14828	0.19750	0.27877
0.85	0.17919	0.30647	0.76515

R ²	0.91790	0.98970	0.99900
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Sorption Isotherms for Oatmeal Cookies

Calculated data based on Iglesias and Chirife, 1982

Water Content Determined Using Vacuum Oven Method

Aw	80 F	100 F	120 F
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Kg Water/Kg Product d.b.

0.00	0.00000	0.00000	0.00000
0.05	0.02036	0.01843	0.01793
0.10	0.02592	0.02247	0.01968
0.15	0.02946	0.02519	0.02128
0.20	0.03248	0.02768	0.02303
0.25	0.03544	0.03024	0.02501
0.30	0.03854	0.03306	0.02733
0.35	0.04193	0.03626	0.03009
0.40	0.04576	0.04002	0.03346
0.45	0.05018	0.04452	0.03765
0.50	0.05539	0.05006	0.04302
0.55	0.06167	0.05707	0.05016
0.60	0.06943	0.06628	0.06013
0.65	0.07929	0.07891	0.07503
0.70	0.09229	0.09737	0.09970
0.75	0.11022	0.12693	0.14850
0.80	0.13659	0.18194	0.29070
0.85	0.17928	0.32040	0.76515

R ²	0.94280	0.94920	0.97510
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Sorption Isotherms for Shortbread Cookies

Actual Data Collected

Water Content Determined Using 100C Oven Method

Aw	80F	100F	120F
M (kg Water/kg Product d.b.)			
0.000	0.00673	0.00348	0.00292
0.111			0.02385
0.112		0.02639	
0.113	0.02932		
0.308			0.04142
0.318		0.04941	
0.326	0.05541		
0.432	0.05642		
0.462			0.05253
0.492		0.06112	
0.568	0.07374		
0.665		0.08312	
0.684	0.09552		
0.745			0.13940
0.748		0.11185	
0.752	0.11870		

Sorption Isotherms for Shortbread Cookies

Actual Data Collected

Water Content Determined Using Vacuum Oven Method

Aw	80F	100F	120F
M (kg Water/kg Product d.b.)			
0.000	0.00050	-0.00485	-0.00565
0.111			0.01150
0.112		0.01841	
0.113	0.02006		
0.308			0.03303
0.318		0.03616	
0.326	0.04182		
0.432	0.04960		
0.462			0.04201
0.492		0.05629	
0.568	0.06658		
0.665		0.07148	
0.684	0.08828		
0.745			0.13278
0.748		0.10373	
0.752	0.10626		

Sorption Isotherms for Shortbread Cookies

Calculated data based on Iglesias and Chirife, 1982

Water Content Determined Using 100C Oven Method

Aw	80 F	100 F	120 F
Kg Water/Kg Product d.b.			
0.00	0.00000	0.00000	0.00000
0.05	0.03011	0.02712	0.02373
0.10	0.03516	0.03229	0.02744
0.15	0.03848	0.03562	0.03013
0.20	0.04147	0.03855	0.03273
0.25	0.04450	0.04148	0.03551
0.30	0.04775	0.04459	0.03863
0.35	0.05133	0.04801	0.04221
0.40	0.05537	0.05185	0.04644
0.45	0.06000	0.05624	0.05154
0.50	0.06538	0.06135	0.05782
0.55	0.07176	0.06740	0.06577
0.60	0.07946	0.07469	0.07620
0.65	0.08893	0.08369	0.09050
0.70	0.10091	0.09506	0.11130
0.75	0.11654	0.10994	0.14443
0.80	0.13784	0.13026	0.20543
0.85	0.16855	0.15966	0.35520
R ²	0.97090	0.97090	0.97090

Sorption Isotherms for Shortbread Cookies

Calculated data based on Iglesias and Chirife, 1982

Water Content Determined Using Vacuum Oven Method

Aw	80 F	100 F	120 F
Kg Water/Kg Product d.b.			
0.00	0.00000	0.00000	0.00000
0.05	0.02036	0.01856	0.01237
0.10	0.02592	0.02356	0.01687
0.15	0.02946	0.02675	0.01990
0.20	0.03248	0.02950	0.02255

0.25	0.03544	0.03219	0.02520
0.30	0.03854	0.03504	0.02806
0.35	0.04193	0.03817	0.03128
0.40	0.04576	0.04172	0.03507
0.45	0.05018	0.04584	0.03966
0.50	0.05539	0.05072	0.04543
0.55	0.06167	0.05664	0.05294
0.60	0.06943	0.06401	0.06320
0.65	0.07929	0.07346	0.07813
0.70	0.09229	0.08606	0.10193
0.75	0.11022	0.10372	0.14599
0.80	0.13659	0.13031	0.25568
0.85	0.17928	0.17493	

R ²	0.94280	0.92060	0.78510
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Sorption Isotherms for Cheese Combos

Inner Shell Portion

Actual Data Collected

Water Content Determined Using 100C Oven Method

Aw	80F	100F	120F
M (kg Water/kg Product d.b.)			
0.000	0.00685	0.02552	0.00461
0.111			0.02881
0.112		0.02938	
0.113	0.04483		
0.308			0.05056
0.318		0.05466	
0.326	0.07905		
0.432	0.08672		
0.462			0.07838
0.492		0.07022	
0.568	0.10529		
0.665		0.10370	
0.684	0.14444		
0.745			0.16174
0.748		0.16494	
0.752	0.16450		

Sorption Isotherms for Cheese Combos

Inner Shell Portion

Actual Data Collected

Water Content Determined Using Vacuum Oven Method

Aw	80F	100F	120F
M (kg Water/kg Product d.b.)			
0.000	0.00488	0.00200	0.00313
0.111			0.02470
0.112		0.02988	
0.113	0.02824		
0.308			0.04971
0.318		0.05548	
0.326	0.04971		
0.432	0.08613		
0.462			0.05205
0.492		0.07152	
0.568	0.08913		
0.665		0.10476	
0.684	0.12485		
0.745			0.14968
0.748		0.15417	
0.752	0.16494		

Sorption Isotherms for Cheese Combos

Inner Shell Portion

Calculated data based on Iglesias and Chirife, 1982

Water Content Determined Using 100C Oven Method

Aw	80 F	100 F	120 F
Kg Water/Kg Product d.b.			
0.00	0.00000	0.00000	0.00000
0.05	0.04537	0.02992	0.02825
0.10	0.05285	0.03490	0.03509
0.15	0.05773	0.03836	0.03956
0.20	0.06211	0.04162	0.04352
0.25	0.06652	0.04504	0.04751
0.30	0.07123	0.04881	0.05181
0.35	0.07640	0.05310	0.05663
0.40	0.08219	0.05807	0.06219
0.45	0.08879	0.06397	0.06874
0.50	0.09643	0.07111	0.07666

0.55	0.10540	0.07997	0.08648
0.60	0.11612	0.09125	0.09901
0.65	0.12918	0.10616	0.11562
0.70	0.14546	0.12680	0.13873
0.75	0.16633	0.15727	0.17314
0.80	0.19411	0.20686	0.22992
0.85	0.23290	0.30183	0.34146

R^2	0.9818	0.9658	0.9406
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Sorption Isotherms for Cheese Combos

Inner Shell Portion

Calculated data based on Iglesias and Chirife, 1982

Water Content Determined Using Vacuum Oven Method

Aw	80 F	100 F	120 F
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Kg Water/Kg Product d.b.

0.00	0.00000	0.00000	0.00000
0.05	0.02774	0.03036	0.02580
0.10	0.03503	0.03578	0.02966
0.15	0.03977	0.03945	0.03249
0.20	0.04393	0.04283	0.03524
0.25	0.04808	0.04632	0.03818
0.30	0.05253	0.05012	0.04149
0.35	0.05750	0.05440	0.04529
0.40	0.06322	0.05934	0.04976
0.45	0.06995	0.06513	0.05514
0.50	0.07808	0.07207	0.06175
0.55	0.08816	0.08058	0.07010
0.60	0.10103	0.09128	0.08100
0.65	0.11811	0.10515	0.09585
0.70	0.14190	0.12390	0.11728
0.75	0.17742	0.15067	0.15095
0.80	0.23623	0.19203	0.21156
0.85	0.35263	0.26444	0.35313

R^2	0.8746	0.9705	0.9379
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Sorption Isotherms for Cheese Combos

Whole Product
Actual Data Collected
 Water Content Determined Using 100C Oven Method

Aw	80F	100F	120F
M (kg Water/kg Product d.b.)			
0.000	0.01217	0.01084	0.00897
0.111			0.03379
0.112		0.03235	
0.113	0.04855		
0.308			0.04830
0.318		0.05225	
0.326	0.07224		
0.432	0.07276		
0.462			0.07138
0.492		0.06803	
0.568	0.09965		
0.665		0.09885	
0.684	0.13384		
0.745			0.15108
0.748		0.15304	
0.752	0.15923		

Sorption Isotherms for Cheese Combos
Whole Product
Actual Data Collected
 Water Content Determined Using Vacuum Oven Method

Aw	80F	100F	120F
M (kg Water/kg Product d.b.)			
0.000	0.00069	0.00205	0.00360
0.111			0.02021
0.112		0.02578	
0.113	0.02517		
0.308			0.04139
0.318		0.04771	
0.326	0.03966		
0.432	0.06783		
0.462			0.05316
0.492		0.06390	
0.568	0.08048		
0.665		0.09605	

0.684	0.10690		
0.745			0.14131
0.748		0.13087	
0.752	0.14588		

Sorption Isotherms for Cheese Combos

Whole Product

Calculated data based on Iglesias and Chirife, 1982

Water Content Determined Using 100C Oven Method

Aw	80 F	100 F	120 F
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Kg Water/Kg Product d.b.

0.00	0.00000	0.00000	0.00000
0.05	0.04731	0.03208	0.03180
0.10	0.05028	0.03574	0.03631
0.15	0.05324	0.03860	0.03959
0.20	0.05645	0.04147	0.04277
0.25	0.06003	0.04458	0.04616
0.30	0.06405	0.04806	0.04992
0.35	0.06864	0.05205	0.05421
0.40	0.07393	0.05669	0.05921
0.45	0.08008	0.06219	0.06514
0.50	0.08734	0.06883	0.07233
0.55	0.09604	0.07702	0.08123
0.60	0.10666	0.08737	0.09256
0.65	0.11991	0.10091	0.10750
0.70	0.13691	0.11937	0.12812
0.75	0.15953	0.14604	0.15845
0.80	0.19108	0.18798	0.20745
0.85	0.23818	0.26360	0.30010

R ²	0.9879	0.9840	0.9847
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Sorption Isotherms for Cheese Combos

Whole Product

Calculated data based on Iglesias and Chirife, 1982

Water Content Determined Using Vacuum Oven Method

Aw	80 F	100 F	120 F
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Kg Water/Kg Product d.b.

0.00	0.00000	0.00000	0.00000
0.05	0.02372	0.02593	0.02071
0.10	0.02947	0.03109	0.02555
0.15	0.03324	0.03451	0.02877
0.20	0.03659	0.03760	0.03168
0.25	0.03998	0.04075	0.03466
0.30	0.04363	0.04416	0.03792
0.35	0.04774	0.04798	0.04162
0.40	0.05248	0.05237	0.04594
0.45	0.05809	0.05751	0.05112
0.50	0.06490	0.06366	0.05747
0.55	0.07336	0.07118	0.06550
0.60	0.08422	0.08063	0.07602
0.65	0.09870	0.09287	0.09042
0.70	0.11903	0.10938	0.11140
0.75	0.14968	0.13292	0.14484
0.80	0.20129	0.16920	0.20658
0.85	0.30660	0.23245	0.35916

R^2	0.89970	0.97240	0.94280
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