The Effects of Packaging Gas, Temperature and Storage Time on Germination, Loaf Volume and Protein Solubility of Wheat

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Scott W. Myers

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John Hal Johnson, Committee Chairman

H. Gill Hilton, Committee Member

Clayton S. Huber, Committee Member

7/9/91
Date

Mark J. Rowe, Department Chairman

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Introduction and Literature Review

Barton (1961) stated that the three major factors which influence seed viability during storage are temperature, moisture content and oxygen pressure. Wheat functionality may be damaged in the field before or during harvest, during artificial drying operations or during subsequent storage and handling (Halverson and Zeleny, 1988). The extent and nature of this damage will govern the viability and quality of wheat.

Temperature

Heat damage occurs in wheat exposed to relatively high temperatures, causing decreases in germination and bread-making quality. Glass et al. (1959) stored wheat in flasks sealed under air or nitrogen at 20°C and 30°C for up to 48 weeks. Storage at 30°C showed accelerated decreases in germination and bread-making quality when compared to storage at 20°C. Storage in nitrogen delayed deterioration somewhat at 30°C and significantly at 20°C. Burges et al. (1963) stored barley at 13.2% moisture content in sealed jars at 18°C, 32°C, 35°C and 40°C for 26 weeks. They found that at 18°C, germination remained close to 95% for the entire 26 weeks. Within 10 weeks, germination levels at 40°C dropped to essentially 0%, while germination levels at 32°C and 35°C were similar to those at 18°C. After 26 weeks, however, germination levels at 32°C and 35°C had dropped to less than 20%.

One of the signs of exposure to high temperatures and aging in seeds is a decrease in α-amylase activity. This decrease in α-amylase activity is partially due to thermal inactivation of α-amylase which can lead to decreased germination due to the lack of utilizable substrate [Bhattacharyya and Sen-Mandi, 1985}. The release of substrate to the germinating embryo is controlled by the rate at which α-amylase is synthesized and reaches the starch granules (Wrigley and Bietz, 1988). Bhattacharyya and Sen-Mandi (1985) demonstrated that embryos of aged non-germinating wheat germinated well when placed on agar containing 3% sucrose or 2% glucose. The same aged wheat completely failed to germinate when placed on agar alone. An amylase activity assay showed that the aged wheat had no α-amylase activity.

Moisture Content

Physical and chemical changes which take place in stored grain increase greatly with moisture content of the grain (Hunt and Pixton, 1974). Seeds with high moisture show increased susceptibility to germination and development of germ damage. Germ damage is apparent when the kernels take on a dull appearance and when the germ becomes darkened (Milner and Geddes, 1954). Petruzzelli (1986) stored wheat, having moisture contents ranging from 15 to 33 percent, under either hermetic and aerobic conditions at 25°C. Under hermetic storage, wheat lost viability more rapidly with increased moisture. Wheat stored aerobically showed enhanced viability as moisture increased from 24 to 31 percent but had a drastic drop in viability at 33 percent. At 24 to 31 percent moisture, the wheat maintained viability longer when stored aerobically than stored hermetically. Glass et al. (1959) reported that for wheat stored in air at 30°C, germ damage occurred much earlier at 16 to 18% moisture than at 13 to 15% moisture. After eighteen weeks, half of the wheat at 16% and all of the wheat at 18% moisture had developed germ damage. Germ damage was much slower at 15% moisture; 36 weeks were required before 75% of the wheat developed germ damage. Germ damage was virtually nonexistent in wheat with moisture contents below 14% at 30°C. Hunt and Pixton (1974) stated that for most cereal grains, critical values for moisture content are about 14%. Most species of seeds remain viable longer during storage when moisture is reduced to five percent (Roberts, 1972).

Oxygen Level

Long-term storage experiments were conducted with seeds stored in sealed ampoules filled with air, oxygen, carbon dioxide or nitrogen. Temperature, moisture content and gaseous composition were maintained at constant levels. Roberts (1961) stored rice at temperatures of 27°C to 47°C for 1.5 years sealed with air, oxygen, carbon dioxide or nitrogen. Germination results were complex; the influence on viability by each gas was not the same under all temperatures and moisture contents. Harrison (1966) stored 10 varieties of lettuce seeds for three years at 18°C and 6% moisture content under various gases. At the end of three years, he found that seeds stored in oxygen had a mean viability of 8%; in air it was 57%; whereas in both nitrogen and carbon dioxide it was 78%. Similar results were obtained using onion seed at 18°C and 8% moisture.

Roberts and Abdalla (1968) found the viability of barley, broad beans and peas decreased when stored under various levels of oxygen. Increasing the oxygen from 0 to 21% significantly accelerated the loss of viability. Peterson et al. (1956) reported that wheat stored 16 days at 25°C gradually decreased in mold growth, germ damage and respiration as oxygen was lowered from 21 to 0.2%.

Glass et al. (1959) stored wheat at 30°C for 42 weeks and at 20°C for 48 weeks in nitrogen or air. At 30°C, storage in nitrogen delayed the onset of deterioration, measured by germ damage and loaf volume, as compared with air. At 20°C, deterioration was much slower in wheat stored in nitrogen. Roberts (1961) reported that for seeds that remain viable for a year when stored in air, storage in nitrogen increased the period of viability.

Storing lettuce and onion seeds sealed under carbon dioxide or air for 18 years, Harrison (1966) showed that carbon dioxide extended viability. Lettuce seeds in air remained viable for about eight years while seeds stored in carbon dioxide remained viable for more than nine years. Similar results were obtained with the onion seed. Bennici et al. (1984) reported early storage in carbon dioxide at 22°C prolonged seed longevity. Wheat was stored in carbon dioxide for 18 months and then in air for 16 years under ambient conditions. Every two years, the viability of the wheat was measured by germination tests. The wheat treated with early storage in carbon dioxide exhibited 58% germination after 10 years while seeds stored in air for the same time period completely failed to germinate. Peterson et al. (1956) stored wheat at 30°C and 18% moisture for 16 days under a carbon dioxide-oxygen mixture with 21% oxygen and up to 79% carbon dioxide. The carbon dioxide-oxygen mixture had little effect on respiration and mold growth until the carbon dioxide concentration exceeded 13.8% where very sharp inhibition occurred. Seeds stored in 50 and 79% carbon dioxide exhibited high viability.

Respiration

Under aerobic conditions, respiration occurs as molecular oxygen reacts with carbohydrates or lipids to produce carbon dioxide, water and energy. Respiration is accelerated by increases in temperature until it is limited by such factors as thermal inactivation of key enzymes, exhaustion of substrate, limitation in oxygen supply or accumulation of inhibitory concentrations of carbon dioxide (Pomeranz, 1974).

Roberts and Abdalla (1968) showed that when pea seeds were stored in sealed ampoules at 25°C, there was a linear increase in carbon dioxide content and a corresponding decrease in oxygen content. After 11.3 weeks, the oxygen content of the ampoules had dropped from 21 to 1.4 percent and the carbon dioxide content rose from 0.03 to about 12 percent. Roberts (1961) stated that if seeds are stored in nitrogen or carbon dioxide instead of air, changes in gaseous environment would be less and stated that storage in oxygen would result in greater changes.

Methods of Measurement

The ultimate measurement of wheat flour performance is established by a bake test (Mailhot and Patton, 1988). Germination is the most sensitive test for detecting heat-damage, however, it does not correlate well with predicting bread baking quality because it is an all-or-nothing measurement. Every (1987) developed a protein solubility test (PST) that more accurately predicts baking quality by detecting the extent of heat damage to soluble wheat proteins. His test was based on Pence et al. (1953) who reported that thermal denaturation of wheat proteins, especially glutenin, drastically reduced germination and baking quality of wheat. Every (1987) showed that heat damaged wheat produced significantly reduced loaf volumes in addition to decreased solubility in a dilute sodium chloride solution. Reductions in solubility are detected by decreases in absorption due to decreased dye binding. Carpenter (1973) demonstrated that heat damaged proteins bind to dyes less than raw proteins. Kratzer et al., (1990) confirmed that heat damage to proteins could be measured using Coomassie Blue G dye-binding. This relationship between dye binding and heat damage establishes the significance of the PST as an indicator of baking quality. The PST, like baking tests, shows gradual decreases in wheat quality and thus is a better indicator of bread-making quality than germination. To better understand the changes in wheat viability and quality under different storage conditions, measurements of percent germination, loaf volume and protein solubility are desirable.

Objective

Most of the early experiments were designed to predict the effects of open air storage. There is little information on the effects of storage conditions on wheat for home use. A five year study has been undertaken to measure the effects of packaging gas, storage temperature and time on the viability and quality of wheat stored in sealed containers. This is a report on the changes occurring during the first 18 months of storage of wheat sampled at 0, 6, 12 and 18 months.

Materials and Methods

Materials

Two varieties of wheat, Freemont and Ute, were obtained from the Brigham Young University Spanish Fork farm in Utah. The Freemont variety is a hard spring wheat harvested in August, 1988. The Ute variety is a hard winter wheat harvested in June, 1988. The wheat was stored in an open air shed in 100 lb. polypropylene sacks until September, 1988.

Packaging

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

Storage

Upon return to Provo, Utah, the canned wheat was randomly assigned to one of four temperatures: 4°C, 21°C, 37°C and 54°C. Cans were taken from storage at six month intervals for analysis. While waiting to undergo analysis, the canned wheat was stored at -17°C for two to three months.

Percent Oxygen Test

The oxygen content of each can was measured with a Beckman Altex Oxygen Analyzer (model 0260). A 4 inch, 7 gauge stainless steel hollow needle inserted through a rubber stopper was used to puncture the can so that a percent oxygen reading could be taken. The rubber stopper served as a temporary gasket to prevent air intrusion. The oxygen content recorded was the lowest oxygen value that registered before it increased due to the intrusion of outside air.

Moisture Test

The percent moisture of the wheat was determined by weighing out 5 grams of whole wheat into a petri dish, drying it in an oven at 95°C $\pm$ 5°C for 36 hours and then reweighing the wheat. The loss in weight was used to calculate the percent moisture of the wheat.

Germination Test

One hundred undamaged wheat kernels were counted out and soaked in a solution of 0.05% sodium benzoate (w/v) for 2 hours. The sodium benzoate solution served to inhibit mold growth. After soaking, the kernels were placed on moist filter paper in a covered petri dish and stored at 20°C in a dark place for four days. The kernels that germinated were then counted and recorded as a percentage.

Grinding and Milling

Whole wheat flour for the baking and protein solubility tests was obtained by grinding the wheat in a high speed rotor-stator pin-mill, Magic Mill III Plus (Magic Mill Co., Salt Lake City, UT 84104). To obtain a bread-type flour, the wheat was ground at the most coarse setting on the mill. The flour was stored in the freezer at -28°C for one to two weeks until used.

Baking Test

Bread was made in an automatic bread maker: Panasonic Bread Bakery, (Model SD-BT2P, Panasonic Inc., 1 Panasonic Way, Secaucus, NJ, 07094). The formulation of the bread was 270 g whole wheat flour, 11 g margarine, 11.9 g sucrose, 8.4 g nonfat dried milk, 4.7 g NaCl, 3.2 g dry active yeast and 210 ml water. After baking and cooling, loaf volume was measured by rapeseed displacement.

Protein Solubility Test

The protein solubility test (PST) (Every, 1987) was used to assess the heat damage of the whole wheat flour. Fifty ml of 2% (w/v) NaCl were measured in a 100 ml graduated cylinder. 1.000 gram of whole wheat flour was added to the salt solution and mixed by inverting the cylinder by hand once every second for 30 seconds. After allowing the flour to settle 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 2 minutes, the absorbance was read at 595 nm by a Perkin-Elmer Coleman 124 spectrophotometer (Hitachi Ltd., Tokyo, Japan) against a blank of the protein stain reagent.

Preparation of the Protein Stain Reagent

The preparation of the reagent was according to Bradford (1976). Ten mg of Coomassie Brilliant Blue G were dissolved in 5 ml of 95% ethanol. Ten ml 85% (w/v) phosphoric acid were added and the volume was brought up to 100 ml with distilled water. Consistent results were obtained by shaking the reagent before use and periodically during use to prevent settling. The reagent was refrigerated when not in use to prolong its lifetime from one month at room temperature to three or more months. No reagent, however, was more than 2 weeks old when used.

Statistical Analysis

A multivariate analysis was performed on the data from the percent oxygen test, germination test and baking test. An analysis of variance was conducted on the data from the protein solubility test. Fisher's LSD multiple comparison procedure was conducted on the main effects or interactions where significance occurred. All hypotheses were tested at a 0.05 level of significance.

Results and Discussion

With multivariate analysis, the tests of percent oxygen, germination and baking showed a significant three-way interaction between packaging gas, temperature and storage time. The two-way interactions between variety and packaging gas and between variety and time were also significant. The main effects were not examined separately due to the significance of these interactions.

Percent Oxygen Test

The Vacu-Dry Company that packaged the wheat into cans reported that the cans sealed under air had 16 to 18% oxygen, those sealed under carbon dioxide 9.5 to 11.5% oxygen, and those sealed under nitrogen had less than 2% oxygen. The oxygen content from cans with carbon dioxide and nitrogen was determined using a flushing procedure. The differences in these readings and those from the study were probably due to the methods of measurement and the number of cans measured.

Percent oxygen results using the Altex oxygen analyzer showed a three-way interaction between packaging gas, temperature and storage time. Table 1 shows the percent oxygen for cans sealed with air or nitrogen. Cans with air showed the most significant changes in oxygen content. Cans sealed with air stored at 4°C showed no significant changes in oxygen content over 18 months of storage. Cans stored at 21°C for 6 months and 12 months had significantly greater

Table 1: The effect of temperature and storage time on the percent oxygen of wheat sealed in cans under air or nitrogen.

	Percent Oxygen Present		
	months		
air			
	6	12	18
4°C	17.1%	17.3%	17.6%
21°C	14.4%	13.5%	11.4%
37°C	12.3%	6.8%	5.2%
54°C	8.9%	6.3%	3.7%
nitrogen			
	6	12	18
4°C	4.9%	4.0%	4.4%
21°C	4.1%	4.5%	3.4%
37°C	4.7%	3.1%	2.8%
54°C	5.6%	4.4%	2.8%

oxygen contents than those cans stored at 21°C for 18 months. Cans stored at 37°C and 54°C had significant decreases in oxygen content as time progressed during the study. As respiration rates and other processes such as oxidation increase at higher temperatures, oxygen uptake occurs resulting in decreases in percent oxygen as shown. Cans packaged under air and stored at high temperatures would probably reach a point where carbon dioxide exerts a greater influence over the wheat than does oxygen.

The cans sealed with carbon dioxide did not show any significant changes in oxygen content with temperature or storage time according to our method of analysis. This did not agree with the expected results, therefore, the oxygen data from the carbon dioxide cans is considered to be inaccurate for the following reasons. First, the analyses of the Vacu-Dry Company measured 50% less oxygen than our analyses. Second, the data for carbon dioxide is not consistent with that of the other gas treatments. For both air and nitrogen, oxygen was diminished with storage at the warmer temperatures as respiration occurred. The carbon dioxide results should have reflected similar changes. Third, the oxygen levels would be expected to be lower as a result of flushing as seen for the nitrogen cans. The flushing should have also lowered the oxygen content of the carbon dioxide cans. The reason for the inaccuracy of the carbon dioxide oxygen data is unknown. An alternative method of measuring oxygen should show that oxygen levels for carbon dioxide are more consistent with the expected results.

Cans sealed with nitrogen had more complex interactions with time and temperature for oxygen content. There were no significant differences in oxygen content at 4°C and 21°C. At 37°C, the oxygen content at 6 months was significantly greater than that at 12 and 18 months. At 54°C, the oxygen content at 6 and 12 months was greater than that at 18 months. This data is starting to show that the oxygen content decreases at higher temperatures as it did in the cans packaged under air. The smaller changes in oxygen content for nitrogen are probably due to the low initial amount of oxygen and possible inhibition of respiration by nitrogen.

Multivariate analysis showed that percent oxygen in cans was affected by a three-way interaction between packaging gas, temperature and storage time. It was not influenced by the wheat variety. This was expected since both varieties were packaged under the same conditions and nothing occurred that should cause differences.

Moisture Test

The moisture content of the wheat was determined for each variety. The Freemont variety averaged 8.1% ± 0.3% moisture and the Ute variety averaged 8.7% ± 0.6% moisture. These values were considerably lower than the 14% moisture levels of commercially stored grain (Hunt and Pixton, 1974) but well within the levels needed for the wheat seeds to remain viable

(Roberts, 1972). The lower moisture levels in the wheat were encouraged by drought conditions in Utah during the past few years.

Germination Test

The percentage of wheat that germinated was affected by an interaction between variety and packaging gas. Germination results for the Freemont variety for air and nitrogen were not significantly different. Both gases produced significantly better germination results than carbon dioxide. The percentage of wheat that germinated for carbon dioxide averaged about 6% lower than those of the other gases. For the Ute variety, germination with nitrogen was significantly greater than with air, there being a 6.5% difference. The results for carbon dioxide fell between these two gases and were not significantly different from either one. After 18 months of storage, no trends were found that would establish which packaging gas was best to ensure optimal germination because of the variation between the varieties.

The interaction of temperature and time on germination is depicted in Figure 1. The 4°C and 21°C treatments did not significantly affect germination over 18 months. Some variation in the wheat itself or in the testing may account for small temperature differences. The 6 month germination levels at 37°C did not differ significantly from those at 4°C and 21°C. Germination levels at 37°C for 6 months were significantly higher than those at 12 and 18 months, dropping

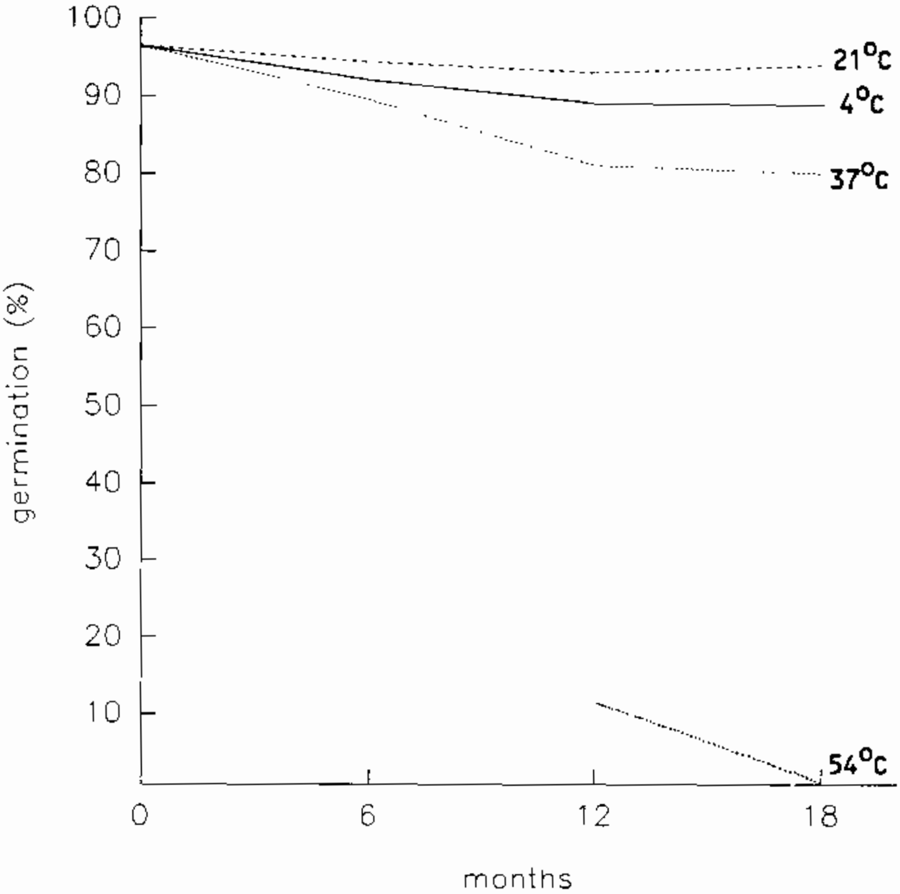

Figure 1: The effect of storage temperature and time on the germination of wheat (SEM = 2.79).

from 90% ± 3% to 81% ± 8% and 80% ± 6%, respectively. This trend was even more significant at 54°C. After only 6 months, 71% ± 9% of the wheat germinated. Germination further dropped to 11% ± 9% after 12 months and 0% ± 0% after 18 months of storage at 54°C. From these results it is clear that storage at elevated temperatures becomes increasingly detrimental to wheat germination over time.

These results correspond with those of other researchers. Every (1987) showed that heat-treating wheat, which had an initial moisture content of 18%, for 3 hours at 60°C and 80°C resulted in 63% and 0% germination respectively (SEM = 6). Lesser heat treatments had germination values ranging from 82 to 97%. While the heat treatment in his study was more harsh than those of this study, his results also indicate that heat seriously affects germination. The prolonged 54°C heat treatment of the current study could have caused a loss of α-amylase activity after 18 months of storage. Bhattacharyya and Sen-Mandi (1985) showed that aged wheat, that lacked α-amylase activity, germinated when placed on agar containing sucrose.

Baking Test

The baking quality of the stored wheat was measured by loaf volume. An automatic bread maker was used to bake the loaves to avoid the variation associated with making the bread by hand. Multivariate analysis showed interactions between variety and time and between temperature and time.

Significant differences in loaf volume were also found among the three packaging gases.

The relationship between variety and time showed that at 6 months, the Ute variety produced significantly larger loaves than the Freemont variety. However, the Freemont variety gave significantly larger loaf volumes at 12 months. There were no significant differences between loaf volumes of Freemont and Ute varieties at 18 months. The reason for this variation between the varieties is not known. It might be due to the varieties undergoing changes in proteins at different times during storage.

As with germination, there is a significant interaction between temperature and time on loaf volume as shown in Figure 2. After 6 months, there were no significant differences between loaf volumes of wheat stored at 4°C, 21°C and 37°C. Loaf volumes at all three temperatures were significantly greater than those at 54°C. Twelve months of storage showed no significant differences between loaf volumes of wheat stored at 4°C and 21°C and between those of wheat stored at 37°C and 54°. Loaf volumes of wheat stored at 4°C and 21°C were significantly greater than those of wheat stored at 37°C and 54°C. After 18 months, loaf volume decreased significantly as the storage temperature increased. At 4°C and 18 months, the average of loaf volumes was 1328 ml ± 34 ml. The average loaf volumes at 18 months dropped to 1242 ml ± 46 ml for 21°C, 1204 ml ± 32 ml for 37°C and 939 ml ± 51 ml

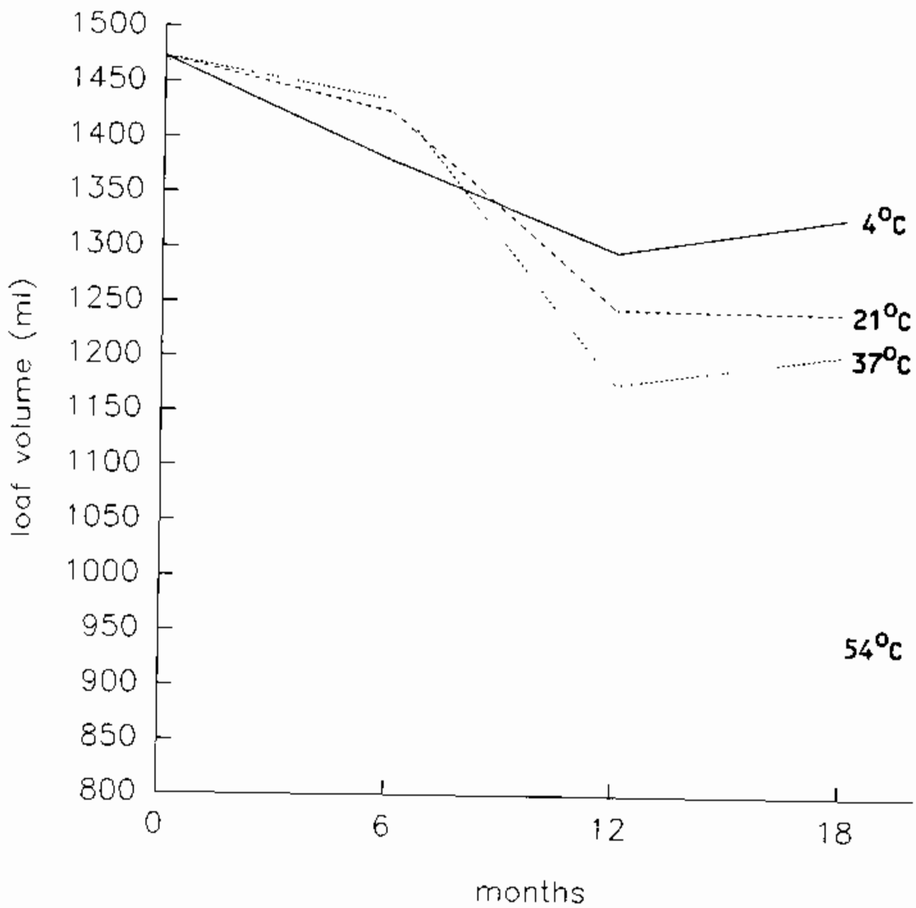

Figure 2: The effect of storage temperature and time on loaf volume of wheat (SEM = 13.00).

for 54°C. While no measurements were made, the average loaf volume for 18 months at 54°C appeared only slightly larger than the volume of the ingredients.

As the stored wheat received increasing amounts of temperature and time, the loaves showed signs of protein damage. The loaves rose but could not hold their structure and the bread became increasingly more compact. Storage at 37°C and 54°C adversely affected bread quality in a relatively short time period. Every (1987) also conducted baking tests on heat treated wheat and found that temperatures of 60°C and 80°C for 3 hours produced loaves of less than 50% volume of the controls.

The effect of packaging gas on loaf volume was slight but significant. The average loaf volume from wheat packaged under the three gases differed by only 41 ml. The loaf volume of the wheat packaged under air averaged 1271 ml ± 40 ml, which was significantly greater than the average loaf volume of carbon dioxide, 1230 ml ± 49 ml. The nitrogen packaged wheat averaged 1250 ml ± 43 ml, which was not significantly different from the results of either of the other two gases. The effects of each packaging gas versus temperature and time are shown in Figures 3, 4 and 5 for comparison. From these graphs it can be seen that for carbon dioxide at 18 months and 21°C, wheat gave loaves lower in volume than loaves at 37°C for air or nitrogen. While the above results are significant, only slight overall differences between loaf volumes of the

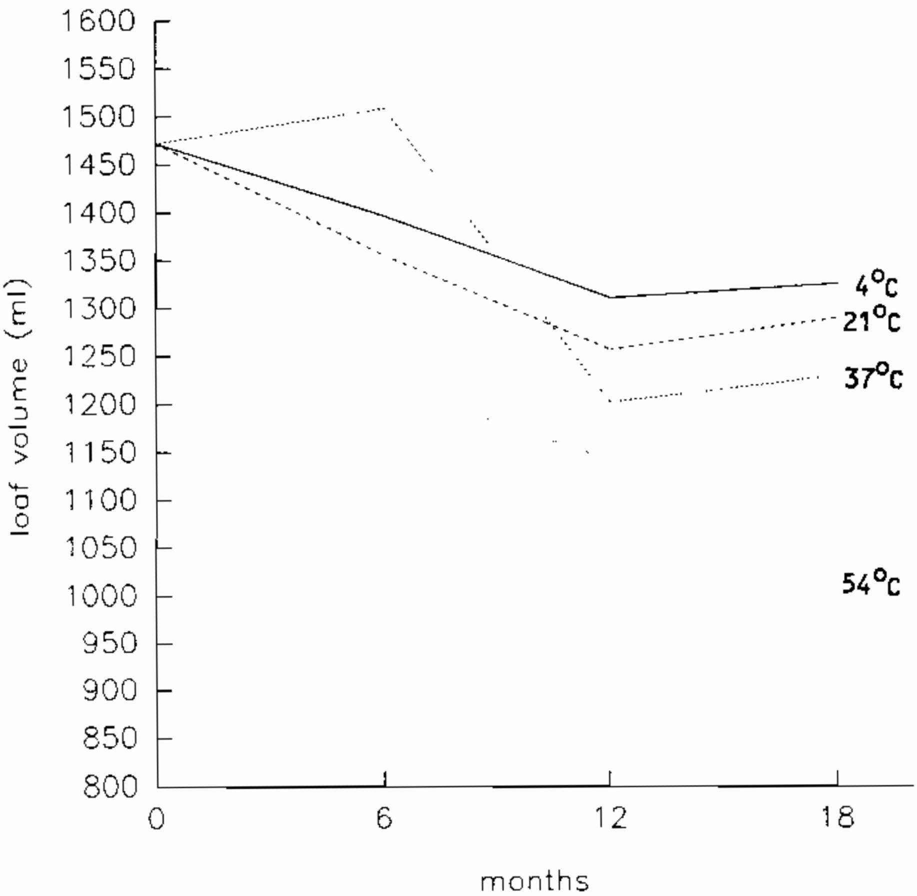

Figure 3: The effect of storage temperature and time on loaf volume of wheat packaged with air (SEM = 20.65).

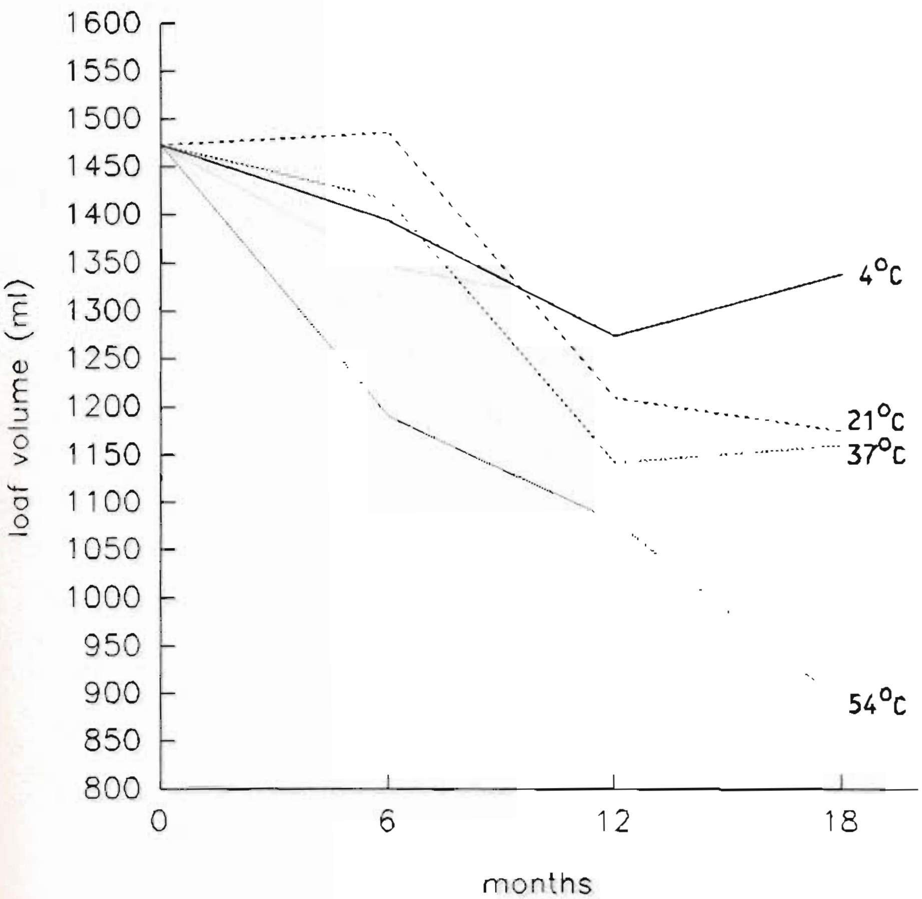

Figure 4: **The effect of storage temperature and time on loaf volume of wheat packaged with carbon dioxide (SEM = 24.85).**

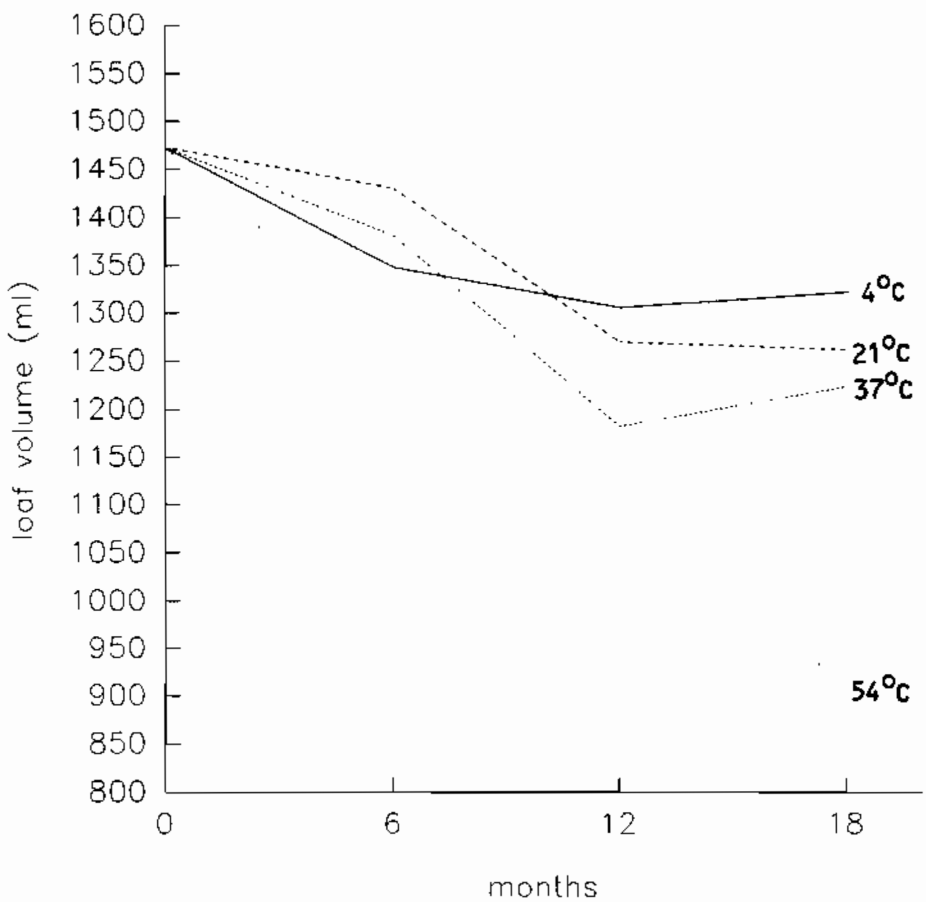

Figure 5: The effect of storage temperature and time on loaf volume of wheat packaged with nitrogen (SEM = 21.91).

packaging gases exist as shown by overlapping confidence intervals for air and carbon dioxide. With additional storage, the effects of packaging gases may become more pronounced.

Protein Solubility Test

An analysis of variance on the results from the protein solubility test (PST) showed that, like the other tests, there was a significant interaction between temperature and time. Additionally, significant differences were shown between varieties and between packaging gases.

Temperature and time effects on protein solubility are shown in Figure 6. The PST for the 4°C wheat showed that absorbance at 6 months was significantly greater than at 12 and 18 months. The increase in absorbance at 6 months over the control absorbance at 0 months cannot be explained except for by experimental error. The PST requires exact methodology to get good results and this probably accounts for the variation in results. There were no significant differences in absorbance during 18 months of storage at 21°C. The 6 month absorbance at 21°C was significantly lower than that at 37°C. At 37°C, there were significant differences in absorbance at each time period. The average absorbance at 6 months, 0.532 ± 0.014, was significantly greater than that at 12 months, 0.482 ± 0.018. Similarly, the average absorbance at 12 months was significantly greater than that at 18 months, 0.445 ± 0.012. The 6 and 12 month absorbances at 54°C,

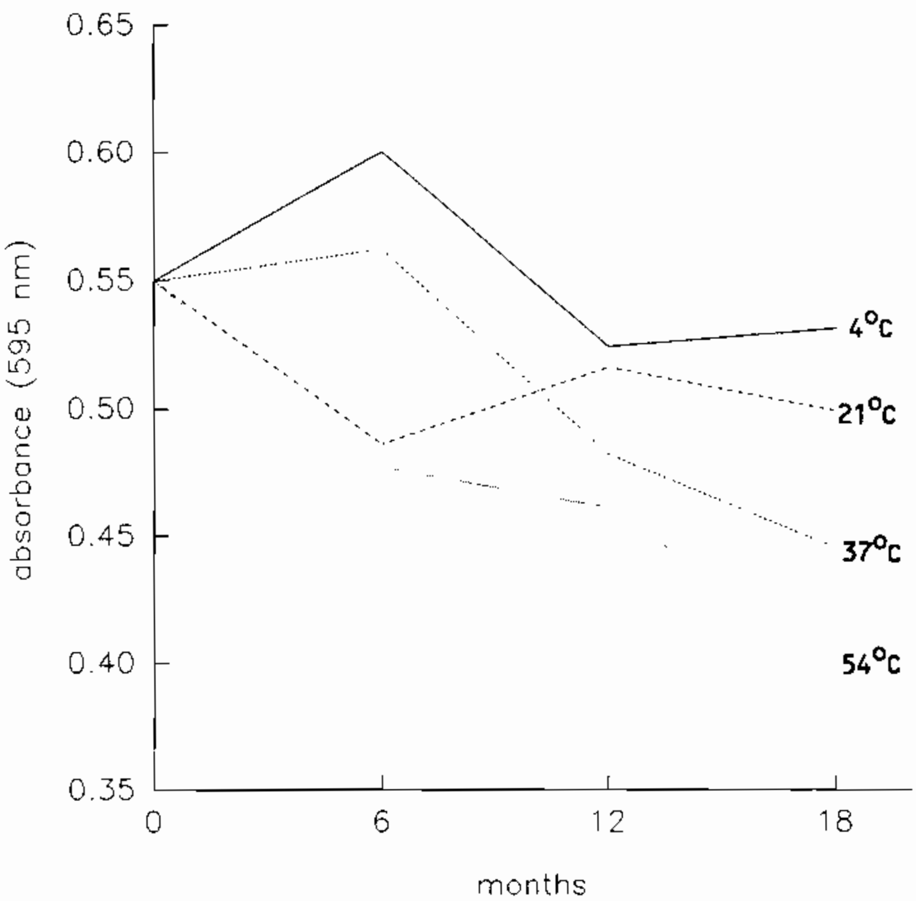

Figure 6: The effect of storage temperature and time on protein solubility of wheat (SEM = 0.0069).

0.447 ± 0.011 and 0.461 ± 0.032, were not significantly different from each other. They both were significantly greater than the 18 month absorbance, 0.400 ± 0.014. At 12 and 18 months of storage, significant decreases in absorbance were seen with each sequential increase in storage temperature. From this, it is evident that there is a significant trend for decreased absorbance at higher temperatures. This indicates protein degradation is occurring and concurs with decreasing germination and lower loaf volumes under the same conditions.

These results concur with the findings of Every (1987) who showed heat damaged wheat exhibited decreased absorbance with the PST. Three hours at 60°C and 80°C showed decreased absorbances of 0.286 and 0.145, respectively, from the control absorbance of 0.349. These values are lower than those of the current study but Every used more severe heat treatments and different varieties of wheat.

Freemont and Ute varieties of wheat had initial average absorbances of 0.481 ± 0.010 and 0.513 ± 0.011 respectively. The Ute variety had significant and consistent higher absorbances than the Freemont variety due to initially higher levels of soluble protein in the Ute variety.

There were also significant differences in protein absorbance among the packaging gases. Wheat packaged in nitrogen had a significantly higher average absorbance, 0.516 ± 0.012, than wheat packaged in carbon dioxide, 0.494 ± 0.014, or air, 0.480 ± 0.014. There was no significant difference in average absorbance between the carbon dioxide and air packaged wheat. Nitrogen, the most inert gas, had the mildest effect on protein solubility. The absorbance values of the three packaging gases, however, are within 0.036 of each other so further study is needed before decisive conclusions are made about these effects.

Conclusion

In summary, the percent oxygen test showed that time, temperature and packaging gas all played a role in the oxygen content of the wheat cans. This interaction was most pronounced for the wheat sealed under air. The germination, baking and protein solubility tests showed that temperature significantly affects wheat quality as a function of time. At higher storage temperatures, wheat suffers increasing degradation over shorter periods of time. This was especially pronounced at 54°C. Eventually, wheat is neither able to germinate nor to produce bread that is acceptable. The germination test showed that the wheat varieties responded differently to each packaging gas. The Freemont variety responded best to air and nitrogen packaging while the Ute variety responded best to nitrogen and carbon dioxide packaging. The baking test showed that varieties responded differently over time and that wheat packaged under air produced significantly larger loaf volumes than wheat packaged under carbon dioxide. The PST showed the Ute variety and packaging under nitrogen had the highest average absorbances. In all three tests, the differences between packaging gases were small but significant. Within 18 months of storage, a single packaging gas did not stand out as the best so no conclusions on packaging gas could be made. Differences due to packaging gases may become more significant during the three and a half years left in this study.

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Appendix

Wheat Data Summary Sheet - Percent Oxygen - 6 months

code	$\%O_2$	ave	code	$\%O_2$	ave
FA 4-6	17.0%	17.0%	UA 4-6	17.1%	17.1%
	--[a]			--[a]	
FN 4-6	5.9%	5.9%	UN 4-6	4.6%	4.4%
	--[a]			4.1%	
FA 21-6	15.9%	14.4%	UA 21-6	15.2%	14.4%
	12.8%			13.6%	
FN 21-6	5.1%	4.2%	UN 21-6	4.3%	3.9%
	3.3%			3.5%	
FA 37-6	11.8%	14.2%	UA 37-6	10.6%	10.4%
	16.5%			10.2%	
FN 37-6	5.7%	5.2%	UN 37-6	4.1%	4.3%
	4.6%			4.4%	
FA 54-6	8.5%	9.1%	UA 54-6	9.1%	8.8%
	9.7%			8.4%	
FN 54-6	5.6%	5.8%	UN 54-6	5.6%	5.4%
	5.9%			5.1%	

a - these cans were opened improperly so the percent oxygen could not be measured.

note: the percent oxygen readings from the carbon dioxide cans were inaccurate and are not reported. See text for details.

---

code:

F - Freemont
A - air
N - nitrogen
U - Ute
C - carbon dioxide

the numbers signify temperature and time
i.e. 4-6 = 4°C - 6 months

Wheat Data Summary Sheet - Percent Oxygen - 12 months

code	%O_2	ave	code	%O_2	ave
FA 4-12	16.2%	17.4%	UA 4-12	16.4%	17.1%
	18.6%			17.8%	
FN 4-12	2.9%	4.1%	UN 4-12	3.5%	4.0%
	5.2%			4.4%	
FA 21-12	14.0%	14.0%	UA 21-12	13.1%	13.0%
	14.0%			12.8%	
FN 21-12	4.1%	4.0%	UN 21-12	5.4%	5.1%
	3.9%			4.7%	
FA 37-12	7.5%	6.5%	UA 37-12	7.8%	7.1%
	5.5%			6.3%	
FN 37-12	4.3%	3.5%	UN 37-12	2.8%	2.8%
	2.6%			2.8%	
FA 54-12	7.9%	7.3%	UA 54-12	6.9%	5.3%
	6.6%			3.7%	
FN 54-12	4.3%	4.7%	UN 54-12	4.1%	4.1%
	5.1%			4.0%	

note: the percent oxygen readings from the carbon dioxide cans were inaccurate and are not reported. See text for details.

---

code:

F - Freemont
A - air
N - nitrogen
U - Ute
C - carbon dioxide

the numbers signify temperature and time
i.e. 4-12 = 4°C - 12 months

Wheat Data Summary Sheet - Percent Oxygen - 18 months

code	$\%O_2$	ave	code	$\%O_2$	ave
FA 4-18	18.0%	17.6%	UA 4-18	18.0%	17.7%
	17.2%			17.3%	
FN 4-18	4.6%	4.0%	UN 4-18	4.6%	4.7%
	3.4%			4.8%	
FA 21-18	12.5%	11.9%	UA 21-18	11.5%	10.9%
	11.2%			10.3%	
FN 21-18	4.0%	3.3%	UN 21-18	3.1%	3.4%
	2.7%			3.7%	
FA 37-18	5.7%	5.4%	UA 37-18	5.4%	5.0%
	5.0%			4.7%	
FN 37-18	2.9%	2.8%	UN 37-18	2.9%	2.8%
	2.7%			2.6%	
FA 54-18	4.0%	3.6%	UA 54-18	3.9%	3.7%
	3.2%			3.5%	
FN 54-18	3.2%	3.0%	UN 54-18	2.8%	2.6%
	2.8%			2.4%	

note: the percent oxygen readings from the carbon dioxide cans were inaccurate and are not reported. See text for details.

---

code:

F - Freemont
A - air
N - nitrogen
U - Ute
C - carbon dioxide

the numbers signify temperature and time
i.e. 4-18 = 4°C - 18 months

Wheat Data Summary Sheet - Germination Test - control

code	%germ	ave	code	%germ	ave
Fre ctrl	98%	96%	Ute ctrl	95%	94%
	94%			93%	

Wheat Data Summary Sheet - Germination Test - 6 months

code	%germ	ave	code	%germ	ave
FA 4-6	94%	93.5%	UA 4-6	95%	91.5%
	93%			88%	
FC 4-6	89%	90%	UC 4-6	93%	93.5%
	91%			94%	
FN 4-6	92%	91%	UN 4-6	90%	92.5%
	90%			95%	
FA 21-6	96%	94.5%	UA 21-6	97%	94.5%
	93%			92%	
FC 21-6	94%	92.5%	UC 21-6	95%	94.5%
	91%			94%	
FN 21-6	94%	94%	UN 21-6	96%	96%
	94%			96%	
FA 37-6	86%	88%	UA 37-6	81%	83%
	90%			85%	
FC 37-6	88%	88.5%	UC 37-6	92%	94.5%
	89%			97%	
FN 37-6	97%	91%	UN 37-6	87%	92%
	85%			97%	
FA 54-6	83%	78.5%	UA 54-6	50%	55%
	74%			60%	
FC 54-6	41%	56.5%	UC 54-6	79%	77%
	72%			75%	
FN 54-6	82%	77.5%	UN 54-6	87%	81.5%
	73%			76%	

---

code:

F - Freemont
A - air
N - nitrogen
U - Ute
C - carbon dioxide

the numbers signify temperature and time
i.e. 4-6 = 4°C - 6 months

Wheat Data Summary Sheet - Germination Test - 12 months

code	%germ	ave	code	%germ	ave
FA 4-12	92%	93.5%	UA 4-12	91%	89.5%
	95%			88%	
FC 4-12	91%	89%	UC 4-12	85%	87%
	87%			89%	
FN 4-12	92%	89.5%	UN 4-12	89%	85.5%
	87%			82%	
FA 21-12	89%	93.5%	UA 21-12	95%	94.5%
	98%			94%	
FC 21-12	92%	91%	UC 21-12	93%	92.5%
	90%			92%	
FN 21-12	91%	92%	UN 21-12	93%	94%
	93%			95%	
FA 37-12	84%	89%	UA 37-12	78%	81.5%
	94%			85%	
FC 37-12	49%	68%	UC 37-12	70%	80.5%
	87%			91%	
FN 37-12	79%	85%	UN 37-12	81%	82%
	91%			83%	
FA 54-12	13%	6.5%	UA 54-12	8%	4%
	0%			0%	
FC 54-12	0%	0%	UC 54-12	23%	13%
	0%			3%	
FN 54-12	9%	9.5%	UN 54-12	45%	34.5%
	10%			24%	

---

code:

F - Freemont
A - air
N - nitrogen

U - Ute
C - carbon dioxide

the numbers signify temperature and time
i.e. 4-12 = 4°C - 12 months

Wheat Data Summary Sheet - Germination Test - 18 months

code	%germ	ave	code	%germ	ave
FA 4-18	91%	90.5%	UA 4-18	91%	89.5%
	90%			88%	
FC 4-18	86%	84.5%	UC 4-18	92%	89.5%
	83%			87%	
FN 4-18	84%	86%	UN 4-18	93%	92.5%
	88%			92%	
FA 21-18	97%	93.5%	UA 21-18	98%	96%
	90%			94%	
FC 21-18	90%	92.5%	UC 21-18	94%	91%
	95%			88%	
FN 21-18	95%	95.5%	UN 21-18	95%	94%
	96%			93%	
FA 37-18	87%	80%	UA 37-18	74%	78.5%
	73%			83%	
FC 37-18	63%	65.5%	UC 37-18	82%	86%
	68%			90%	
FN 37-18	75%	78.5%	UN 37-18	87%	91%
	82%			95%	
FA 54-18	0%	0%	UA 54-18	0%	0%
	0%			0%	
FC 54-18	0%	0%	UC 54-18	0%	0%
	0%			0%	
FN 54-18	0%	0%	UN 54-18	0%	0%
	0%			0%	

---

code:

- F - Freemont
- A - air
- N - nitrogen
- U - Ute
- C - carbon dioxide

the numbers signify temperature and time
i.e. 4-18 = 4°C - 18 months

Wheat Data Summary Sheet - Baking Test - control

code	volume	ave	code	volume	ave
Fre ctrl	1450 ml	1465 ml	Ute ctrl	1490 ml	1480 ml
	1480 ml			1470 ml	

Wheat Data Summary Sheet - Baking Test - 6 months

code	volume	ave	code	volume	ave
FA 4-6	1285 ml	1323 ml	UA 4-6	1540 ml	1470 ml
	1360 ml			1400 ml	
FC 4-6	1290 ml	1313 ml	UC 4-6	1540 ml	1475 ml
	1335 ml			1410 ml	
FN 4-6	1250 ml	1320 ml	UN 4-6	1360 ml	1375 ml
	1390 ml			1390 ml	
FA 21-6	1500 ml	1410 ml	UA 21-6	1300 ml	1300 ml
	1320 ml			1300 ml	
FC 21-6	1560 ml	1460 ml	UC 21-6	1560 ml	1510 ml
	1360 ml			1460 ml	
FN 21-6	1590 ml	1480 ml	UN 21-6	1440 ml	1380 ml
	1370 ml			1320 ml	
FA 37-6	1460 ml	1450 ml	UA 37-6	1495 ml	1565 ml
	1440 ml			1635 ml	
FC 37-6	1500 ml	1365 ml	UC 37-6	1450 ml	1465 ml
	1230 ml			1480 ml	
FN 37-6	1460 ml	1400 ml	UN 37-6	1495 ml	1363 ml
	1340 ml			1230 ml	
FA 54-6	1130 ml	1105 ml	UA 54-6	1315 ml	1338 ml
	1080 ml			1360 ml	
FC 54-6	1175 ml	1198 ml	UC 54-6	1135 ml	1183 ml
	1220 ml			1230 ml	
FN 54-6	1120 ml	1175 ml	UN 54-6	1340 ml	1370 ml
	1230 ml			1400 ml	

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code:

F - Freemont
A - air
N - nitrogen
U - Ute
C - carbon dioxide

the numbers signify temperature and time
i.e. 4-6 = 4°C - 6 months

Wheat Data Summary Sheet - Baking Test - 12 months

code	volume	ave	code	volume	ave
FA 4-12	1355 ml	1333 ml	UA 4-12	1340 ml	1286 ml
	1310 ml			1235 ml	
FC 4-12	1300 ml	1290 ml	UC 4-12	1305 ml	1258 ml
	1280 ml			1210 ml	
FN 4-12	1285 ml	1373 ml	UN 4-12	1275 ml	1238 ml
	1460 ml			1200 ml	
FA 21-12	1270 ml	1258 ml	UA 21-12	1315 ml	1255 ml
	1245 ml			1195 ml	
FC 21-12	1260 ml	1268 ml	UC 21-12	1125 ml	1150 ml
	1275 ml			1175 ml	
FN 21-12	1280 ml	1270 ml	UN 21-12	1240 ml	1268 ml
	1260 ml			1295 ml	
FA 37-12	1300 ml	1245 ml	UA 37-12	1115 ml	1158 ml
	1190 ml			1200 ml	
FC 37-12	1265 ml	1220 ml	UC 37-12	1000 ml	1065 ml
	1175 ml			1130 ml	
FN 37-12	1125 ml	1175 ml	UN 37-12	1150 ml	1190 ml
	1225 ml			1230 ml	
FA 54-12	1310 ml	1220 ml	UA 54-12	1025 ml	1063 ml
	1130 ml			1100 ml	
FC 54-12	1075 ml	1108 ml	UC 54-12	1040 ml	1053 ml
	1140 ml			1065 ml	
FN 54-12	1105 ml	1140 ml	UN 54-12	1010 ml	1060 ml
	1175 ml			1110 ml	

---

code:

F - Freemont
A - air
N - nitrogen

U - Ute
C - carbon dioxide

the numbers signify temperature and time
i.e. 4-12 = 4°C - 12 months

Wheat Data Summary Sheet - Baking Test - 18 months

code	volume	ave	code	volume	ave
FA 4-18	1285 ml	1340 ml	UA 4-12	1395 ml	1310 ml
	1395 ml			1225 ml	
FC 4-18	1325 ml	1343 ml	UC 4-18	1315 ml	1335 ml
	1360 ml			1355 ml	
FN 4-18	1350 ml	1355 ml	UN 4-18	1245 ml	1288 ml
	1360 ml			1330 ml	
FA 21-18	1315 ml	1303 ml	UA 21-18	1240 ml	1275 ml
	1290 ml			1310 ml	
FC 21-18	1185 ml	1190 ml	UC 21-18	1100 ml	1160 ml
	1195 ml			1220 ml	
FN 21-18	1250 ml	1255 ml	UN 21-18	1175 ml	1277 ml
	1260 ml			1360 ml	
FA 37-18	1200 ml	1233 ml	UA 37-18	1230 ml	1225 ml
	1265 ml			1220 ml	
FC 37-18	1170 ml	1200 ml	UC 37-18	1140 ml	1120 ml
	1230 ml			1100 ml	
FN 37-18	1235 ml	1238 ml	UN 37-18	1260 ml	1210 ml
	1240 ml			1160 ml	
FA 54-18	960 ml	1025 ml	UA 54-18	950 ml	1005 ml
	1090 ml			1060 ml	
FC 54-18	820 ml	875 ml	UC 54-18	990 ml	910 ml
	930 ml			830 ml	
FN 54-18	900 ml	910 ml	UN 54-18	920 ml	910 ml
	920 ml			900 ml	

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code:

F - Freemont

A - air

N - nitrogen

U - Ute

C - carbon dioxide

the numbers signify temperature and time
i.e. 4-18 = 4°C - 18 months

Wheat Data Summary Sheet - Protein Solubility - control

code	abs.	ave	code	abs.	ave
Fre ctrl	0.469	0.503	Ute ctrl	0.593	0.597
	0.521			0.617	
	0.518			0.582	

Wheat Data Summary Sheet - Protein Solubility - 6 months

code	abs.	ave	code	abs.	ave
FA 4-6	0.521	0.544	UA 4-6	0.631	0.628
	0.558			0.624	
	0.554			0.628	
FC 4-6	0.551	0.544	UC 4-6	0.648	0.648
	0.512			0.653	
	0.569			0.642	
FN 4-6	0.602	0.620	UN 4-6	0.612	0.614
	0.625			0.613	
	0.632			0.618	
FA 21-6	0.432	0.470	UA 21-6	0.537	0.526
	0.486			0.521	
	0.493			0.520	
FC 21-6	0.509	0.505	UC 21-6	0.479	0.459
	0.515			0.445	
	0.491			0.453	
FN 21-6	0.473	0.477	UN 21-6	0.468	0.479
	0.488			0.479	
	0.469			0.489	
FA 37-6	0.488	0.499	UA 37-6	0.493	0.504
	0.505			0.511	
	0.503			0.507	
FC 37-6	0.561	0.570	UC 37-6	0.521	0.536
	0.559			0.541	
	0.590			0.545	
FN 37-6	0.491	0.523	UN 37-6	0.539	0.558
	0.539			0.575	
	0.538			0.561	
FA 54-6	0.455	0.446	UA 54-6	0.462	0.481
	0.461			0.483	
	0.423			0.497	
FC 54-6	0.451	0.460	UC 54-6	0.455	0.483
	0.478			0.508	
	0.450			0.485	
FN 54-6	0.448	0.487	UN 54-6	0.484	0.506
	0.501			0.513	
	0.511			0.522	

Wheat Data Summary Sheet - Protein Solubility - 12 months

code	abs.	ave	code	abs.	ave
FA 4-12	0.483	0.492	UA 4-12	0.555	0.527
	0.504			0.509	
	0.489			0.518	
FC 4-12	0.531	0.524	UC 4-12	0.518	0.530
	0.515			0.539	
	0.525			0.532	
FN 4-12	0.521	0.527	UN 4-12	0.531	0.546
	0.518			0.550	
	0.541			0.556	
FA 21-12	0.522	0.508	UA 21-12	0.535	0.518
	0.480			0.507	
	0.522			0.511	
FC 21-12	0.453	0.476	UC 21-12	0.495	0.497
	0.482			0.489	
	0.492			0.507	
FN 21-12	0.501	0.512	UN 21-12	0.570	0.588
	0.515			0.583	
	0.519			0.610	
FA 37-12	0.440	0.454	UA 37-12	0.430	0.439
	0.472			0.449	
	0.451			0.439	
FC 37-12	0.455	0.458	UC 37-12	0.493	0.509
	0.449			0.529	
	0.469			0.504	
FN 37-12	0.479	0.498	UN 37-12	0.513	0.534
	0.522			0.544	
	0.493			0.546	
FA 54-12	0.359	0.360	UA 54-12	0.502	0.509
	0.359			0.519	
	0.362			0.507	
FC 54-12	0.401	0.410	UC 54-12	0.514	0.507
	0.399			0.519	
	0.429			0.489	
FN 54-12	0.459	0.470	UN 54-12	0.499	0.514
	0.468			0.521	
	0.482			0.522	

Wheat Data Summary Sheet - Protein Solubility - 18 months

code	abs.	ave	code	abs.	ave
FA 4-18	0.481	0.486	UA 4-18	0.502	0.521
	0.498			0.512	
	0.480			0.550	
FC 4-18	0.488	0.504	UC 4-18	0.559	0.563
	0.493			0.576	
	0.530			0.553	
FN 4-18	0.512	0.538	UN 4-18	0.572	0.582
	0.539			0.586	
	0.562			0.587	
FA 21-18	0.452	0.465	UA 21-18	0.481	0.516
	0.450			0.542	
	0.493			0.524	
FC 21-18	0.481	0.493	UC 21-18	0.520	0.516
	0.495			0.519	
	0.502			0.508	
FN 21-18	0.472	0.445	UN 21-18	0.562	0.560
	0.468			0.578	
	0.395			0.539	
FA 37-18	0.421	0.439	UA 37-18	0.420	0.424
	0.435			0.411	
	0.462			0.440	
FC 37-18	0.432	0.443	UC 37-18	0.425	0.437
	0.456			0.441	
	0.441			0.444	
FN 37-18	0.463	0.471	UN 37-18	0.480	0.485
	0.460			0.478	
	0.489			0.498	
FA 54-18	0.372	0.394	UA 54-18	0.391	0.366
	0.412			0.332	
	0.398			0.375	
FC 54-18	0.345	0.384	UC 54-18	0.392	0.395
	0.398			0.409	
	0.409			0.383	
FN 54-18	0.391	0.406	UN 54-18	0.428	0.452
	0.439			0.441	
	0.389			0.487	

The Effects of Packaging Gas, Temperature and Storage Time on Germination, Loaf Volume and Protein Solubility of Wheat

Scott W. Myers

Department of Food Science and Nutrition

M. S. Degree, August 1991

ABSTRACT

Freemont and Ute wheat cultivars were stored for 18 months in cans under air, carbon dioxide or nitrogen at temperatures of 4°C, 21°C, 37°C or 54°C. Replicate cans were removed from storage at 6 month intervals and analyzed for percent oxygen, percent germination, loaf volume, and protein solubility.

After 18 months of storage, temperature had the greatest effect on wheat viability and quality. Storage at 37°C and 54°C, resulted in significant decreases in oxygen, germination, loaf volume and protein solubility. Effects at 21°C were not as severe, however, loaf volume and protein solubility were significantly reduced. Effects at 54°C differed significantly from those at 4°C after 6 months. After 12 months at 37°C and 18 months at 21°C significant differences were also found. The three packaging gases performed differently depending on the test involved. No packaging gas was the best among all of the tests.

COMMITTEE APPROVAL:

John Hal Johnson, Committee Chairman

H. Gill Hilton, Committee Member

Clayton S. Huber, Committee Member

Mark J. Rowe, Department Chairman