Temperature, Time, and Packaging Gas Affect Quality of Hermetically Stored Wheat

A Thesis

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Table of Contents

List of Figures

Introduction and Literature Review

Bread has been called the staff of life. One of the foundations of our civilization has been the ability to store wheat in its natural state, the kernel (Fellers and Bean, 1977). Even though the kernel is an excellent protective package for the nutrients and life it contains, it is very sensitive to moisture, temperature, and oxygen after harvest (Roberts, 1972).

Hermetic Storage

Controlled atmosphere storage has been used since ancient times to preserve grain in simple underground pits. These pits were often lined with straw or chaff which absorbed moisture and also became a bed for mold which would use up the oxygen (Hyde and Burrell, 1982). The depletion of oxygen was important to kill or inactivate insects or molds before they could cause extensive damage to the grain.

Modern methods of creating a low-oxygen atmosphere typically involve adding carbon dioxide or nitrogen until the desired lethality is reached (Hyde and Burrell, 1982). Bailey (1965) reported that when the oxygen concentration fell to about 2% by volume of the intergranular air, most species of insects would be killed. If there is sufficient moisture, oxygen concentration must not exceed 0.2% to stop mold growth (Peterson et al., 1956).

Moisture Content

Moisture is by far the most important factor that influences the rate of deterioration of wheat (Pomeranz, 1982). An equilibrium relative humidity of 65% is accepted as a safe maximum for long-time storage of wheat (Pomeranz, 1982) and (Pixton, 1980). Generally, 14% moisture is accepted as the safe maximum moisture content for stored wheat (Hunt and Pixton, 1974; Hoseney, 1986). Fellers and Bean (1977) stated that "wheat with moisture content of 10-12% has a very long storage life if protected from insects and held under reasonable conditions." Most species of seeds benefit from lower moisture down to around 5% (Roberts, 1972).

Glass et al. (1959) stored two varieties of wheat in air and in nitrogen for 48 weeks at moisture contents ranging from 13 to 18% and at temperatures of 20 and 30°C. Quality of the wheat was measured by germ damage, free fat acidity, reducing sugars, carbon dioxide production, and mold count. Quality deteriorated at a much higher rate at moisture levels above 14%. Quality changes for wheat above 14% moisture were delayed under nitrogen atmosphere, but once the deterioration started, it progressed at about the same rate as in air. Mold count was the exception since it was completely inhibited by nitrogen packaging.

Petruzzelli (1986) stored wheat ranging in moisture content from 15 to 33% at 25°C under hermetic and aerobic conditions. The hermetic condition consisted of being sealed in a laminated foil packet. For the hermetically stored wheat, loss of viability increased with increased water content. The same was true for wheat stored aerobically except that at moisture contents of 26 to 31% it survived longer. This was attributed to activation of seed metabolism. Even so, all of the wheat with moisture content above 24% lost its viability in about a month. Wheat with 15 to 24% moisture retained viability longer under hermetic storage. Petruzzelli (1986) expected oxygen would dramatically accelerate loss of wheat viability at lower moisture.

Temperature

Storage temperature affects the keeping quality of wheat. Increase in temperature accelerates the rate of respiration until it is limited by oxygen supply, build up of carbon dioxide concentration, exhaustion of substrate, and/or thermal inactivation of essential enzymes (Pomeranz, 1982). Heat can damage the gluten proteins and even discolor the kernels (Halverson and Zeleny, 1988). Jones and Gersdorff (1941) stored hard red winter wheat with moisture content of 10.95% in sealed half-gallon glass jars at -1°C and 24°C for two years. They found that the protein quality of wheat over time decreased at a faster rate at the higher temperature. Changes noted in the proteins were decreased solubility, protein break down shown by increased amino nitrogen and decreased nitrogen precipitation by trichloracetic acid, and decreased digestibility. There was also a greater increase in free fatty acids at 24°C. Glass et al. (1959) found that wheat stored at 30°C deteriorated much faster than at 20°C. This was attributed mostly to seed metabolism being greatly reduced at lower temperatures. Pixton (1980) stored hard and soft wheat for 18 years at 5°C or ambient temperature in bins being flushed with air or nitrogen until there was less than 2% oxygen. Ambient temperature had an annual cycle of 2 to 20°C. The hard wheat moisture was 11.9%, and that of the soft was 12.6%. Free fatty acid level rose in the ambient temperature bins to twice the level found at 5°C after 18 years with both types of wheat. Also higher viscosity of the dough was found for ambient stored wheat. This resulted in slightly lower loaf volume. Germinative capacity also fell more quickly under ambient conditions. There was no change in the viability of wheat stored at 5°C while that stored at the higher temperature was not viable after 18 years.

Packaging Gas

Peterson et al. (1956) stored wheat with 18% moisture at 30°C 16 days under carbon dioxide-oxygen mixtures containing 21% oxygen and up to 79% carbon dioxide. Respiration and mold growth was significantly inhibited when the carbon dioxide content exceeded 13.8%. Wheat stored at carbon dioxide concentrations of 50 and 79% had high viability and little or no germ damage. They also found wheat stored for 16 days at 25°C in nitrogen-oxygen mixtures ranging in oxygen from 0.2 to 21% experienced less germ damage, mold growth, and respiration as the oxygen level was lowered. Glass et al. (1959) found that wheat stored at 16% moisture in nitrogen had very little germ damage after a year while the same wheat stored in air had over 95% germ damage. They suggested that moist grain stored hermetically at temperatures below 20°C might store well since most wheat enzymes would be sufficiently inactive and mold growth would be prevented. Pixton (1980) found low oxygen tension gave some protection to seed viability, but did not affect loaf volume.

Methods of Measurement

Baking, germination, and protein solubility tests are all helpful in assessing the quality of stored wheat. The best test for measuring the end performance of flour is the bake test (Mailhot and Patton, 1988). The most sensitive test for heat damage to wheat is a germination test, but seed viability tests do not correlate well with predicting bread baking quality since the ability to germinate is often lost long before its ability to make quality bread (Pixton, 1980). A protein solubility test (PST) was developed by Every (1987) which correlated better with baking quality than germination tests. Pence et al. (1953) found that soluble proteins played an important role in gluten performance. Jones and Gersdorff (1941) noted that protein solubility of wheat decreased with increased storage time and temperature. Kratzer et al. (1990) showed that the degree of heat damage to proteins of wheat flour could be measured by the reduction in dye-binding of the sample using Coomassie Blue G dye. The PST is better than the germination test for predicting baking quality since the PST is not an all-or-nothing measurement.

Objective

The purpose of this study funded by The Church of Jesus Christ of Latter-day Saints was to measure the effects of storage temperature, time, and packaging gas on the quality and viability of wheat stored in sealed containers.

Myers (1991) set up a five year study and did analyses on the wheat every six months for the first 18 months. The research reported here is from the second, third, and fourth years of storage.

Materials and Methods

Materials

Two varieties of hard red wheat, Fremont with 8.1% and Ute with 8.7% moisture, were obtained from the Brigham Young University Spanish Fork farm in Utah. Ute, a winter wheat, and Fremont, a spring wheat, were harvested in June and August of 1988 respectively. The wheat was stored in 100 lb. polypropylene sacks in an open air shed until obtained for this study in September of 1988 (Myers, 1991).

Packaging

Each variety of wheat was randomly divided for packaging under one of three packaging gases: air, carbon dioxide, or nitrogen. The Vacu-Dry Company (Sebastopol, California) packaged and sealed the wheat in No. 2 1/2 cans (Myers, 1991).

Storage

Upon return to Provo, Utah, one of four storage temperatures: 4, 21, 37, and 54°C was randomly assigned to the cans of wheat (Myers, 1991). Two different cans representing each variety/gas/temperature situation, were taken out of storage after 2, 3, and 4 years and analyzed. While waiting to undergo analysis, the canned wheat was stored at -28°C.

Headspace Gas Analysis

The oxygen, nitrogen, and carbon dioxide content of each can was measured with a dual column Packard Gas Chromatograph equipped with a thermal conductivity detector (Model 886). An Alltech can piercer (#8013, Alltech Associates, Inc., Deerfield, IL) was used to puncture the cans and take gas samples using a Dynatech syringe (#010033 Pressure-Lok Series A, Precision Sampling Corp., Baton Rouge, LA). A molecular sieve column separated the oxygen and nitrogen contained in one injection, and a Porapak-Q column separated the carbon dioxide fraction from another injection. Helium was used as the carrier gas with the dual flow controller (Model 824) set at 40 ml/min. The deviation temperature controller (Model 873) was set at 40°C for the inlet, 30°C for the columns, and 200°C for the detector. The peak areas were calculated and recorded on a Hewlett-Packard (3390A) integrator. Standards were determined each year by injecting known volumes of the gases measured. The appropriate standard was then used to calculate a percent of the gas in the headspace.

Germination Test

One hundred undamaged wheat kernels from each can were soaked for two hours in a 0.05% (w/v) sodium benzoate solution and then placed on wet filter paper in covered petri dishes for four days in the dark at 22°C. The kernels which germinated were recorded as percent germination.

Grinding and Milling

Flour was ground for the baking and protein tests using a Magic Mill III Plus (Magic Mill Co., Salt Lake City, UT) on the coarsest setting. The high speed rotor-stator pin-mill was used to minimize heat damage to the protein during grinding. The coarse setting provided the best particle size for bread flour. The flour was stored in the freezer at -28°C until all the tests were run on it. All testing was usually completed within two weeks of grinding.

Baking Test

Yeast was purchased before each testing period, and its functionality checked. A loaf of bread was made from each can of wheat using an automatic bread maker, Panasonic Bread Bakery, (Model SD-BT2P, Panasonic Inc., Secaucus, NJ) and a standard bread formulation: 270.0 g whole wheat flour, 11.9 g granulated sucrose, 11.0 g margarine, 8.4 g nonfat dry milk, 4.7 g NaCl, 3.2g Fleischmann's Active Dry Yeast For Baking and 210 ml water. After the loaves cooled, their volume was measured by rapeseed displacement.

Protein Solubility Test

Protein solubility tests (PST) (Every, 1987) were done on duplicate 1.000 g samples of flour from each can to assess the heat damage to the wheat. The flour sample was added to a 100 ml graduated cylinder containing 50 ml of a 2% (w/v) NaCl solution. The cylinder was stoppered, and the contents mixed by inverting it by hand once every second for 30 seconds. After the sample had set for 30 seconds, a 100 μl extract was removed from the top layer of the liquid and immediately mixed with 3 ml of Coomassie Brilliant Blue G (Sigma Chemical Company, St. Louis, MO, No. B-0770) protein stain reagent. After two minutes, the absorbance was read on a Pharmacia

Ultrospec III UV/Visible Spectrophotometer (Pharmacia LKB Biotechnology, S-751 82, Uppsala, Sweden) at 595 nm.

The protein stain reagent was prepared according to the Bradford (1976) Method. Ten mg of Coomassie Brilliant Blue G were added to a volumetric flask and dissolved in 5 ml of 95% ethanol. Ten ml of 85% phosphoric acid were added, and the volume was brought up to 100 ml with distilled water. New stain reagent was made for each day of protein solubility testing.

Statistical Analysis

The independent variables were all fixed factors and consisted of wheat variety, packaging gas, storage time, and temperature. A multivariate analysis of variance using a fully crossed model involving all four independent variables was run with percent oxygen, percent nitrogen, percent carbon dioxide, percent germination, and protein solubility as dependent variables. Univariate analyses of variance, using all five dependent variables in the multivariate analysis of variance, were run using a model based on the terms found to be significant in the multivariate analysis. These univariate models were reduced to include only significant terms for each dependent variable. Loaf volume, the other dependent variable in this study, was treated separately because of missing data. Univariate analyses of variance were run on loaf volume reducing the model by removing the insignificant terms. After examining the nature of higher order interactions, some were removed from the model because they explained very little variation. Duncan's Multiple Range Tests were run for significant terms to determine significant differences between means. All hypotheses were tested at an alpha of 0.05.

Results and Discussion

Headspace Gas Analysis

At the beginning of the study, oxygen content in the cans of wheat according to the Vacu-Dry Company was 16 to 18% for cans sealed under air, 9.5 to 11.5% for cans sealed under carbon dioxide, and less than 2% for those sealed under nitrogen (Myers, 1991).

Headspace oxygen percent was found to be practically nonexistent after two years storage for all cans of wheat except those packaged in air at 4 and 21°C. The oxygen content of the headspace decreased generally with time and temperature increase. The low oxygen readings for the wheat stored at 4°C for two years are suspect. After analyzing data from the third and fourth years, I concluded that the readings taken for headspace oxygen and nitrogen at the second year of storage are low, but still show some valuable information. They show the significant effect storage temperature had on headspace oxygen. Packaging gas and storage temperature affected headspace oxygen the most. Even though packaging gas by year and temperature by year were statistically significant, they were not practically significant. Figure 1 shows the two-way interaction between packaging gas and storage temperature as it affects headspace oxygen. As expected, wheat packaged in air had the most headspace oxygen, and the oxygen content decreased at a faster rate at 21 and

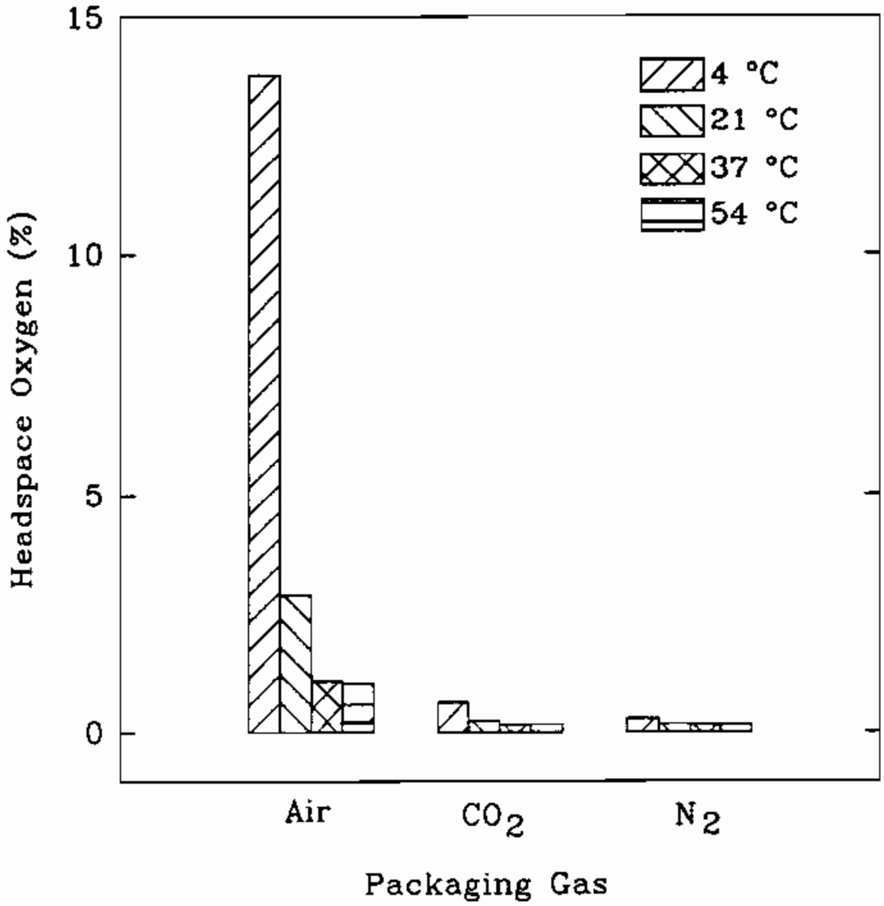

Figure 1: Effect of temperature and packaging gas on headspace oxygen of canned dry wheat averaged across storage time and wheat variety.

37°C. The increased loss of oxygen at the higher temperatures might be due to increased respiration and oxidation rates.

Headspace nitrogen percent was most dependent on packaging gas (Figure 2). Nitrogen percent increased with increased storage time (Figure 3). This increase would be expected since oxygen decreased over time, and therefore nitrogen would constitute a greater percentage of the headspace gas as long as it was not used up or another gas was not being produced at a faster rate. The increase in nitrogen between the second and third year of storage may not have been as dramatic as shown due to suspected low readings at the second year of storage. A significant difference was not found between the headspace nitrogen percentages for the third and fourth year of storage, possibly because carbon dioxide was being produced much faster in some cans, particularly those stored at 54°C, than oxygen was being consumed.

Headspace carbon dioxide percent was most dependent on packaging gas followed by storage temperature and time respectively. Carbon dioxide content was also affected by a couple of two-way interactions. Figure 4 shows the interaction between packaging gas and storage temperature. As expected, more carbon dioxide was found in cans with wheat packaged in carbon dioxide. As temperature increased more carbon dioxide was found. Wheat at 37 and 54°C had high positive pressure due to gas production during storage. Figure 5 shows the interaction between storage time and

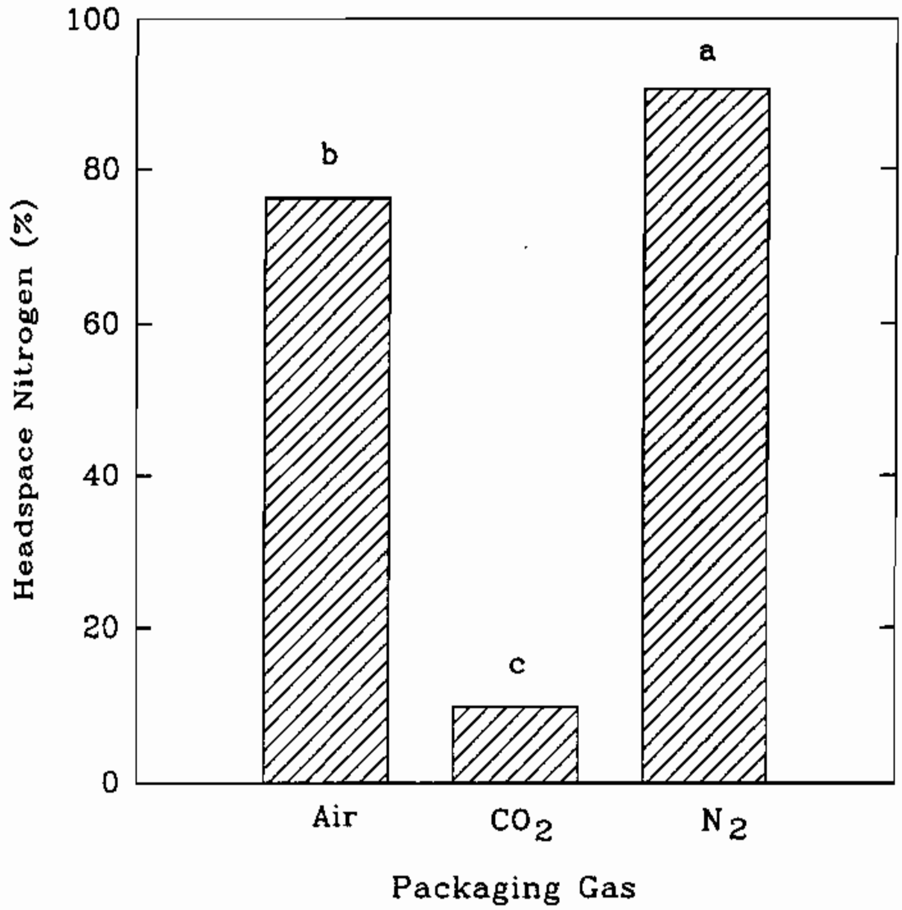

Figure 2: Effect of initial packaging gas on the headspace nitrogen of wheat averaged across storage temperature, time, and wheat variety.

Significant differences are indicated by different letters.

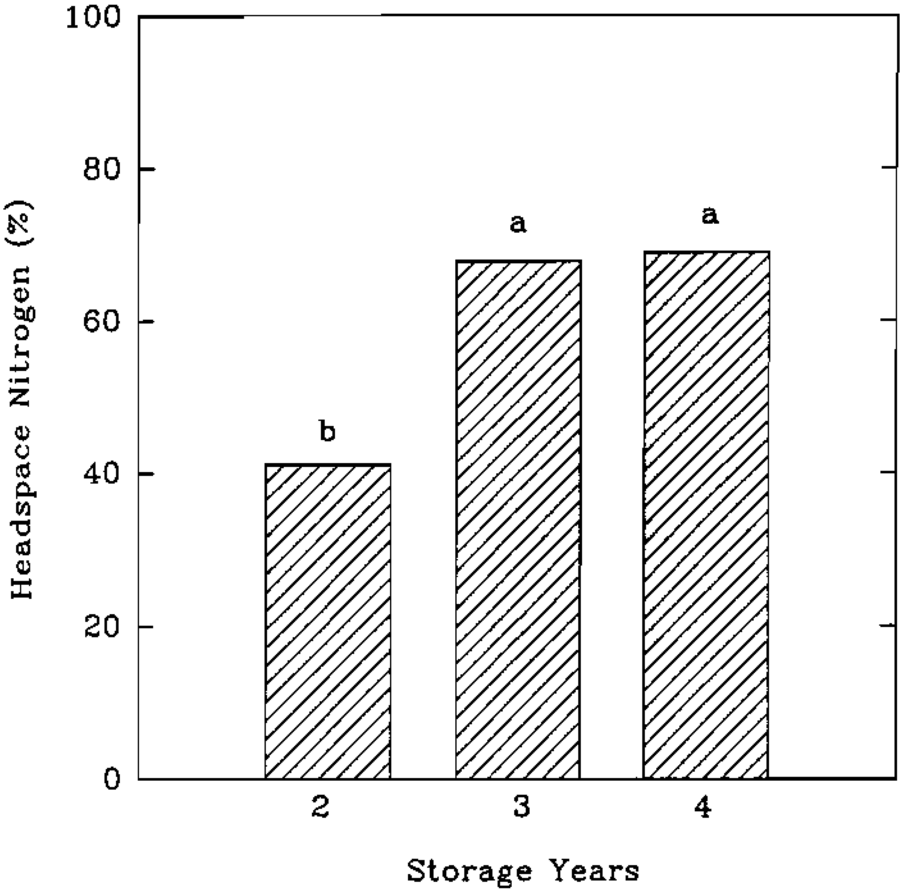

Figure 3: Effect of storage on the headspace nitrogen of wheat averaged across storage temperature, packaging gas, and wheat variety.

Significant differences are indicated by different letters.

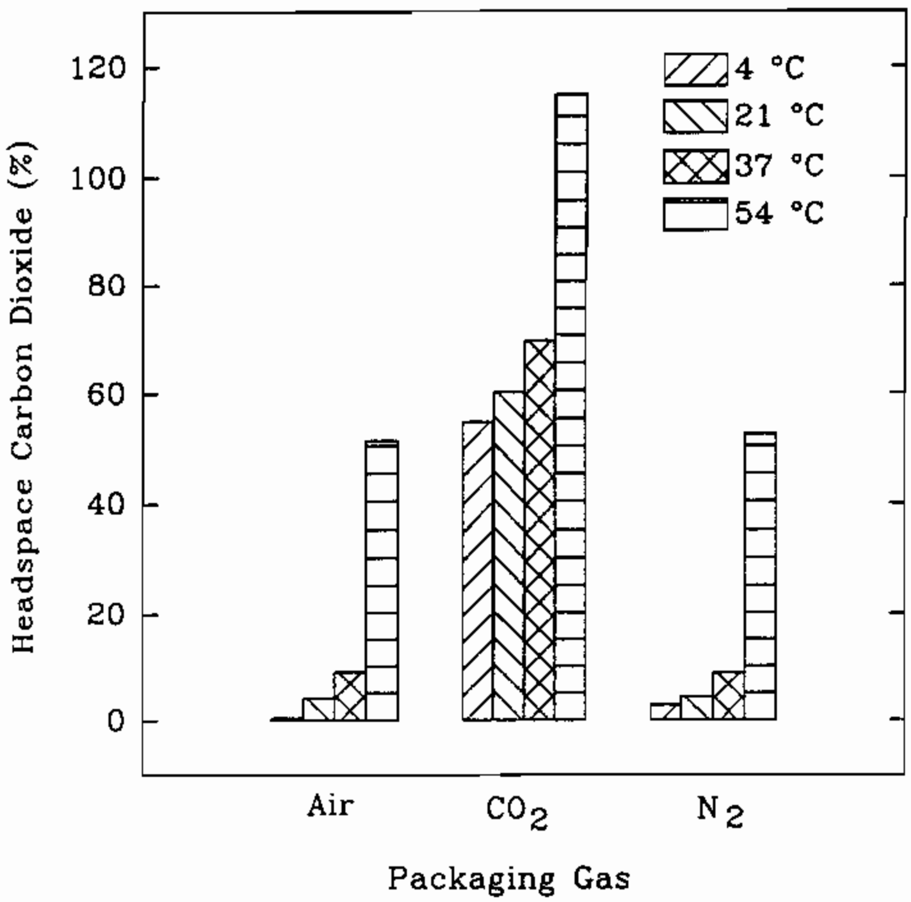

Figure 4: Effect of temperature and packaging gas on the headspace carbon dioxide of wheat averaged across storage time and wheat variety.

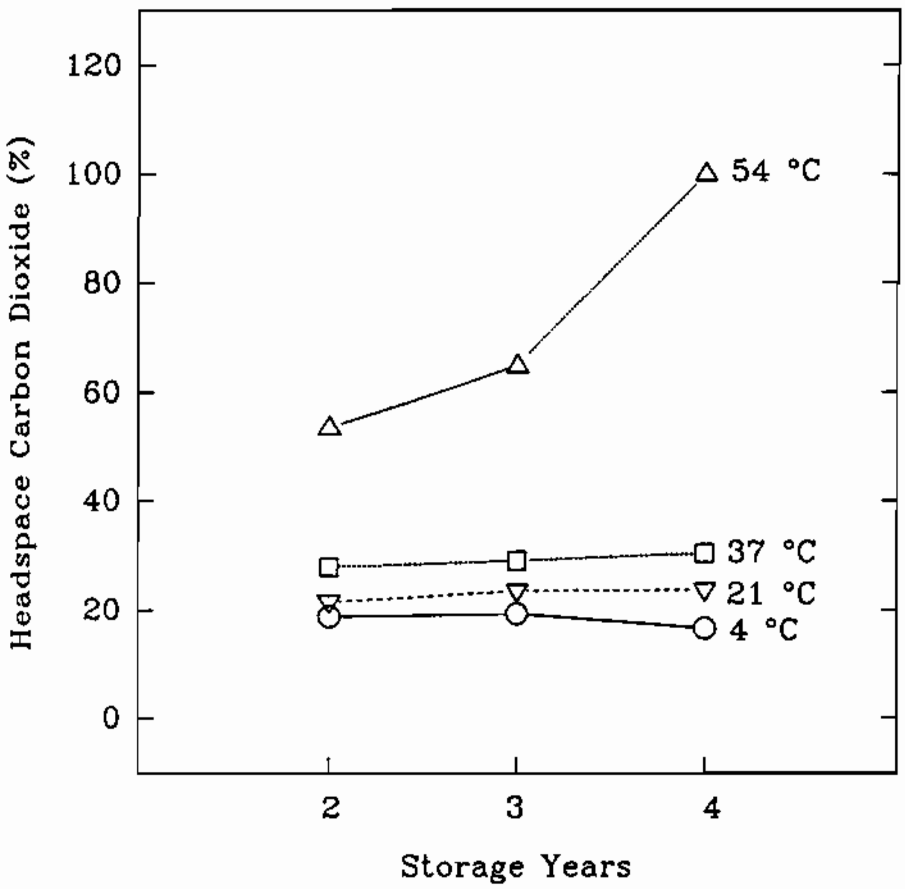

Figure 5: Effect of temperature and time on the headspace carbon dioxide of wheat stored in sealed cans averaged across packaging gas and wheat variety.

temperature affecting headspace carbon dioxide. Generally speaking, headspace carbon dioxide increased with increased storage time and temperature. This would be expected since increased rates of respiration and breakdown of components of the wheat kernel at high temperatures would cause carbon dioxide production. Flavor, aroma, and color changes in the wheat prove the wheat was breaking down. Flavor, aroma, and color changes were evident in the wheat stored at 37 and 54°C at two years and became more pronounced as storage time increased. Norseth (1986) also found aroma changes in wheat packaged in air and nitrogen after 3 years storage at 37°C.

Germination Test

Germination was affected most by storage temperature followed by time. Three two-way interactions also significantly influenced germination.

Figure 6 shows the interaction between storage time and temperature affecting percent germination. During these storage times the 4 and 21°C stored wheat had no loss in viability. Percent germination for wheat stored at 37°C dropped rapidly between 2 and 4 years storage. At 54°C the wheat had already lost germinability during the first 18 months (Myers, 1991).

Figure 7 shows the packaging gas and variety interaction. Fremont variety stored better under air, and Ute stored better with nitrogen. Wheat in carbon dioxide had the lowest percent germination. Myers (1991) found similar results.

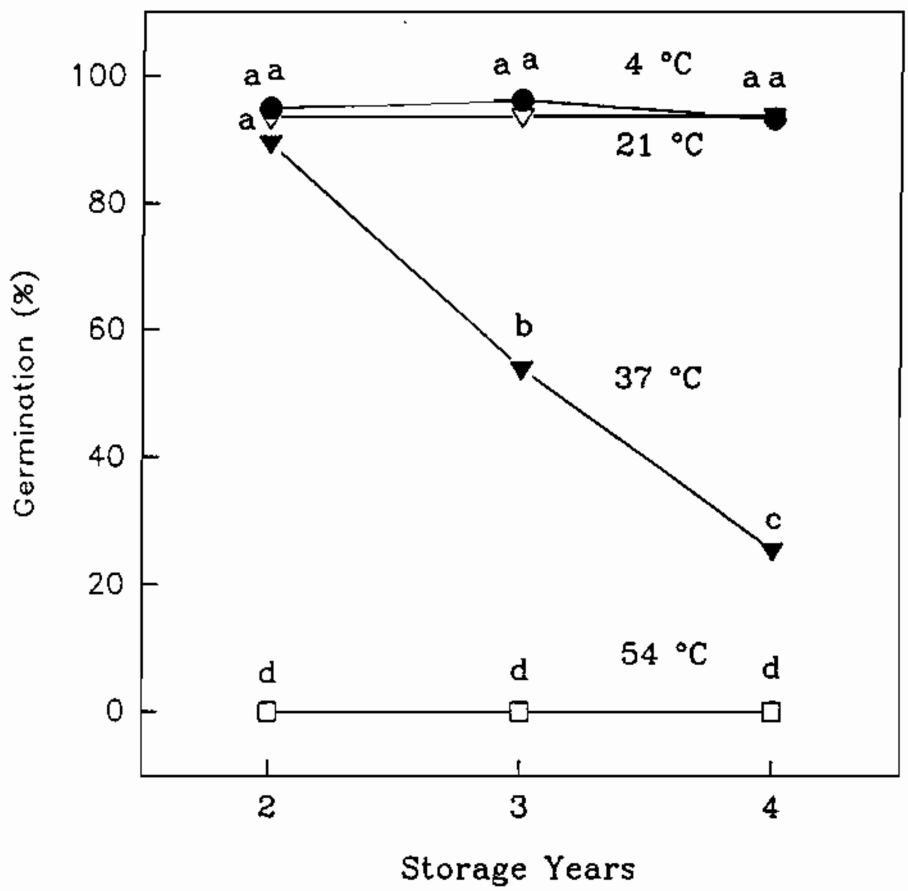

Figure 6: Effect of temperature and time on germination of wheat stored in sealed cans averaged across packaging gas and wheat variety.

Significant differences are indicated by different letters.

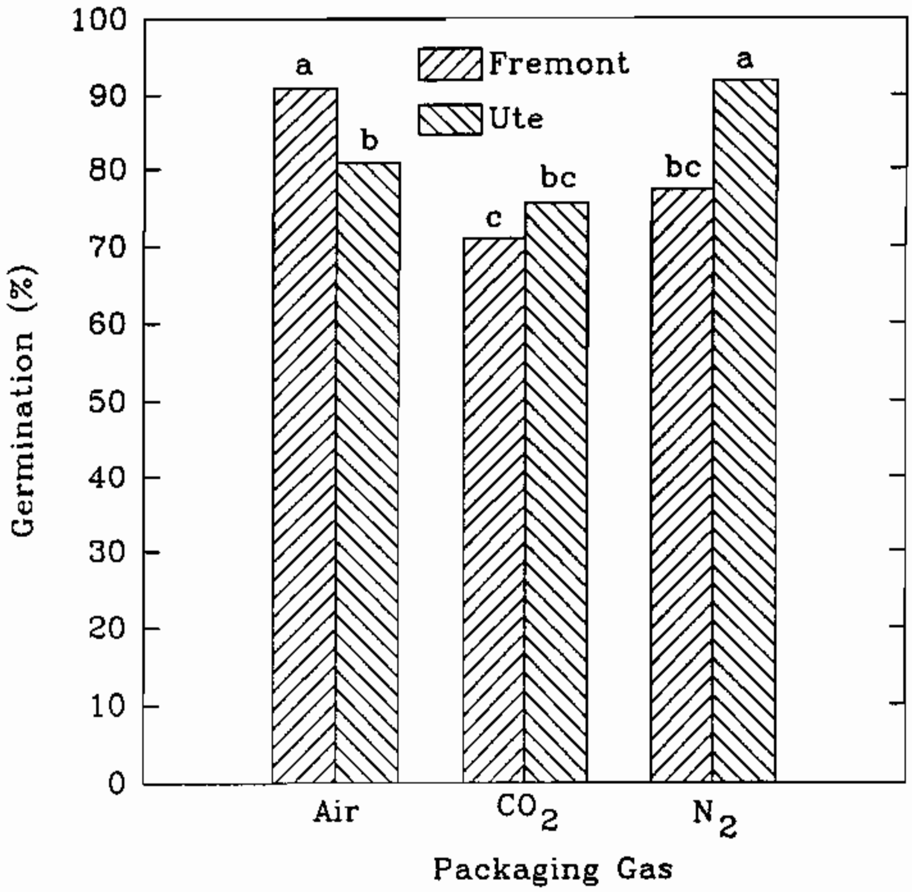

Figure 7: Effect of wheat variety and packaging gas on germination of wheat averaged across storage temperature and time.

Significant differences are indicated by different letters. Wheat at 54°C did not germinate and was not included.

Figure 8 shows the interaction between packaging gas and storage temperature as they relate to percent germination. Percent germination decreased most for wheat packaged in carbon dioxide stored at 37°C. After five years storage, a significant drop in germination may show up for wheat packaged in carbon dioxide stored at 21°C. There was a significant drop in wheat germination in all three packaging gases at 37°C. At the third and fourth year, the wheat stored at 37°C which germinated was stunted.

Baking Test

Loaf volume was most dependent on storage temperature and time. A couple of two-way interactions also affected loaf volume. Even though packaging gas showed statistical significance for loaf volume, it had no practical significance since it was no longer significant when loaf volumes from the 54°C wheat were removed from the analysis.

The 54°C stored wheat did not make bread. Some dense "bricks" were made at the two year storage time, but even then some of the dough would not mix enough to make a "brick". The dough mixed like wet sand. Adding more water to the formulation did not help. The high storage temperature had severely damaged the gluten proteins. Bread made from wheat stored at 4, 21, and 37°C still gave acceptable but not exceptional volume after four years. Loaves from wheat stored at 37°C had a stronger whole wheat flavor.

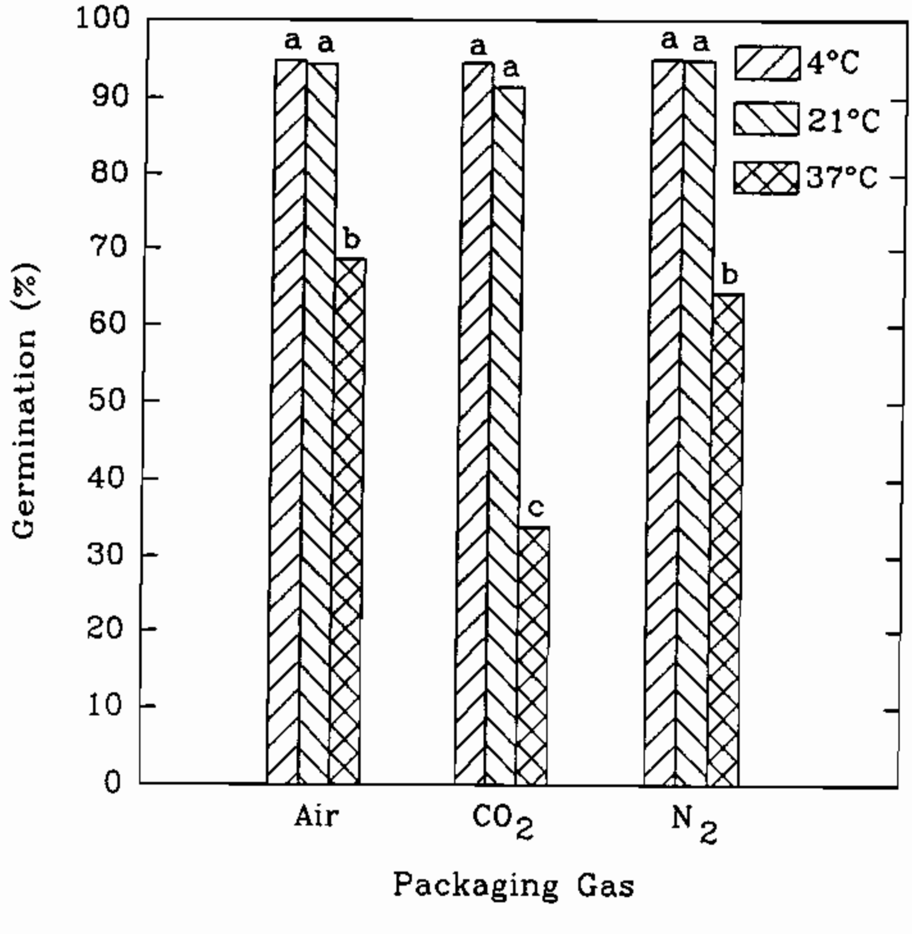

Figure 8: Effect of temperature and packaging gas on germination of wheat averaged across storage time and wheat variety.

Significant differences are indicated by different letters.

Figure 9 shows the interaction between storage time and temperature affecting loaf volumes. Loaf volumes decreased with increased storage time and temperature. Wheat stored two years at 37°C produced a loaf volume not significantly different than the wheat stored three years at 4°C. Also, wheat stored 3 years at 37°C produced a loaf volume not significantly different from wheat stored for 4 years at 4°C. Loaf volume reduction of wheat stored at 4°C seems to be one year behind the wheat stored at 37°C. The volumes from wheat at 4 and 21°C were quite close at 3 and 4 years.

Loaf volume was also affected by a two-way interaction between storage time and wheat variety (Figure 10). Ute variety had a higher loaf volume than Fremont at two years storage but not afterwards. Myers (1991) also found Ute variety had a significantly higher loaf volume after six months storage but not thereafter. He suggested protein changes might occur at different rates in the varieties.

Protein Solubility Test

Protein solubility was most significantly affected by storage temperature (Figure 11). The Coomassie Blue solubility test developed by Every (1987) was designed to measure heat damage to proteins. The wheat stored at 4°C had significantly higher protein solubility than the wheat stored at the other three temperatures. The wheats stored at 21 and 37°C did not differ in protein solubility but did have

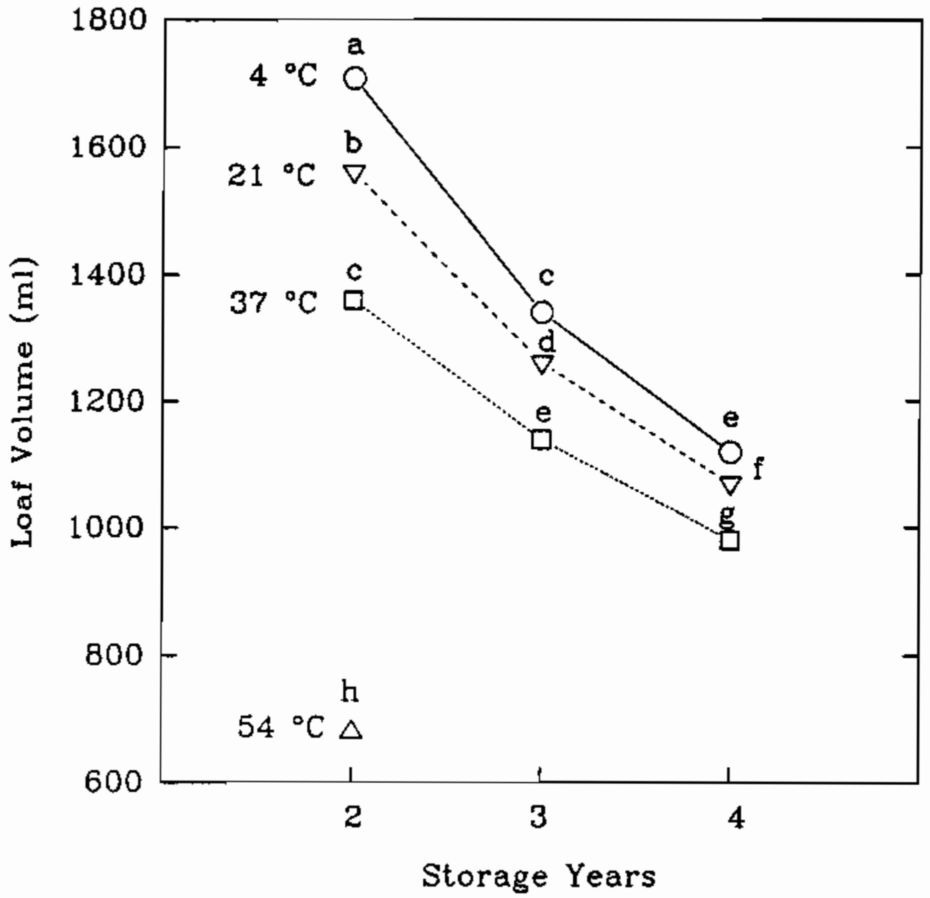

Figure 9: Effect of temperature and time on loaf volume of wheat averaged across packaging gas and wheat variety.

Significant differences are indicated by different letters.

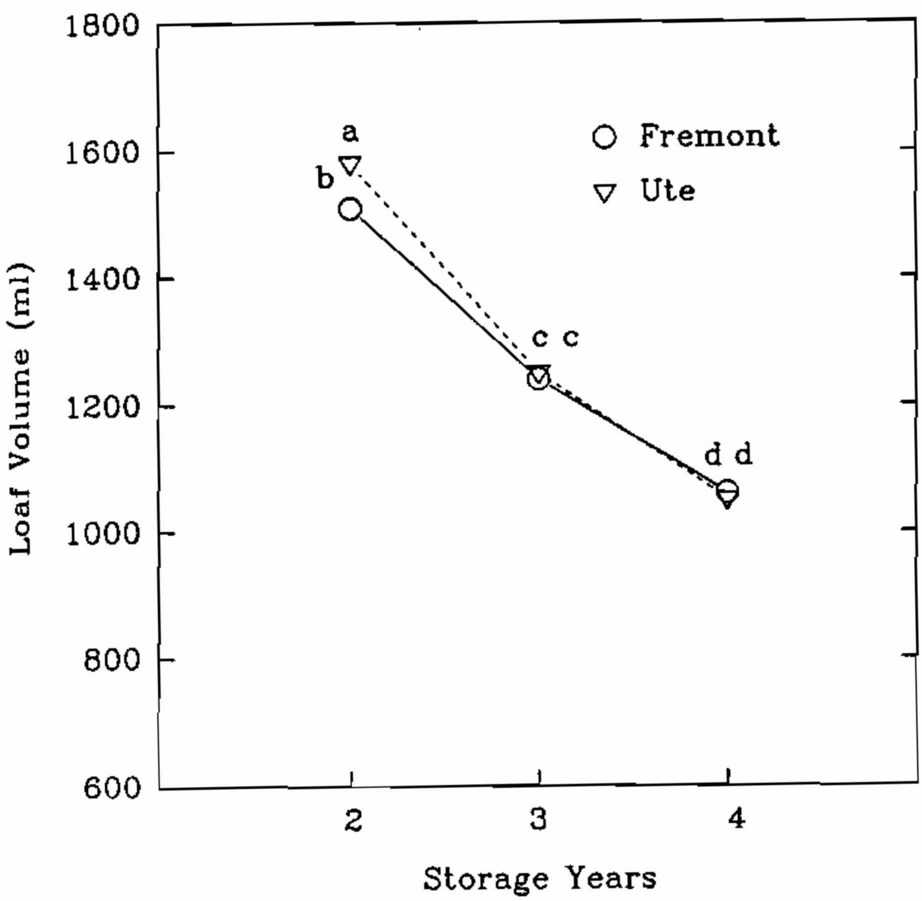

Figure 10: Effect of wheat variety and storage time on mean loaf volumes averaged across storage temperature and packaging gas.

Significant differences indicated by different letters. Wheat at 54°C did not leaven and was not included.

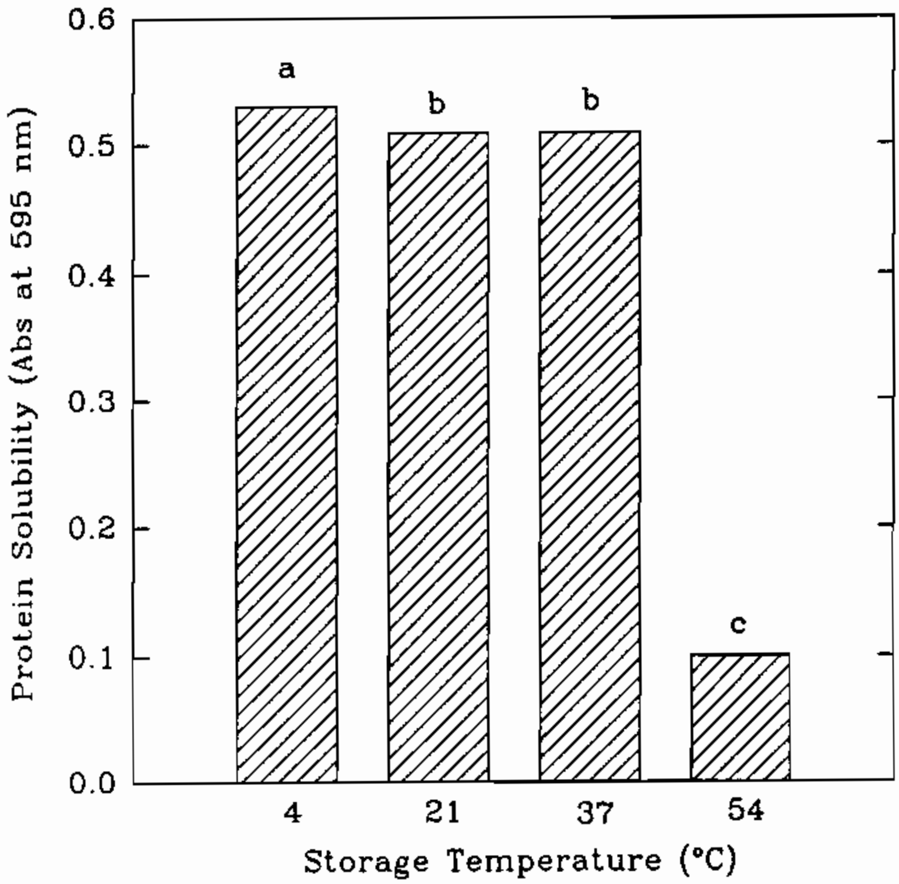

Figure 11: Effect of temperature on protein solubility of wheat averaged across storage time, packaging gas, and wheat variety.

Significant differences are indicated by different letters.

significantly much greater protein solubility than wheat at 54°C.

Storage time also affected protein solubility as shown in Figure 12. Protein solubility decreased with increased storage time. The protein solubility test for wheat stored at 54°C after four years was barely readable at 595 nm. Besides heat damage to the protein, there were nonenzymic browning products which might have been interfering with the readings.

There was a significant difference in protein solubility between the varieties. Ute had the highest with a mean of 0.419 absorbance units. Fremont had a mean of 0.405 absorbance units. Myers (1991) also found that protein solubility was significantly higher for the Ute variety.

The results of the protein solubility test correspond well with the loaf volume test and thus confirm the claim by Every (1987) that wheat protein solubility gives a good indication of bread baking quality.

Conclusion

Wheat quality is affected by storage temperature, time, and packaging gas,. Wheat viability, loaf volume, and protein solubility decreased at a faster rate at 54°C than at 4, 21, or 37°C. Wheat viability, loaf volume, and protein solubility decreased with increased storage time. Loaf volume seemed to decrease at a faster rate than protein solubility. Seed viability of Fremont and Ute varieties depends on packaging

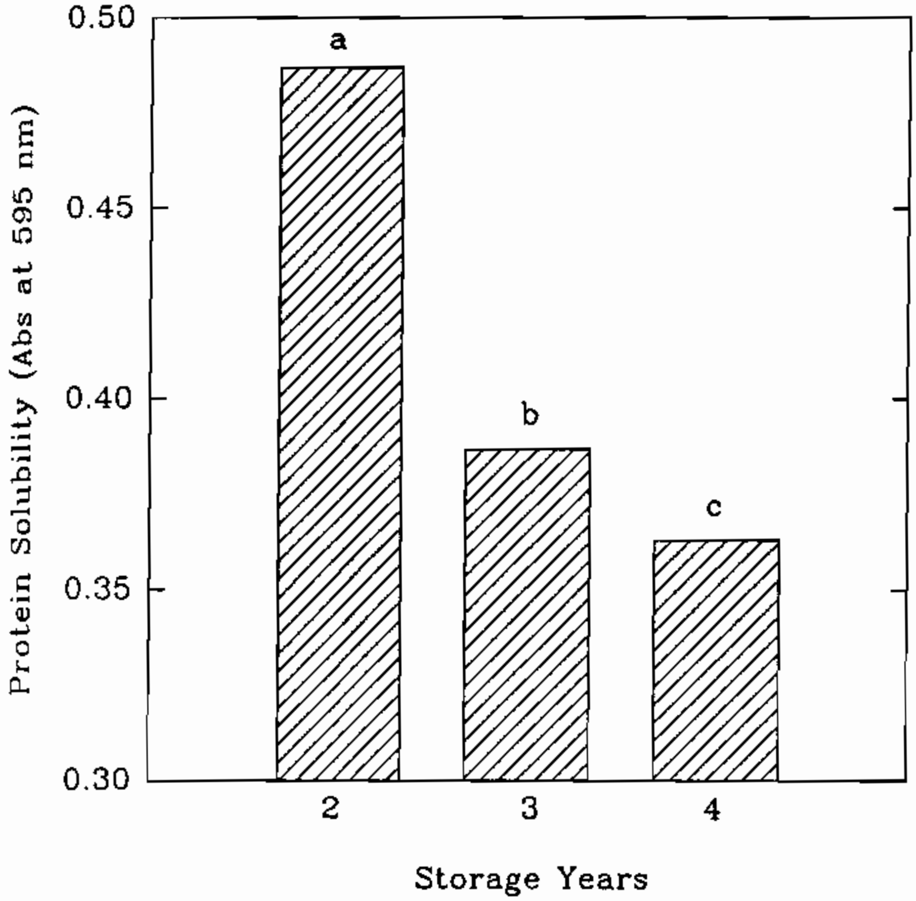

Figure 12: Effect of time on protein solubility of wheat averaged across storage temperature, packaging gas, and wheat variety.

Significant differences are indicated by different letters.

gas. Viability is preserved best for Fremont under air while viability for Ute is best preserved under nitrogen packaging.

The findings suggest wheat should be stored at low temperatures to preserve quality. Stored wheat should be used before it loses significant quality. The results of this study would suggest wheat may not have desired bread baking quality after four to five years storage. For preserving wheat seed viability, air might be the best packaging gas of the ones tested because it is the least expensive. If insects are a concern, nitrogen might be the preferred packaging. Research on how low moisture content and inhibited respiration of wheat affect loaf volume would be useful. Also, further research involving more varieties of wheat on the variety and packaging gas interaction with germination might be of interest.

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Appendix

Stored Canned Wheat Data - Headspace Oxygen % - 24 Months

Code	%O_2	Avg	Code	%O_2	Avg
FA 4-24	11.5	11.5%	UA 4-24	10.8	11.0%
	11.4			11.1	
FC 4-24	.706	.805%	UC 4-24	.572	.613%
	.903			.654	
FN 4-24	.372	.407%	UN 4-24	.373	.388%
	.441			.403	
FA 21-24	4.45	4.37%	UA 21-24	4.09	3.98%
	4.29			3.87	
FC 21-24	.121	.129%	UC 21-24	0	.0605%
	.136			.121	
FN 21-24	.0791	.0744%	UN 21-24	.0916	.0935%
	.0696			.0954	
FA 37-24	.703	.709%	UA 37-24	.781	.791%
	.714			.800	
FC 37-24	0	.060%	UC 37-24	.122	.123%
	.120			.124	
FN 37-24	.0697	.0831%	UN 37-24	.106	.0971%
	.0964			.0881	
FA 54-24	.706	.693%	UA 54-24	.664	.690%
	.680			.716	
FC 54-24	.119	.121%	UC 54-24	.117	.109%
	.123			.100	
FN 54-24	.0996	.0996%	UN 54-24	.103	.108%
	.0996			.112	

---

code legend: Wheat Variety — F - Fremont; U - Ute

Packaging Gas — A - air; C - carbon dioxide; N - nitrogen

The numbers signify storage temperature and storage time
i.e. 4-24 = 4°C - 24 months

Stored Canned Wheat Data - Headspace Oxygen % - 36 Months

Code	$\%O_2$	Avg	Code	$\%O_2$	Avg
FA 4-36	16.6	16.6%	UA 4-36	16.1	16.0%
	16.5			15.9	
FC 4-36	.935	.901%	UC 4-36	.499	.531%
	.866			.563	
FN 4-36	.290	.319%	UN 4-36	.273	.215%
	.347			.156	
FA 21-36	1.06	2.53%	UA 21-36	3.49	3.35%
	4.00			3.20	
FC 21-36	.838	.525%	UC 21-36	.188	.190%
	.212			.191	
FN 21-36	.171	.156%	UN 21-36	.169	.293%
	.141			.417	
FA 37-36	1.15	1.17%	UA 37-36	1.16	1.18%
	1.19			1.20	
FC 37-36	.187	.193%	UC 37-36	.201	.199%
	.199			.196	
FN 37-36	.156	.182%	UN 37-36	.160	.171%
	.208			.181	
FA 54-36	1.13	1.16%	UA 54-36	1.14	1.14%
	1.19			1.14	
FC 54-36	.171	.179%	UC 54-36	.165	.195%
	.186			.225	
FN 54-36	.150	.159%	UN 54-36	.155	.167%
	.167			.179	

---

code legend: Wheat Variety
F - Fremont
U - Ute

Packaging Gas
A - air
C - carbon dioxide
N - nitrogen

The numbers signify storage temperature and storage time i.e. 4-36 = 4°C - 36 months

---

Stored Canned Wheat Data - Headspace Oxygen % - 48 Months

Code	%O_2	Avg	Code	%O_2	Avg
FA 4-48	13.5 14.1	13.8%	UA 4-48	14.0 14.2	14.1%
FC 4-48	**** .524	.524%	UC 4-48	.214 .344	.279%
FN 4-48	.180 .151	.166%	UN 4-48	.181 .172	.177%
FA 21-48	1.23 1.23	1.23%	UA 21-48	1.71 1.57	1.64%
FC 21-48	.228 .214	.221%	UC 21-48	.208 .202	.205%
FN 21-48	.179 .141	.160%	UN 21-48	.253 .172	.213%
FA 37-48	1.20 1.23	1.22%	UA 37-48	1.26 1.22	1.24%
FC 37-48	.200 .136	.168%	UC 37-48	.224 .210	.217%
FN 37-48	.183 .165	.174%	UN 37-48	.198 .176	.187%
FA 54-48	1.16 1.16	1.16%	UA 54-48	1.17 1.18	1.18%
FC 54-48	.236 .188	.212%	UC 54-48	.221 .210	.216%
FN 54-48	.183 .172	.178%	UN 54-48	.185 .176	.181%

**** - The headspace gas measurements from this can were suspect and not included in the statistical analysis. The measurement was 14.9%.

---

code legend: Wheat Variety
- F - Fremont
- U - Ute

Packaging Gas
- A - air
- C - carbon dioxide
- N - nitrogen

The numbers signify storage temperature and storage time i.e. 4-48 = 4°C - 48 months

---

Stored Canned Wheat Data - Headspace Nitrogen % - 24 Months

Code	$\%N_2$	Avg	Code	$\%N_2$	Avg
FA 4-24	53.0 52.3	52.7%	UA 4-24	52.1 52.3	52.2%
FC 4-24	8.40 7.17	7.79%	UC 4-24	6.16 6.44	6.30%
FN 4-24	63.6 64.0	63.8%	UN 4-24	65.5 65.1	65.3%
FA 21-24	54.1 53.3	53.7%	UA 21-24	53.4 52.3	52.9%
FC 21-24	6.83 7.73	7.28%	UC 21-24	7.74 6.48	7.11%
FN 21-24	63.6 63.1	63.4%	UN 21-24	65.5 65.1	65.3%
FA 37-24	52.1 52.2	52.2%	UA 37-24	51.8 52.4	52.1%
FC 37-24	6.77 6.71	6.74%	UC 37-24	7.13 7.06	7.10%
FN 37-24	63.5 63.8	63.7%	UN 37-24	65.9 65.0	65.5%
FA 54-24	52.3 52.4	52.4%	UA 54-24	51.8 51.7	51.8%
FC 54-24	6.59 6.86	6.73%	UC 54-24	6.85 5.60	6.23%
FN 54-24	62.5 61.5	62.0%	UN 54-24	63.6 63.8	63.7%

---

code legend: Wheat Variety
F - Fremont
U - Ute

Packaging Gas
A - air
C - carbon dioxide
N - nitrogen

The numbers signify storage temperature and storage time i.e. 4-24 = 4°C - 24 months

---

Stored Canned Wheat Data - Headspace Nitrogen % - 36 Months

Code	$\%N_2$	Avg	Code	$\%N_2$	Avg
FA 4-36	88.4	89.1%	UA 4-36	87.9	89.5%
	89.7			91.0	
FC 4-36	12.0	12.1%	UC 4-36	10.6	10.9%
	12.1			11.2	
FN 4-36	103	105%	UN 4-36	104	107%
	107			110	
FA 21-36	81.7	85.7%	UA 21-36	86.5	88.1%
	89.7			89.7	
FC 21-36	27.5	19.4%	UC 21-36	10.2	9.84%
	11.2			9.47	
FN 21-36	102	104%	UN 21-36	105	103%
	106			100	
FA 37-36	87.5	89.3%	UA 37-36	89.5	90.2%
	91.1			90.9	
FC 37-36	11.2	11.1%	UC 37-36	12.1	11.3%
	10.9			10.5	
FN 37-36	102	105%	UN 37-36	104	107%
	107			110	
FA 54-36	83.7	85.8%	UA 54-36	82.9	84.3%
	87.9			85.6	
FC 54-36	9.82	10.1%	UC 54-36	9.88	10.6%
	10.4			11.3	
FN 54-36	95.1	97.5%	UN 54-36	101	103%
	99.9			105	

---

code legend: Wheat Variety / Packaging Gas

Wheat Variety	Packaging Gas
F - Fremont	A - air
U - Ute	C - carbon dioxide
	N - nitrogen

The numbers signify storage temperature and storage time i.e. 4-36 = 4°C - 36 months

---

Stored Canned Wheat Data - Headspace Nitrogen % - 48 Months

Code	$\%N_2$	Avg	Code	$\%N_2$	Avg
FA 4-48	86.9	87.0%	UA 4-48	90.8	90.9%
	87.1			90.9	
FC 4-48	****	12.7%	UC 4-48	10.5	11.7%
	12.7			12.9	
FN 4-48	105	105%	UN 4-48	107	107%
	105			107	
FA 21-48	89.6	90.0%	UA 21-48	91.0	90.5%
	90.4			90.0	
FC 21-48	10.1	11.1%	UC 21-48	10.6	10.3%
	12.1			10.0	
FN 21-48	104	105%	UN 21-48	106	109%
	105			111	
FA 37-48	89.6	89.6%	UA 37-48	90.7	90.5%
	89.5			90.3	
FC 37-48	10.3	9.14%	UC 37-48	11.1	11.5%
	7.97			11.8	
FN 37-48	104	104%	UN 37-48	108	108%
	104			107	
FA 54-48	85.2	86.0%	UA 54-48	82.3	82.8%
	86.7			83.2	
FC 54-48	10.9	10.5%	UC 54-48	11.0	10.4%
	10.1			9.84	
FN 54-48	97.2	96.6%	UN 54-48	100	99.5%
	96.0			98.9	

**** - The headspace gas measurements from this can were suspect and not included in the statistical analysis. The measurement was 65.6%.

---

code legend: Wheat Variety — F - Fremont, U - Ute; Packaging Gas — A - air, C - carbon dioxide, N - nitrogen

The numbers signify storage temperature and storage time i.e. 4-48 = 4°C - 48 months

---

Stored Canned Wheat Data - Headspace CO_2 % - 24 Months

Code	%CO_2	Avg	Code	%CO_2	Avg
FA 4-24	.360	.349%	UA 4-24	.271	.270%
	.337			.268	
FC 4-24	59.1	55.7%	UC 4-24	51.8	51.8%
	52.2			51.7	
FN 4-24	3.37	3.24%	UN 4-24	1.83	1.77%
	3.11			1.70	
FA 21-24	2.19	2.21%	UA 21-24	2.54	2.43%
	2.22			2.32	
FC 21-24	56.5	57.7%	UC 21-24	65.3	59.2%
	58.8			53.0	
FN 21-24	4.38	4.62%	UN 21-24	2.83	3.00%
	4.85			3.16	
FA 37-24	7.65	7.31%	UA 37-24	10.3	8.96%
	6.97			7.61	
FC 37-24	82.5	72.2%	UC 37-24	64.3	64.6%
	61.8			64.9	
FN 37-24	8.73	8.77%	UN 37-24	5.96	5.91%
	8.80			5.85	
FA 54-24	22.9	17.7%	UA 54-24	40.3	39.4%
	12.4			38.4	
FC 54-24	106	106%	UC 54-24	91.7	94.1%
	106			96.4	
FN 54-24	36.0	36.1%	UN 54-24	28.3	28.7%
	36.2			29.0	

---

code legend: Wheat Variety
F - Fremont
U - Ute

Packaging Gas
A - air
C - carbon dioxide
N - nitrogen

The numbers signify storage temperature and storage time i.e. 4-24 = 4°C - 24 months

---

Stored Canned Wheat Data - Headspace CO_2 % - 36 Months

Code	%CO_2	Avg	Code	%CO_2	Avg
FA 4-36	.550 .609	.580%	UA 4-36	.529 .529	.529%
FC 4-36	55.2 55.2	55.2%	UC 4-36	54.9 53.3	54.1%
FN 4-36	3.52 3.50	3.51%	UN 4-36	2.13 2.18	2.16%
FA 21-36	8.80 3.02	5.91%	UA 21-36	3.90 3.38	3.64%
FC 21-36	63.5 59.0	61.3%	UC 21-36	63.0 59.8	61.4%
FN 21-36	5.58 5.25	5.42%	UN 21-36	3.75 3.61	3.68%
FA 37-36	10.8 13.1	12.0%	UA 37-36	9.29 7.46	8.38%
FC 37-36	75.9 69.9	72.9%	UC 37-36	72.6 55.9	64.3%
FN 37-36	11.5 8.29	9.90%	UN 37-36	7.65 5.64	6.65%
FA 54-36	57.2 39.0	48.1%	UA 54-36	54.3 47.3	50.8%
FC 54-36	99.0 101	100%	UC 54-36	94.1 98.5	96.3%
FN 54-36	47.2 53.4	50.3%	UN 54-36	42.3 44.1	43.2%

---

code legend: <u>Wheat Variety</u> — F - Fremont, U - Ute

<u>Packaging Gas</u> — A - air, C - carbon dioxide, N - nitrogen

The numbers signify storage temperature and storage time i.e. 4-36 = 4°C - 36 months

---

Stored Canned Wheat Data - Headspace CO_2 % - 48 Months

Code	%CO_2	Avg	Code	%CO_2	Avg
FA 4-48	.653	.592%	UA 4-48	.399	.484%
	.531			.568	
FC 4-48	****	56.7%	UC 4-48	56.9	55.8%
	56.7			54.6	
FN 4-48	3.45	3.70%	UN 4-48	2.37	2.28%
	3.94			2.18	
FA 21-48	7.71	7.03%	UA 21-48	3.06	2.21%
	6.35			3.36	
FC 21-48	58.5	61.3%	UC 21-48	60.5	61.3%
	64.1			62.0	
FN 21-48	5.99	5.72%	UN 21-48	3.80	3.79%
	5.45			3.78	
FA 37-48	6.93	8.29%	UA 37-48	7.97	9.24%
	9.65			10.5	
FC 37-48	72.8	71.8%	UC 37-48	69.6	71.7%
	70.8			73.7	
FN 37-48	13.1	13.3%	UN 37-48	8.05	8.13%
	13.4			8.21	
FA 54-48	47.9	58.9%	UA 54-48	97.0	93.7%
	69.9			90.4	
FC 54-48	143	147%	UC 54-48	140	144%
	151			148	
FN 54-48	80.1	80.5%	UN 54-48	74.1	76.8%
	80.9			79.5	

**** - The headspace gas measurements from this can were suspect and not included in the statistical analysis. The measurement was 30.0%.

---

code legend:

Wheat Variety	Packaging Gas
F - Fremont	A - air
U - Ute	C - carbon dioxide
	N - nitrogen

The numbers signify storage temperature and storage time i.e. 4-48 = 4°C - 48 months

---

Stored Canned Wheat Data - Germination Test - 24 Months

Code	%Germ	Avg	Code	%Germ	Avg
FA 4-24	95	96.0%	UA 4-24	96	95.5%
	97			95	
FC 4-24	97	98.0%	UC 4-24	90	92.5%
	99			95	
FN 4-24	96	93.5%	UN 4-24	95	94.5%
	91			94	
FA 21-24	96	96.5%	UA 21-24	93	94.0%
	97			95	
FC 21-24	86	84.5%	UC 21-24	93	94.0%
	83			95	
FN 21-24	98	96.0%	UN 21-24	93	95.5%
	94			98	
FA 37-24	97	92.0%	UA 37-24	89	89.0%
	87			89	
FC 37-24	86	82.5%	UC 37-24	82	84.5%
	79			87	
FN 37-24	94	94.5%	UN 37-24	95	94.5%
	95			94	
FA 54-24	0	0%	UA 54-24	0	0%
	0			0	
FC 54-24	0	0%	UC 54-24	0	0%
	0			0	
FN 54-24	0	0%	UN 54-24	0	0%
	0			0	

---

code legend:

Wheat Variety
F - Fremont
U - Ute

Packaging Gas
A - air
C - carbon dioxide
N - nitrogen

The numbers signify storage temperature and storage time
i.e. 4-24 = 4°C - 24 months

Stored Canned Wheat Data - Germination Test - 36 Months

Code	%Germ	Avg	Code	%Germ	Avg
FA 4-36	95	95.0%	UA 4-36	96	96.0%
	95			96	
FC 4-36	97	96.0%	UC 4-36	98	96.5%
	95			95	
FN 4-36	96	96.0%	UN 4-36	97	97.0%
	96			97	
FA 21-36	98	98.0%	UA 21-36	94	94.5%
	98			95	
FC 21-36	90	88.0%	UC 21-36	93	94.0%
	86			95	
FN 21-36	97	97.0%	UN 21-36	89	90.5%
	97			92	
FA 37-36	93	87.0%	UA 37-36	84	75.5%
	81			67	
FC 37-36	0	0%	UC 37-36	72	36.5%
	0			1	
FN 37-36	43	33.5%	UN 37-36	91	91.5%
	24			92	
FA 54-36	0	0%	UA 54-36	0	0%
	0			0	
FC 54-36	0	0%	UC 54-36	0	0%
	0			0	
FN 54-36	0	0%	UN 54-36	0	0%
	0			0	

---

code legend:

Wheat Variety	Packaging Gas
F - Fremont	A - air
U - Ute	C - carbon dioxide
	N - nitrogen

The numbers signify storage temperature and storage time i.e. 4-36 = 4°C - 36 months

---

Stored Canned Wheat Data - Germination Test - 48 Months

Code	%Germ	Avg	Code	%Germ	Avg
FA 4-48	94	95.5%	UA 4-48	89	91.0%
	97			93	
FC 4-48	96	93.5%	UC 4-48	91	90.5%
	91			90	
FN 4-48	94	93.0%	UN 4-48	97	96.0%
	92			95	
FA 21-48	91	90.5%	UA 21-48	93	93.0%
	90			93	
FC 21-48	94	96.5%	UC 21-48	91	91.5%
	99			92	
FN 21-48	91	93.5%	UN 21-48	96	97.0%
	96			98	
FA 37-48	82	68.5%	UA 37-48	0	0%
	55			0	
FC 37-48	0	0%	UC 37-48	0	0%
	0			0	
FN 37-48	0	0%	UN 37-48	68	71.5%
	0			75	
FA 54-48	0	0%	UA 54-48	0	0%
	0			0	
FC 54-48	0	0%	UC 54-48	0	0%
	0			0	
FN 54-48	0	0%	UN 54-48	0	0%
	0			0	

---

code legend:

Wheat Variety	Packaging Gas
F - Fremont	A - air
U - Ute	C - carbon dioxide
	N - nitrogen

The numbers signify storage temperature and storage time i.e. 4-48 = 4°C - 48 months

---

Stored Canned Wheat Data - Loaf Volume - 24 Months

Code	Volume	Avg	Code	Volume	Avg
FA 4-24	1530 ml	1585 ml	UA 4-24	1840 ml	1855 ml
	1640 ml			1870 ml	
FC 4-24	1700 ml	1670 ml	UC 4-24	1760 ml	1720 ml
	1640 ml			1680 ml	
FN 4-24	1620 ml	1710 ml	UN 4-24	1760 ml	1700 ml
	1800 ml			1640 ml	
FA 21-24	1590 ml	1580 ml	UA 21-24	1560 ml	1585 ml
	1570 ml			1610 ml	
FC 21-24	1620 ml	1605 ml	UC 21-24	1670 ml	1550 ml
	1590 ml			1430 ml	
FN 21-24	1430 ml	1465 ml	UN 21-24	1550 ml	1585 ml
	1500 ml			1620 ml	
FA 37-24	1320 ml	1405 ml	UA 37-24	1440 ml	1455 ml
	1490 ml			1470 ml	
FC 37-24	1280 ml	1285 ml	UC 37-24	1300 ml	1360 ml
	1290 ml			1420 ml	
FN 37-24	1250 ml	1240 ml	UN 37-24	1380 ml	1410 ml
	1230 ml			1440 ml	
FA 54-24	790 ml	790 ml	UA 54-24	*** ml	*** ml
	790 ml			*** ml	
FC 54-24	*** ml	540 ml	UC 54-24	700 ml	740 ml
	540 ml			780 ml	
FN 54-24	580 ml	625 ml	UN 54-24	600 ml	630 ml
	670 ml			660 ml	

*** - means the ingredients did not mix well enough to make a loaf. All of the "loaves" made from wheat stored at 54°C had a sticky dough and were very dense.

---

code legend: Wheat Variety — F - Fremont; U - Ute

Packaging Gas — A - air; C - carbon dioxide; N - nitrogen

The numbers signify storage temperature and storage time i.e. 4-24 = 4°C - 24 months

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Stored Canned Wheat Data - Loaf Volume - 36 Months

Code	Volume	Avg	Code	Volume	Avg
FA 4-36	1360 ml	1365 ml	UA 4-36	1380 ml	1360 ml
	1370 ml			1340 ml	
FC 4-36	1310 ml	1325 ml	UC 4-36	1350 ml	1320 ml
	1340 ml			1290 ml	
FN 4-36	1360 ml	1335 ml	UN 4-36	1340 ml	1330 ml
	1310 ml			1320 ml	
FA 21-36	1280 ml	1250 ml	UA 21-36	1250 ml	1265 ml
	1220 ml			1280 ml	
FC 21-36	1250 ml	1235 ml	UC 21-36	1260 ml	1270 ml
	1220 ml			1280 ml	
FN 21-36	1260 ml	1265 ml	UN 21-36	1220 ml	1260 ml
	1270 ml			1300 ml	
FA 37-36	1190 ml	1135 ml	UA 37-36	1100 ml	1155 ml
	1080 ml			1210 ml	
FC 37-36	1100 ml	1070 ml	UC 37-36	1150 ml	1180 ml
	1040 ml			1210 ml	
FN 37-36	1210 ml	1215 ml	UN 37-36	1120 ml	1080 ml
	1220 ml			1040 ml	
FA 54-36	*** ml	*** ml	UA 54-36	*** ml	*** ml
	*** ml			*** ml	
FC 54-36	*** ml	*** ml	UC 54-36	*** ml	*** ml
	*** ml			*** ml	
FN 54-36	*** ml	*** ml	UN 54-36	*** ml	*** ml
	*** ml			*** ml	

*** - The flour from this wheat could no longer mix well enough to make bread. It was like stirring wet sand.

---

code legend: Wheat Variety / Packaging Gas

Wheat Variety	Packaging Gas
F - Fremont	A - air
U - Ute	C - carbon dioxide
	N - nitrogen

The numbers signify storage temperature and storage time i.e. 4-36 = 4°C - 36 months

---

Stored Canned Wheat Data - Loaf Volume - 48 Months

Code	Volume	Avg	Code	Volume	Avg
FA 4-48	1150 ml	1165 ml	UA 4-48	1080 ml	1090 ml
	1180 ml			1100 ml	
FC 4-48	1090 ml	1090 ml	UC 4-48	1110 ml	1115 ml
	1090 ml			1120 ml	
FN 4-48	1100 ml	1110 ml	UN 4-48	1120 ml	1125 ml
	1120 ml			1130 ml	
FA 21-48	1080 ml	1065 ml	UA 21-48	1040 ml	1060 ml
	1050 ml			1080 ml	
FC 21-48	1050 ml	1075 ml	UC 21-48	1030 ml	1040 ml
	1100 ml			1050 ml	
FN 21-48	1090 ml	1090 ml	UN 21-48	1050 ml	1070 ml
	1090 ml			1090 ml	
FA 37-48	1010 ml	1005 ml	UA 37-48	910 ml	980 ml
	1000 ml			1050 ml	
FC 37-48	910 ml	960 ml	UC 37-48	960 ml	980 ml
	1010 ml			1000 ml	
FN 37-48	1000 ml	965 ml	UN 37-48	990 ml	960 ml
	930 ml			930 ml	
FA 54-48	*** ml	*** ml	UA 54-48	*** ml	*** ml
	*** ml			*** ml	
FC 54-48	*** ml	*** ml	UC 54-48	*** ml	*** ml
	*** ml			*** ml	
FN 54-48	*** ml	*** ml	UN 54-48	*** ml	*** ml
	*** ml			*** ml	

*** - The flour from this wheat could no longer mix well enough to make bread. It was like stirring wet sand.

---

code legend:

	Wheat Variety	Packaging Gas
	F - Fremont	A - air
	U - Ute	C - carbon dioxide
		N - nitrogen

The numbers signify storage temperature and storage time
i.e. 4-48 = 4°C - 48 months

Stored Canned Wheat Data - Protein Solubility - 24 Months

	Absorbance				Absorbance		
Code	Meas1	Meas2	Avg	Code	Meas1	Meas2	Avg
FA 4-24	0.586	0.595	0.591	UA 4-24	0.626	0.607	0.617
	0.520	0.536	0.528		0.361	0.610	0.621
FC 4-24	0.595	0.598	0.597	UC 4-24	0.594	0.589	0.592
	0.553	0.550	0.552		0.601	0.598	0.600
FN 4-24	0.599	0.592	0.596	UN 4-24	0.583	0.584	0.584
	0.557	0.534	0.546		0.625	0.610	0.618
FA 21-24	0.553	0.550	0.552	UA 21-24	0.541	0.541	0.541
	0.537	0.518	0.528		0.619	0.625	0.622
FC 21-24	0.541	0.526	0.534	UC 21-24	0.553	0.539	0.546
	0.567	0.552	0.560		0.541	0.530	0.536
FN 21-24	0.543	0.559	0.551	UN 21-24	0.597	0.586	0.592
	0.545	0.525	0.535		0.594	0.611	0.603
FA 37-24	0.557	0.559	0.558	UA 37-24	0.567	0.559	0.563
	0.599	0.598	0.599		0.605	0.592	0.599
FC 37-24	0.601	0.585	0.593	UC 37-24	0.581	0.567	0.574
	0.532	0.529	0.531		0.557	0.550	0.554
FN 37-24	0.514	0.517	0.516	UN 37-24	0.571	0.590	0.581
	0.536	0.550	0.543		0.618	0.597	0.608
FA 54-24	0.365	0.352	0.359	UA 54-24	0.156	0.167	0.162
	0.260	0.279	0.270		0.227	0.208	0.218
FC 54-24	0.137	0.133	0.135	UC 54-24	0.284	0.268	0.276
	0.204	0.189	0.197		0.285	0.267	0.276
FN 54-24	0.227	0.216	0.222	UN 54-24	0.252	0.267	0.260
	0.192	0.193	0.193		0.256	0.244	0.250

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code legend: Wheat Variety — F - Fremont; U - Ute

Packaging Gas — A - air; C - carbon dioxide; N - nitrogen

The numbers signify storage temperature and storage time i.e. 4-24 = 4°C - 24 months

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Stored Canned Wheat Data - Protein Solubility - 36 Months

Code	Absorbance Meas1	Meas2	Avg	Code	Absorbance Meas1	Meas2	Avg
FA 4-36	0.563	0.568	0.566	UA 4-36	0.554	0.573	0.564
	0.497	0.489	0.493		0.488	0.487	0.488
FC 4-36	0.497	0.491	0.494	UC 4-36	0.505	0.511	0.508
	0.526	0.533	0.530		0.486	0.488	0.487
FN 4-36	0.511	0.519	0.515	UN 4-36	0.499	0.501	0.500
	0.509	0.494	0.502		0.562	0.552	0.557
FA 21-36	0.461	0.463	0.462	UA 21-36	0.496	0.498	0.497
	0.427	0.446	0.437		0.513	0.531	0.522
FC 21-36	0.495	0.512	0.504	UC 21-36	0.450	0.460	0.455
	0.472	0.478	0.475		0.504	0.523	0.514
FN 21-36	0.467	0.480	0.474	UN 21-36	0.490	0.507	0.499
	0.518	0.530	0.524		0.529	0.547	0.538
FA 37-36	0.515	0.519	0.517	UA 37-36	0.476	0.496	0.486
	0.501	0.500	0.501		0.556	0.552	0.554
FC 37-36	0.510	0.501	0.506	UC 37-36	0.505	0.518	0.512
	0.419	0.422	0.421		0.452	0.471	0.462
FN 37-36	0.514	0.510	0.512	UN 37-36	0.515	0.516	0.516
	0.427	0.439	0.433		0.518	0.520	0.519
FA 54-36	0.030	0.024	0.027	UA 54-36	0.028	0.039	0.034
	0.033	0.023	0.028		0.080	0.089	0.085
FC 54-36	0.043	0.055	0.049	UC 54-36	0.043	0.057	0.050
	0.065	0.080	0.073		0.000	0.012	0.006
FN 54-36	0.042	0.043	0.043	UN 54-36	0.069	0.076	0.073
	0.031	0.050	0.041		0.015	0.020	0.018

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code legend: Wheat Variety — F - Fremont; U - Ute

Packaging Gas — A - air; C - carbon dioxide; N - nitrogen

The numbers signify storage temperature and storage time i.e. 4-36 = 4°C - 36 months

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Stored Canned Wheat Data - Protein Solubility - 48 Months

Code	Absorbance Meas1	Meas2	Avg	Code	Absorbance Meas1	Meas2	Avg
FA 4-48	0.521	0.512	0.517	UA 4-48	0.487	0.471	0.479
	0.497	0.492	0.495		0.508	0.512	0.510
FC 4-48	0.488	0.478	0.473	UC 4-48	0.466	0.468	0.467
	0.474	0.494	0.484		0.490	0.495	0.493
FN 4-48	0.476	0.471	0.474	UN 4-48	0.485	0.505	0.495
	0.482	0.469	0.476		0.472	0.489	0.481
FA 21-48	0.501	0.494	0.498	UA 21-48	0.477	0.483	0.480
	0.445	0.455	0.450		0.492	0.508	0.500
FC 21-48	0.498	0.483	0.491	UC 21-48	0.498	0.490	0.494
	0.477	0.494	0.486		0.485	0.492	0.489
FN 21-48	0.470	0.465	0.468	UN 21-48	0.428	0.432	0.430
	0.469	0.476	0.473		0.471	0.477	0.474
FA 37-48	0.464	0.479	0.472	UA 37-48	0.470	0.462	0.466
	0.445	0.435	0.440		0.486	0.486	0.486
FC 37-48	0.429	0.432	0.431	UC 37-48	0.495	0.487	0.491
	0.480	0.469	0.475		0.467	0.467	0.467
FN 37-48	0.471	0.483	0.477	UN 37-48	0.470	0.484	0.477
	0.470	0.454	0.462		0.433	0.449	0.441
FA 54-48	0.015	0.032	0.024	UA 54-48	0.014	0.000	0.007
	0.008	0.022	0.015		0.066	0.080	0.073
FC 54-48	0.018	0.014	0.016	UC 54-48	0.032	0.029	0.031
	0.054	0.057	0.056		0.004	0.019	0.012
FN 54-48	0.027	0.017	0.022	UN 54-48	0.018	0.002	0.010
	0.006	0.005	0.006		0.003	0.005	0.004

code legend:

Wheat Variety	Packaging Gas
F - Fremont	A - air
U - Ute	C - carbon dioxide
	N - nitrogen

The numbers signify storage temperature and storage time i.e. 4-48 = 4°C - 48 months

The SAS System

General Linear Models Procedure
Class Level Information

Class	Levels	Values
YEAR	3	2 3 4
ATMOS	3	A C N
TEMP	4	4 21 37 54

Number of observations in data set = 144

NOTE: Due to missing values, only 143 observations can be used in this analysis.

General Linear Models Procedure

Dependent Variable: **OXYGEN**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	23	2020.6819	87.8557	223.93	0.0001
Error	119	46.6881	0.3923		
Corrected Total	142	2067.3700			

R-Square	C.V.	Root MSE	OXYGEN Mean
0.977417	36.28705	0.6264	1.7261

Source	DF	Type I SS	Mean Square	F Value	Pr > F
YEAR	2	5.12876	2.56438	6.54	0.0020
TEMP	3	513.05630	171.01877	435.90	0.0001
ATMOS	2	620.59105	310.29553	790.89	0.0001
YEAR*TEMP	6	16.79871	2.79978	7.14	0.0001
YEAR*ATMOS	4	7.93390	1.98347	5.06	0.0008
ATMOS*TEMP	6	857.17317	142.86220	364.13	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
YEAR	2	5.29497	2.64749	6.75	0.0017
TEMP	3	483.93105	161.31035	411.15	0.0001
ATMOS	2	628.41373	314.20687	800.86	0.0001
YEAR*TEMP	6	16.19084	2.69847	6.88	0.0001
YEAR*ATMOS	4	7.27397	1.81849	4.64	0.0016
ATMOS*TEMP	6	857.17317	142.86220	364.13	0.0001

General Linear Models Procedure
Class Level Information

Class	Levels	Values
YEAR	3	2 3 4
ATMOS	3	A C N

Number of observations in data set = 144

NOTE: Due to missing values, only 143 observations can be used in this analysis.

General Linear Models Procedure

Dependent Variable: **NITROGEN**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	198585.03	49646.26	762.95	0.0001
Error	138	8979.85	65.07		
Corrected Total	142	207564.88			

R-Square	C.V.	Root MSE	NITRO Mean
0.956737	13.61683	8.0667	59.241

Source	DF	Type I SS	Mean Square	F Value	Pr > F
YEAR	2	23681.65	11840.83	181.97	0.0001
ATMOS	2	174903.38	87451.69	1343.93	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
YEAR	2	22763.48	11381.74	174.91	0.0001
ATMOS	2	174903.38	87451.69	1343.93	0.0001

General Linear Models Procedure
Class Level Information

Class	Levels	Values
YEAR	3	2 3 4
ATMOS	3	A C N
TEMP	4	4 21 37 54

Number of observations in data set = 144

NOTE: Due to missing values, only 143 observations can be used in this analysis.

General Linear Models Procedure

Dependent Variable: **CARBON DIOXIDE**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	19	189182.55	9956.98	296.59	0.0001
Error	123	4129.27	33.57		
Corrected Total	142	193311.82			

R-Square	C.V.	Root MSE	CO2 Mean
0.978639	16.13014	5.7941	35.921

Source	DF	Type I SS	Mean Square	F Value	Pr > F
YEAR	2	4101.56	2050.78	61.09	0.0001
TEMP	3	67475.08	22491.69	669.97	0.0001
ATMOS	2	107351.96	53675.98	1598.86	0.0001
YEAR*TEMP	6	9801.85	1633.64	48.66	0.0001
ATMOS*TEMP	6	452.10	75.35	2.24	0.0433

Source	DF	Type III SS	Mean Square	F Value	Pr > F
YEAR	2	4267.59	2133.80	63.56	0.0001
TEMP	3	66454.56	22151.52	659.83	0.0001
ATMOS	2	106366.47	53183.23	1584.19	0.0001
YEAR*TEMP	6	9848.26	1641.38	48.89	0.0001
ATMOS*TEMP	6	452.10	75.35	2.24	0.0433

General Linear Models Procedure
Class Level Information

Class	Levels	Values
YEAR	3	2 3 4
VARIT	2	F U
ATMOS	3	A C N
TEMP	4	4 21 37 54

Number of observations in data set = 144

General Linear Models Procedure

Dependent Variable: **GERMINATION**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	22	251588.88	11435.86	70.42	0.0001
Error	121	19650.12	162.40		
Corrected Total	143	271238.99			

R-Square	C.V.	Root MSE	GERMIN Mean
0.927554	20.89342	12.744	60.993

Source	DF	Type I SS	Mean Square	F Value	Pr > F
YEAR	2	6868.39	3434.19	21.15	0.0001
VARIT	1	184.51	184.51	1.14	0.2886
TEMP	3	214295.47	71431.82	439.86	0.0001
ATMOS	2	2643.18	1321.59	8.14	0.0005
YEAR*TEMP	6	19496.06	3249.34	20.01	0.0001
VARIT*ATMOS	2	2068.18	1034.09	6.37	0.0023
ATMOS*TEMP	6	6033.10	1005.52	6.19	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
YEAR	2	6868.39	3434.19	21.15	0.0001
VARIT	1	184.51	184.51	1.14	0.2886
TEMP	3	214295.47	71431.82	439.86	0.0001
ATMOS	2	2643.18	1321.59	8.14	0.0005
YEAR*TEMP	6	19496.06	3249.34	20.01	0.0001
VARIT*ATMOS	2	2068.18	1034.09	6.37	0.0023
ATMOS*TEMP	6	6033.10	1005.52	6.19	0.0001

General Linear Models Procedure
Class Level Information

Class	Levels	Values
YEAR	3	2 3 4
VARIT	2	F U
ATMOS	3	A C N
TEMP	4	4 21 37 54

Number of observations in data set = 144

NOTE: Due to missing values, only 117 observations can be used in this analysis.

General Linear Models Procedure

Dependent Variable: **LOAF VOLUME**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	8564183.9	611727.4	172.28	0.0001
Error	102	362185.4	3550.8		
Corrected Total	116	8926369.2			

R-Square	C.V.	Root MSE	LOAFVOL Mean
0.959425	4.829524	59.589	1233.8

Source	DF	Type I SS	Mean Square	F Value	Pr > F
YEAR	2	2020099.2	1010049.6	284.45	0.0001
VARIT	1	31835.5	31835.5	8.97	0.0035
TEMP	3	6311286.6	2103762.2	592.47	0.0001
ATMOS	2	30200.2	15100.1	4.25	0.0168
YEAR*VARIT	2	34364.2	17182.1	4.84	0.0098
YEAR*TEMP	4	136398.1	34099.5	9.60	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
YEAR	2	4387251.9	2193625.9	617.78	0.0001
VARIT	1	10160.9	10160.9	2.86	0.0938
TEMP	3	6199762.1	2066587.4	582.00	0.0001
ATMOS	2	32806.7	16403.3	4.62	0.0120
YEAR*VARIT	2	34364.2	17182.1	4.84	0.0098
YEAR*TEMP	4	136398.1	34099.5	9.60	0.0001

General Linear Models Procedure
Class Level Information

Class	Levels	Values
YEAR	3	2 3 4
VARIT	2	F U
TEMP	4	4 21 37 54

Number of observations in data set = 144

General Linear Models Procedure

Dependent Variable: **PROTEIN SOLUBILITY**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	5.1002573	0.8500429	558.44	0.0001
Error	137	0.2085376	0.0015222		
Corrected Total	143	5.3087949			

R-Square	C.V.	Root MSE	PROTEIN Mean
0.960718	9.464561	0.0390	0.4122

Source	DF	Type I SS	Mean Square	F Value	Pr > F
YEAR	2	0.4126824	0.2063412	135.56	0.0001
VARIT	1	0.0068890	0.0068890	4.53	0.0352
TEMP	3	4.6806859	1.5602286	1025.00	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
YEAR	2	0.4126824	0.2063412	135.56	0.0001
VARIT	1	0.0068890	0.0068890	4.53	0.0352
TEMP	3	4.6806859	1.5602286	1025.00	0.0001

Temperature, Time, and Packaging Gas Affect Quality of Hermetically Stored Wheat

Theodore C. Barber

Department of Food Science and Nutrition

M. S. Degree, August 1993

ABSTRACT

Two varieties of hard wheat were sealed in cans with air, carbon dioxide (CO_2), or nitrogen (N_2), and stored at 4, 21, 37, or 54°C. Replicate cans were taken out of storage after 2, 3, and 4 years. Headspace gases, germination, loaf volume, and protein solubility were measured.

Wheat quality and headspace oxygen, in general, decreased with increased storage temperature and time, while headspace CO_2 and N_2 increased. Germinability was preserved best for Fremont variety by air and for Ute by N_2. Most wheat stored at 37°C did not germinate after 3 and 4 years. Wheat stored at 54°C did not germinate nor could it be made into bread. Loaf volume decreased for each increase in storage temperature. Loaf volume also decreased with storage time. Protein solubility was less for the wheat stored at 54°C.

COMMITTEE APPROVAL:

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