FUNCTIONALITY OF OAT-WHEAT COMPOSITE FLOURS IN SUGAR-SNAP COOKIES: EFFECT OF METHOD OF MILLING, PROCESSING, OAT CULTIVAR AND WHEAT CULTIVAR

Volume II

By

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A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Food Science and Human Nutrition

1993

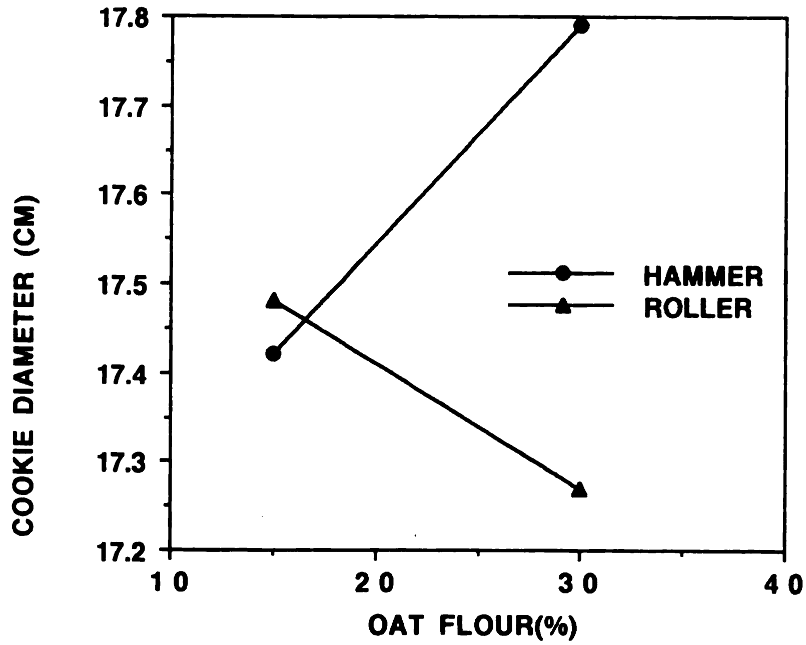
Effect of Milling on Cookie Quality

The effect of milling on cookie quality was determined by comparing cookies made from oat-wheat composite flours of Caldwell soft wheat flour combined with the hammer and roller milled flours of Mariner, Ogle and Porter groats. The composites contained oat flours substituted by weight at two levels (15 and 30 percent) for soft wheat flour. The analysis of variance model had three main effects; type of mill, oat cultivar and level of oat flour substitution. The ANOVA tables for the dependent variables; cookie diameter, surface color, protein content, ash content, lipid content, moisture retention, shear compression, breaking strength and alkaline water retention capacity of the composite flours are located in Appendix. The correlation matrices for the dependent variables by main effect are located in the Appendix. The Caldwell soft wheat cultivar was chosen for the milling study based on results of a preliminary study using commercial whole oat flour which is also provided in the Appendix.

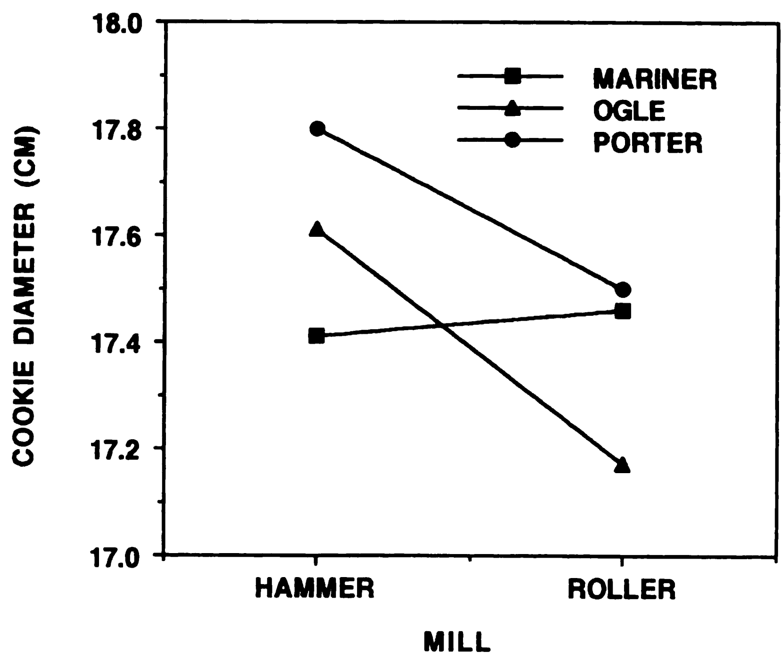
Cookie diameter and top grain scores:

Analysis of variance means for the main effect of mill was influenced by significant interactions of mill x level of oat flour and mill x oat cultivar. The interaction of mill x level was highly significant for sugar-snap cookie diameter as shown in Figure 27a and Table 103 The effect associated with substituting an additional 15 percent hammer milled groat flour to oat-wheat composite flours was an increase in cookie diameter. The opposite effect, a decrease in cookie diameter, was associated with roller milled groat flours.

Figure 27. Interactions for Cookie Diameter: a) Type of Mill x Level of Hammer and Roller Milled Groat Flour Substitution b) Oat Cultivar x Type of Mill



Mill X Level of Oat Flour Interaction for Cookie Diameter



Oat Cultivar x Mill Interaction For Cookie Diameter

The interaction of oat cultivar x mill was also significant for cookie diameter and is illustrated in Figure 27b. Roller milled groat flours of the Porter and Ogle cultivars produced cookies with smaller diameters than hammer milled groats flours of the same cultivar. Cookies prepared from Mariner roller milled groat flours had diameters equivalent to cookies prepared from hammer milled groat flours.

Fogg and Tinklin (1972) had reported cookie spread for cotton seed-wheat composite flours was dependent upon the interaction of particle size (fine vs coarse) and level of flour. Particle Size Index (PSI) values previously reported in Table 5 indicated the difference in relative flour particle size between hammer milled groat flours and roller milled groat flours of the Mariner and Ogle cultivars was similar. There was a greater difference between flour particle size of hammer milled groat flours and roller milled groat flours of the Porter cultivar. The interaction of mill x cultivar had not been significant for PSI of oat flours.

Table 32 contains the mean diameters of cookies prepared from composites of hammer and roller milled groat flours. The mean diameter of two sugar-snap cookies prepared with 100 percent Caldwell wheat flour was 17.05 cm. Cookies containing hammer milled groat flour composites had significantly larger diameters than cookies prepared with rolled milled groat flour composites.

In contrast, Oomah (1983) previously reported cookies made with hammer milled groat composite oat flours had a smaller cookie spread (width to thickness ratio) than cookies made with roller milled groat flour composites. Mailhot and Paton (1988) stated the desired width to thickness ratio for sugar snap cookies was from 8.0 to 9.5. In the Oomah study, only cookies containing 5% hammer milled groat flour and 25% roller milled groat flour had a width to thickness ratio of at least 8.0.

Table 32. Effect of milling: Means for diameters of cookies made with oat-wheat composite flours

Main Effect	Classes	n	Cookie diameter (cm)	Level of Significance
Mill Type	Hammer	12	17.61[a]	
	Roller	12	17.38[b]	0.01
Oat Cultivar	Mariner	8	17.44[ab]	
	Ogle	8	17.39[b]	
	Porter	8	17.65[a]	0.01
Oat Flour Percent	15	12	17.45[a]	
	30	12	17.53[a]	ns

Means in the same main effect having a different superscript are significantly different.

Oomah (1983) theorized that differences in cookie spread of sugar-snap cookies made with oat-wheat composite flours may have been due to differences in oat flour composition as well as viscosity differences observed during pasting. This study milled the three oat cultivars by both methods in an attempt to remove the effect of cultivar on the milling process. The lack of agreement with the published results may be due to the 1983 study utilizing a commercial hammer milled oat flour which can be a blend of oat cultivars and comparing it to a oat flour prepared by roller milling groats from a single cultivar.

The initial pasting temperature of roller milled groat flours was significantly lower than that of hammer milled groat flours used in this study. This result was previously shown in Table 6. The smaller diameter of sugar-snap cookies made with roller milled groat composite flours may have been partially due to an increase in viscosity at a lower temperature than in cookies made with hammer milled groat composite flours.

Table 32 shows there was a cultivar related difference in cookie diameter. Sugar-snap cookies made with composite flours of hammer and roller milled Porter oat flour had a significantly larger mean cookie diameter than cookies made with Ogle hammer and roller milled composite flours. Particle size index results and Hunter Color Difference values of the oat flours as shown in Table 5 had indicated that Ogle flours contained finer flour particles than flours ground from the other two oat cultivars. Flour particle size may have contributed to the smaller sugar-snap cookie diameter by providing an increased surface area for water absorption. However, the influence of viscosity during heating is not clear. Ogle hammer and roller milled oat flours had a significantly higher initial paste temperature than flours from the other two cultivars. Porter oat flours had an increase in viscosity at a lower temperature than Ogle oat flours yet cookies prepared with Porter hammer and roller milled groat composite flours apparently spread more during the baking process.

Proximate analysis of the Porter oat flours had determined that they contained a significantly higher percentage of fat than the other two oat cultivars. Flour lipids have been reported to influence sugar-snap cookie spread. Wheat flour lipids have been shown to increase cookie diameter (Cole et al, 1960; Kissel et al, 1971; Yamazaki and Donelson, 1976). Tsen et al (1973) found that full fat soy flour containing 22.2% crude lipid did not reduce cookie spread as much as defatted soy flours when wheat flour was fortified with soy flour at 8, 12, 16, 20, 24, 30, 40 and 50 percent.

Two levels of oat flour (15 and 30 percent) were blended with Caldwell soft wheat flour to produce composite flours. Sugar-snap cookies made with hammer milled oat-wheat composite flours had larger diameters as increasing amounts of oat flour was present in the composite flour. As increasing amounts of roller milled oat flours were added to the composite, the cookie diameters decreased. This was in agreement with the previously reported results by Oomah (1983) for cookies baked from roller milled groat flour composites. Sugar-snap cookies prepared with thirty percent oat-wheat composite flours had larger diameters than cookies made with 15 percent composite flours as shown in Table 32.

The results were opposite those found for composites using oat bran and soy products. Oat bran substituted at the 20% level in sugar snap cookies by Jeltema et al (1983) resulted in significantly reduced cookie spread when compared to the control. Tsen et al (1973) found that soy products (soy flour and soy protein isolates) progressively reduced sugar-snap cookie spread as more soy product was blended into soft wheat flour.

The mean diameters and top grain scores of cookies made with hammer milled and roller milled flours are given in Table 33. The top grain scores of cookies made with hammer milled groat flours were higher than scores for cookies made with roller milled groat flours. Cookies made with 100 percent soft wheat flour fail to develop the desired top grain if cookie spread or diameter is restricted. McWatters (1978) reported cookies of soybean flour with restricted cookie spread did not develop the typical top grain. When comparing cookies made with hammer milled groat flour to cookies made with roller milled groat flour, top grain development may have been a function of cookie diameter and particle size related properties.

Alkaline water retention capacity:

Analysis of variance means were influenced by the significant interaction of mill x cultivar for alkaline water retention capacity (AWRC) as shown in Figure 28 and Table 104. There was a smaller difference in AWRC between hammer milled groat composite flours and roller milled groat composite flours of the Mariner cultivar than between the composite flours of the two other cultivars.

Hammer milled oat-wheat composite flours had a significantly lower alkaline water retention capacity (AWRC) than composite flours made with rolled milled oat flours as shown in Table 34. Particle Size Index and Hunter Color Difference L-values had indicated roller milled groat flours contained smaller flour particles than hammer milled groat flours. This result for AWRC agreed with previous reports that decreased particle size was

Table 33 Means and standard deviations of cookie diameter and top grain scores of cookies measuring the effect of milling on cookie quality.

Oat-wheat composite flour	Oat flour (%)	Cookie diameter[1] (cm)	Top Grain Score[2]
Hammer milled			
Mariner-Caldwell	30	17.68 ± 0.26	8.7
	15	17.14 ± 0.03	8.0
Ogle-Caldwell	30	17.81 ± 0.01	8.5
	15	17.41 ± 0.05	8.3
Porter-Caldwell	30	17.88 ± 0.05	9.0
	15	17.72 ± 0.18	8.2
Roller milled			
Mariner-Caldwell	30	17.33 ± 0.02	6.5
	15	17.58 ± 0.05	7.5
Ogle-Caldwell	30	17.13 ± 0.19	7.0
	15	17.21 ± 0.15	6.0
Porter-Caldwell	30	17.35 ± 0.07	6.0
	15	17.64 ± 0.03	7.0
Caldwell	0	17.05 ± 0.42	7.0

[1] n= 2

[2] n= 6

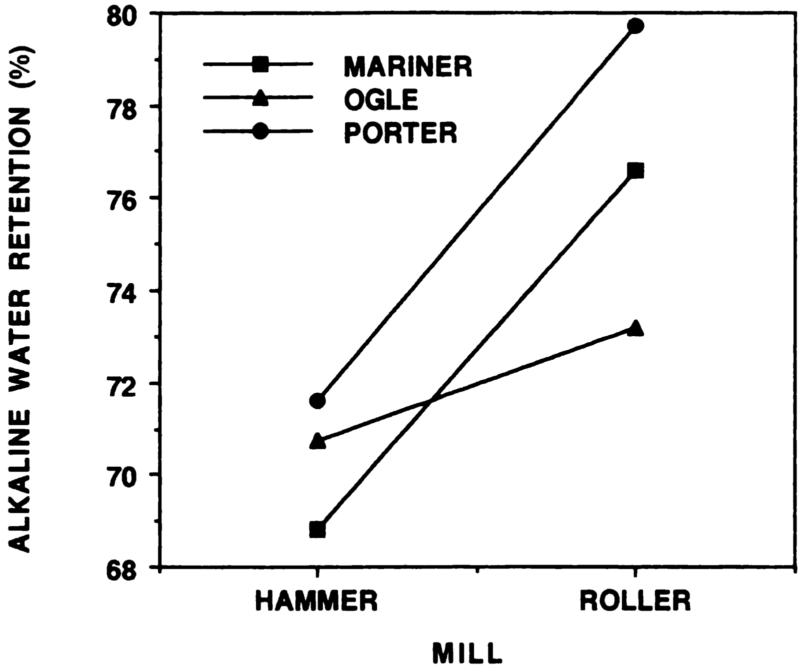


Figure 28. Interaction of Oat Cultivar x Type of Mill for Alkaline Water Retention Capacity of Hammer and Roller Milled Groat Composite Flours

thought to contribute to increased water retention in rice flours (Nishita and Bean, 1982) and in wheat flours (Scalon et al, 1988). Kurimoto and Shelton (1988) suggested that water may penetrate into the core of a finer flour particle faster than a larger sized flour particle and result in a more uniform gel.

Table 34. Effect of milling: Means for alkaline water retention capacity of oat-wheat composite flours

Main Effect	Classes	n	Alkaline water retention[1] (%)	Level of Significance
Mill Type	Hammer	12	70.38[b]	
	Roller	12	76.50[a]	0.01
Oat Cultivar	Mariner	8	72.71[b]	
	Ogle	8	71.95[b]	
	Porter	8	75.66[a]	0.05
Oat Flour Percent	15	12	67.58[b]	
	30	12	79.30[a]	0.01

[1] 14% moisture basis
Means in the same main effect having a different superscript are significantly different.

The alkaline water retention capacity of soft wheat flours is highly negatively correlated to cookie diameter without needing to correct for protein and ash content (Yamazaki, 1953). The Pearson correlation coefficient between alkaline water retention capacity and diameter of cookies made with hammer milled groat composite flours was positive and highly significant ($r = 0.77$, $p<0.003$). The correlation between alkaline water retention capacity and cookie diameter for cookies made with roller milled groat composite flours was negative and not statistically significant ($r= -0.27$, $p<0.39$).

The Oomah study (1983) used centrifuge water retention which does not use water that has been pH adjusted to match the conditions during the cookie mixing process. Centrifuge water retention results were that increasing the proportion of oat flour decreased the water absorption of the resulting composite. The alkaline water retention results in the current study were that increasing the proportion of oat flour increased the water absorption of the resulting composite flour. The importance of pH in measuring water absorption properties of oat-wheat composite flours has not been reported in the literature.

The ability of commercially hammer milled oat flour to entrap larger amounts of water than roller milled oat flour was theorized by Oomah (1983) to be partially due to steam heat treatment during manufacturing of the commercial oat flour product. All groats in this study that were subsequently milled had been subjected to the identical steam heat treatment during the oat lipase inactivation process. Hammer milling has been documented (Nishita and Bean, 1982; Haque, 1991) as generating a larger amount of heat than roller milling. The hammer milled groat flours in this study contained a significantly lower moisture content than their roller milled counterparts. If heat was a major factor in determining the ability of composite flours to entrap water, the hammer milled groat flours had been exposed to a greater amount of heat than the roller milled groat flours.

There was a significant difference in alkaline water retention capacity at the $p<0.05$ level when comparing hammer and roller milled Porter groat composite flours to the other two composite flours as seen in Table 34. The Porter oat flours had been determined to contain a significantly higher percentage of total dietary fiber and β-glucan than the two other oat cultivars. The presence of a higher percentage of total dietary fiber probably contributed to the ability of the Porter hammer and roller milled groat composite flours to entrap water in a gel structure.

The correlations between cookie diameter and AWRC of the composite flours by oat cultivar were relatively small and statistically not significant. The correlations between cookie diameter and AWRC for Mariner, Ogle and Porter composite cookies were respectively; $r= 0.27$ ($p<0.51$), $r=0.06$ ($p<0.87$), $r=-0.57$ ($p<0.13$).

While there was no significant difference in cookie diameter, the alkaline water retention capacity of 15 and 30 percent composite flours was significantly different at the $p<0.01$ level. Therefore, the correlations between cookie diameter and AWRC by level of oat flour was small and statistically not significant. The correlation between cookie diameter and alkaline water retention capacity at the 15 percent substitution level was ($r=0.35$, $p< 0.25$) while the correlation for the 30 percent substitution level was ($r=-0.45$, $p<0.13$).

Thirty percent oat-wheat composite flours required less water addition to produce a desirable dough consistency than 15 percent oat-wheat composite flours. The lower level of water addition required by oat-wheat composite dough is the opposite of water addition requirements for defatted soybean flours. (McWatters, 1978) reported that addition of soybean flour increased the amount of water required to produce a desirable dough consistency.

Table 35 contains the mean and standard deviations of alkaline water retention capacities of the composite flours. Oat-wheat composite flours of roller milled oat flours consistently had larger alkaline water retention capacities than their hammer milled counterparts. The roller milled oat wheat composites also had the largest standard deviations for AWRC.

Cookie surface color:

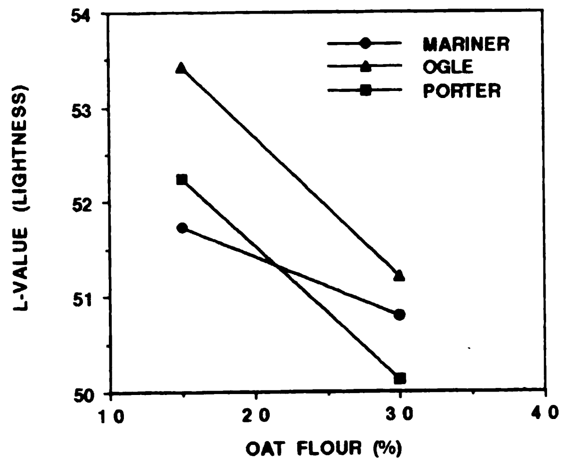
Analysis of variance means for Hunter Color Difference L-value, a-value and b-value were influenced by significant interactions for cultivar x level of oat flour as seen in Tables 105, 106 and 107. Figures 29a-c illustrate the interactions for the color parameters of the cookies. Substitution of 30 percent Mariner hammer milled groat and roller milled groat flour did not decrease L-values for cookie surface color as much as substitution of 30 percent Porter and Ogle groat flours. Figure C29b shows that substitution of 30 percent Porter hammer and roller milled groat flour had no effect on a-values (redness) for cookie surface color. The same level of substitution of Mariner flours in sugar-snap cookies decreased a-values while substitution of Ogle flours increased a-values or redness. Figure 29c shows that the difference in b-values (yellowness) among cookies made with 15 percent

Table 35. Means and standard deviations of alkaline water retention capacity measuring the effect of milling on cookie quality.

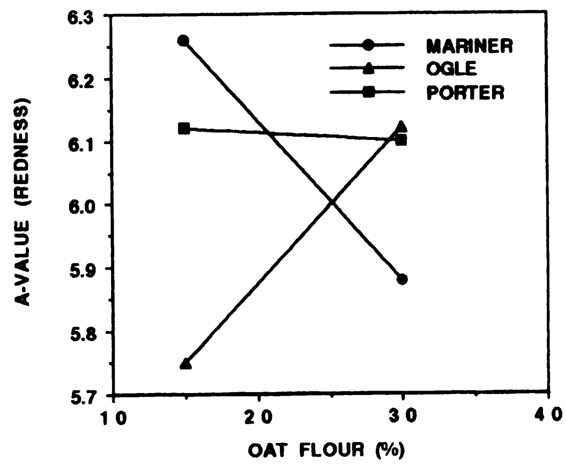
Oat-wheat composite flour	Oat flour (%)	Alkaline Water Retention[1] (%)
Hammer milled		
Mariner-Caldwell	30	74.58 ± 0.71
	15	63.05 ± 1.17
Ogle-Caldwell	30	75.98 ± 0.25
	15	65.46 ± 0.87
Porter-Caldwell	30	77.08 ± 0.18
	15	66.15 ± 0.77
Roller milled		
Mariner-Caldwell	30	83.06 ± 2.00
	15	70.12 ± 2.07
Ogle-Caldwell	30	77.01 ± 1.83
	15	69.35 ± 2.86
Porter-Caldwell	30	88.08 ± 3.94
	15	71.34 ± 2.62
Caldwell	0	58.81 ± 1.05

[1] n= 3 14% moisture basis

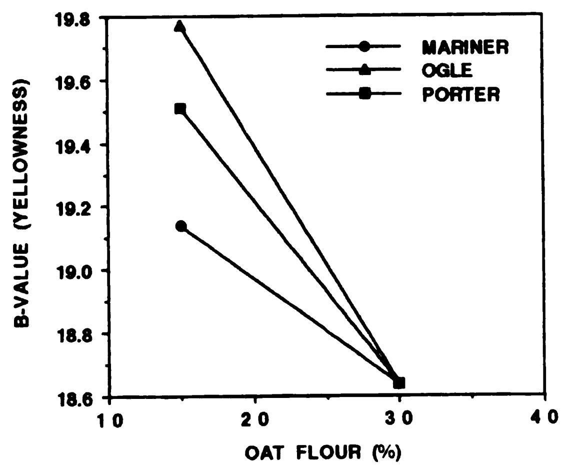
Figure 29. Interaction of Oat Cultivar x Level of Hammer and Roller Milled Groat Flour Substitution for Hunter Color Difference Values of Cookie Surface Color



Oat Cultivar x Level of Oat Flour Interaction for Cookie L-value



Oat Cultivar x Level of Oat Flour Interaction for Cookie a-value



Oat Cultivar x Level of Oat Flour Interaction for Cookie b-value hammer and roller milled groat flours did not exist at the 30 percent substitution level.

Table 36 contains the mean Hunter color difference L-values for cookies prepared from composites of hammer and roller milled groat flours. Analysis of variance results indicated a significant difference at the $p < 0.05$ level in the L-values (lightness vs darkness) of sugar-snap cookies prepared with composite flours containing hammer milled groat flours when compared to cookies prepared with roller milled groat flours.

Table 36. Effect of milling: Means for Hunter Color Difference L-values of cookies made with oat-wheat composite flours

Main Effect	Classes	n	L-value[1]	Level of Significance
Mill Type	Hammer	12	52.08[a]	
	Roller	12	51.27[b]	0.05
Oat Cultivar	Mariner	8	51.52[ab]	
	Ogle	8	52.33[a]	
	Porter	8	51.19[b]	0.05
Oat Flour Percent	15	12	52.47[a]	
	30	12	50.88[b]	0.01

[1] L values = 0 (black) to 100 (white)
Means in the same main effect having a different superscript are significantly different.

There was a significant difference at the $p<0.05$ level in the Hunter Color Difference L-value for sugar snap cookies prepared with the three different oat cultivar hammer and roller milled composite flours as shown in Table 36. Cookies prepared with composites of Ogle hammer and roller milled groat flour had higher L-values than cookies from other oat-wheat composite flours. There was a significant difference between the L-values of Ogle and Porter cookies but not Ogle and Mariner cookies. Analysis of variance indicated that the L-values (darkness to lightness) of cookies significantly decreased as more oat flour was blended into the composite flours.

Mean a-values for cookie surfaces are contained in Table 37. There was a significant difference in the a-value (redness) of the two types of cookies. The baked cookies prepared from roller milled flours had a stronger reddish hue than cookies prepared with hammer milled oat flours. There was no statistically significant difference between the a-values of sugar snap cookies prepared with composites of the three oat cultivars as seen in Table 37. However, cookies prepared from Porter hammer and roller milled groat composite flours were measured as having a more reddish hue than the other cookies.

Table 38 shows there was no significant difference in b-values (yellowness) of sugar-snap cookies prepared with hammer milled groat flours compared to those made with roller milled groat flours. Ogle cookies were measured as having a more yellow hue than cookies baked from composites containing the other two oat cultivars. Kissel et al (1971) had reported that an increase in wheat flour lipids produced a more intense yellow hue in sugar snap cookies made from soft wheat. There have been no published reports of the influence of oat flour lipids on sugar-snap cookie color.

Table 37. Effect of milling: Means for Hunter Color Difference a-values of cookies made with oat-wheat composite flours

Main Effect	Classes	n	a-value[1]	Level of Significance
Mill Type	Hammer	12	5.63^{b}	
	Roller	12	6.40^{a}	0.01
Oat Cultivar	Mariner	8	5.99^{a}	
	Ogle	8	5.94^{a}	
	Porter	8	6.11^{a}	ns
Oat Flour Percent	15	12	6.05^{a}	
	30	12	5.99^{b}	ns

[1] a values = positive values indicate redness
Means in the same main effect having a different superscript are significantly different.

Table 38. Effect of milling: Means for Hunter Color Difference b-values of cookies made with oat-wheat composite flours

Main Effect	Classes	n	b-value[1]	Level of Significance
Mill Type	Hammer	12	19.13^{a}	
	Roller	12	19.04^{a}	ns
Oat Cultivar	Mariner	8	18.98^{a}	
	Ogle	8	19.21^{a}	
	Porter	8	19.08^{a}	ns
Oat Flour Percent	15	12	19.48^{a}	
	30	12	18.70^{b}	0.01

[1] b values = positive values indicate yellowness
Means in the same main effect having a different superscript are significantly different.

There was also a significant decrease in b-values (i.e. less yellow), as the percentage of oat flour increased. At the end of the eleven minute baking period, cookies made with 30 percent oat flour exhibited a greater degree of dough expansion than sugar-snap cookies made with 15 percent oat flour. The surface of the cookie containing 30 percent oat flour was always elevated higher than the surface of a cookie containing 15 percent oat flour. Wade (1988) observed that the raised portions of the cookie surface will always be darker than the surrounding cookie surface.

Table 39 contains the means and standard deviations of Hunter Color Difference values for cookies prepared with hammer milled and rolled milled oat flours. At the 15 and 30 percent level of oat flour in the composite, cookies made with hammer milled oat flours were consistently lighter in color or had larger L-values. Comparison of a-values shows that cookies made with composites containing roller milled oat flours had consistently higher a-values (more redness) than their hammer milled counterpart. There was no comparable trend found in b-values or yellowness.

Cookie proximate analysis:

There were no significant interactions for cookie protein or fat content. The difference between cookie protein means was substantially due to the main effects of mill, cultivar and level as seen in Table 108. Table 109 and Figure 30 shows there was a significant interaction between oat cultivar x level for cookie ash content. Substitution of 30 percent Porter hammer and roller milled

Table 39. Means and standard deviations of Hunter color difference values of cookies measuring effect of milling on cookie quality.[1]

Oat-wheat composite flour	Oat flour (%)	Hunterlab Color Difference L[2]	a[3]	b[4]
Hammer milled				
Mariner-Caldwell	30	50.82 ± 1.17	5.57 ± 0.32	18.46 ± 0.56
	15	51.97 ± 1.24	5.87 ± 0.67	18.97 ± 0.11
Ogle-Caldwell	30	51.40 ± 0.07	6.02 ± 0.46	18.55 ± 0.07
	15	54.00 ± 0.28	5.20 ± 0.07	19.97 ± 0.03
Porter-Caldwell	30	50.30 ± 0.14	5.80 ± 0.00	18.70 ± 0.07
	15	53.00 ± 0.28	5.65 ± 0.07	19.80 ± 0.21
Roller milled				
Mariner-Caldwell	30	50.78 ± 0.37	6.19 ± 0.03	18.82 ± 0.25
	15	51.49 ± 0.87	6.66 ± 0.20	19.32 ± 0.42
Ogle-Caldwell	30	51.03 ± 0.80	6.22 ± 0.17	18.73 ± 0.09
	15	52.87 ± 1.06	6.30 ± 0.28	19.57 ± 0.28
Porter-Caldwell	30	49.95 ± 0.85	6.40 ± 0.28	18.59 ± 0.19
	15	51.49 ± 0.38	6.59 ± 0.11	19.22 ± 0.14
Caldwell	0	56.67 ± 0.18	5.67 ± 0.25	20.15 ± 0.64

[1] n = 2

[2] L values = 0 (black) to 100 (white)

[3] a values = positive values indicate redness

[4] b values = positive values indicate yellowness

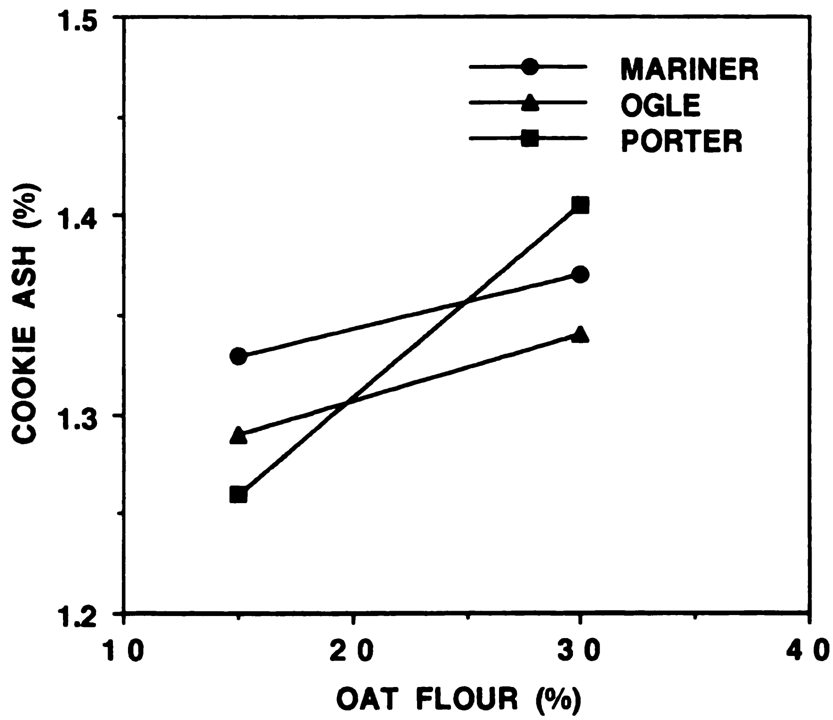


Figure 30. Interaction of Oat Cultivar x Level of Hammer and Roller Milled Groat Flour Substitution for Ash Content of Sugar-Snap Cookies

groat flours increased cookie ash content to a greater degree than substitution of the two other cultivars at the same level.

Analysis of variance results for protein content of the sugar snap cookies are listed in Table 40. Cookies made with composites of hammer milled groat flours contained a significantly higher percentage of protein than cookies made from composites of roller milled groat flours. This agrees with the previously reported protein levels in comparisons of roller and hammer milled groat flours.

Table 40. Effect of milling: Means for protein content of cookies made with oat-wheat composite flours

Main Effect	Classes	n	Protein[1] (%)	Level of Significance
Mill Type	Hammer	12	6.70[a]	
	Roller	12	6.46[b]	0.01
Oat Cultivar	Mariner	8	6.68[a]	
	Ogle	8	6.37[b]	
	Porter	8	6.69[a]	0.01
Oat Flour Percent	15	12	6.42[b]	
	30	12	6.74[a]	0.01

[1] Dry basis

Means in the same main effect having a different superscript are significantly different.

Analysis of variance also compared sugar-snap cookies made with the three different oat cultivars. Sugar-snap cookies made Mariner and Porter composite flours contained a significantly higher percentage of protein than cookies made with Ogle composite flours.

Cookies prepared from 30 percent oat-wheat composite flours contained a significantly higher percentage of protein than cookies prepared from 15 percent composite flours as shown in Table 40.

The higher percentage of protein in the hammer milled cookies was expected to influence the Hunter Color Difference L-values of the cookies due to higher amounts of amino acids available to take part in the Maillard reaction. The correlation between percentage protein and L-value was negative and highly significant for cookies made with composites of hammer milled ($r = -0.73$, $p<0.006$) and roller milled flours ($r = -0.78$, $p<0.002$). However, sugar snap cookies prepared with roller milled composite oat flours that contained a lower percentage of protein were slightly darker in color.

The higher percentage of protein in sugar-snap cookies made with Mariner and Porter hammer and roller milled groat composite flours may have influenced the Hunter Color difference L-values. Sugar-snap cookies made with Mariner and Porter composite flours containing more protein and more oat lipid were darker in color according to Hunter color difference L-values.

Table 41 reports there was no significant difference in ash content when cookies made with hammer milled oat flour were compared to cookies made with roller milled oat flour. There was not a significant difference between means of ash content for Porter and Ogle cookies but Mariner did contain a higher percentage of ash than Ogle cookies. Cookies prepared from 30 percent oat-wheat composite flours contained a significantly higher percentage of protein and ash compared to cookies with 15 percent composite flours as shown in Table 41.

Table 41. Effect of milling: Means for ash content of cookies made with oat-wheat composite flours

Main Effect	Classes	n	Ash[1] %	Level of Significance
Mill Type	Hammer	12	1.32[a]	
	Roller	12	1.35[a]	ns
Oat Cultivar	Mariner	8	1.36[a]	
	Ogle	8	1.31[b]	
	Porter	8	1.33[ab]	0.05
Oat Flour Percent	15	12	1.30[b]	
	30	12	1.37[a]	0.01

[1] Dry basis
Means in the same main effect having a different superscript are significantly different.

The development of the surface color of a sugar snap cookie is partially due to Maillard type reactions between reducing sugars and amino acids (Wade, 1988). However, correlations between protein content and L-value by oat cultivar were negative and statistically not significant. The Pearson correlation coefficients between protein content and L-value for Mariner, Ogle and Porter composite cookies were respectively; $r= -0.03$ ($p<0.94$), $r=-0.42$ ($p<0.29$), $r=-0.58$ ($p<0.12$).

There was no significant difference in fat content of cookies when cookies made with hammer milled oat flour were compared to cookies made with roller milled oat flour as seen in Table 42. There was also not a significant difference in lipid content of cookies made from composite flours of the three different oat cultivars.

Ogle hammer and roller milled groat flour contained a significantly lower percentage of lipid than flours of the other two oat cultivars. The fat used to prepare the cookie sheets may have influenced these results. There was not a significant difference in lipid content of cookies made from 15 or 30 percent oat-wheat composite flour.

Table 42. Effect of milling: Means for fat content of cookies made with oat-wheat composite flours

Main Effect	Classes	n	Fat[1] %	Level of Significance
Mill Type	Hammer	12	17.31[a]	
	Roller	12	17.01[a]	ns
Oat Cultivar	Mariner	8	16.90[a]	
	Ogle	8	17.24[a]	
	Porter	8	17.34[a]	ns
Oat Flour Percent	15	12	17.01[a]	
	30	12	17.31[a]	ns

[1] Dry basis
Means in the same main effect having a different superscript are significantly different.

Oat-wheat composite flours contained a higher percentage of protein than Caldwell soft wheat flour. An increase in Maillard type browning reaction due to increased amounts of amino acids may have contributed to the baked sugar-snap cookie color. However, the correlations between cookie protein percent and Hunter Color Difference L-value (lightness) and b-value (yellowness) by level of oat flour were small and not statistically significant. For the 15 percent level, the correlations for L- and b-value were respectively; r=-0.08 ($p<0.78$), r=0.27 ($p<0.38$). For the 30 percent level, the correlations for L- and b-value respectively were; r= 0.33 ($p<0.28$), r=0.12 ($p<0.70$). The correlations between Hunter Color Difference values and lipid content were not significant at either level.

Table 43 contains the means and standard deviations for protein, ash and fat content of sugar-snap cookies prepared from hammer milled and roller milled oat-wheat composite flours. Cookies prepared with hammer milled oat composite flours contained a higher percentage of protein (on a dry basis) than the comparable cookies prepared with roller milled composite flours. This was in agreement with proximate analysis results for the oat flours. Cookies made with 30 percent oat flour were expected to contain a higher percent of lipid than cookies made with 15 percent oat flour. Table 43 shows that fat extraction of cookies made with Porter-Caldwell hammer milled groat flour composites and Ogle-Caldwell roller milled groat flour composites did not produce expected results.

Moisture retention:

Moisture retention percent was calculated by dividing the percent moisture in cookie crumbs by the percent moisture in the respective cookie dough. There were no significant interactions for cookie moisture retention. Table 44 shows that cookies baked from hammer milled groat flours retained a slightly higher percentage of moisture than cookies made with roller milled groat flours but the difference was not significant at the $p<0.05$ level. The larger

Table 43. Means and standard deviations of protein, ash and fat content of cookies measuring the effect of milling on cookie quality[1]

Oat-wheat composite flour	Oat flour (%)	Protein[2] (%)	Ash[2] (%)	Fat[2] (%)
Hammer milled				
Mariner-Caldwell	30	7.00 ± 0.01	1.36 ± 0.05	17.23 ± 0.25
	15	6.64 ± 0.09	1.31 ± 0.01	16.91 ± 0.01
Ogle-Caldwell	30	6.57 ± 0.12	1.33 ± 0.05	18.00 ± 0.82
	15	6.37 ± 0.02	1.29 ± 0.01	16.77 ± 0.82
Porter-Caldwell	30	7.00 ± 0.07	1.40 ± 0.00	17.36 ± 0.05
	15	6.59 ± 0.11	1.24 ± 0.02	17.57 ± 0.49
Roller milled				
Mariner-Caldwell	30	6.72 ± 0.17	1.39 ± 0.01	17.04 ± 1.02
	15	6.36 ± 0.02	1.36 ± 0.02	16.42 ± 0.47
Ogle-Caldwell	30	6.41 ± 0.10	1.35 ± 0.01	16.70 ± 0.31
	15	6.12 ± 0.09	1.29 ± 0.01	17.49 ± 0.30
Porter-Caldwell	30	6.76 ± 0.01	1.41 ± 0.00	17.50 ± 0.08
	15	6.40 ± 0.01	1.28 ± 0.06	16.90 ± 0.38
Caldwell	0	6.04 ± 0.03	1.12 ± 0.02	15.81 ± 0.46

[1] n = 2 [2] Dry basis

particle size of the hammer milled flours may have retained more moisture through out the baking process because of the presence of a residual matrix structure in the remnants of the aleurone and subaleurone cells. Cadden (1987) concluded that a residual matrix structure in particles physically entraps water while the outer surfaces of the particle provide additional sites for water adsorption.

Table 44. Effect of milling: Means for moisture retention of cookies made with oat-wheat composite flours

Main Effect	Classes	n	Moisture Retention (%)	Level of Significance
Mill Type	Hammer	12	19.78[a]	
	Roller	12	19.60[a]	ns
Oat Cultivar	Mariner	8	20.11[a]	
	Ogle	8	19.73[a]	
	Porter	8	19.22[a]	ns
Oat Flour Percent	15	12	17.30[b]	
	30	12	22.07[a]	0.05

[1] Dry basis
Means in the same main effect having a different superscript are significantly different.

Sugar-snap cookies made with Mariner hammer and roller milled groat composite flours retained a higher percentage of moisture than cookies prepared from Ogle and Porter hammer and roller milled groat composite flours, however the difference was not significant as shown in Table 44. Cookies containing 30 percent oat flour retained a significantly higher percentage of moisture than cookies containing 15 percent oat flour.

Fogg and Tinklin (1972) had concluded that finely ground glandless cotton seed flour had less ability than coarse cotton seed flour to absorb or bind moisture in a sugar-snap cookie during baking Wade (1988) divided the baking process into three stages. The first stage entails expansion of the dough and the beginning of the loss of moisture. During the second stage, dough expansion and moisture loss reach their maximum rate and color development starts on the high spots on the dough surface. The last stage consists of a decrease in the rate of moisture loss and rapid color development on the cookie surface. Cookies prepared with roller milled composite oat flours may have contained less moisture than cookies made from hammer milled composite flours during the last third of baking. The lower percentage of moisture may have facilitated browning of the cookie surface.

<u>Shear compression and breaking strength:</u>

The interaction of oat cultivar x level was significant for cookie tenderness or shear compression as shown in Table 112 and Figure 31. Cookies made with Mariner oat-wheat composites developed a softer texture as increasing levels of Mariner oat flours were incorporated than cookies compared to the two other composites. There were no significant interactions for cookie breaking strength.

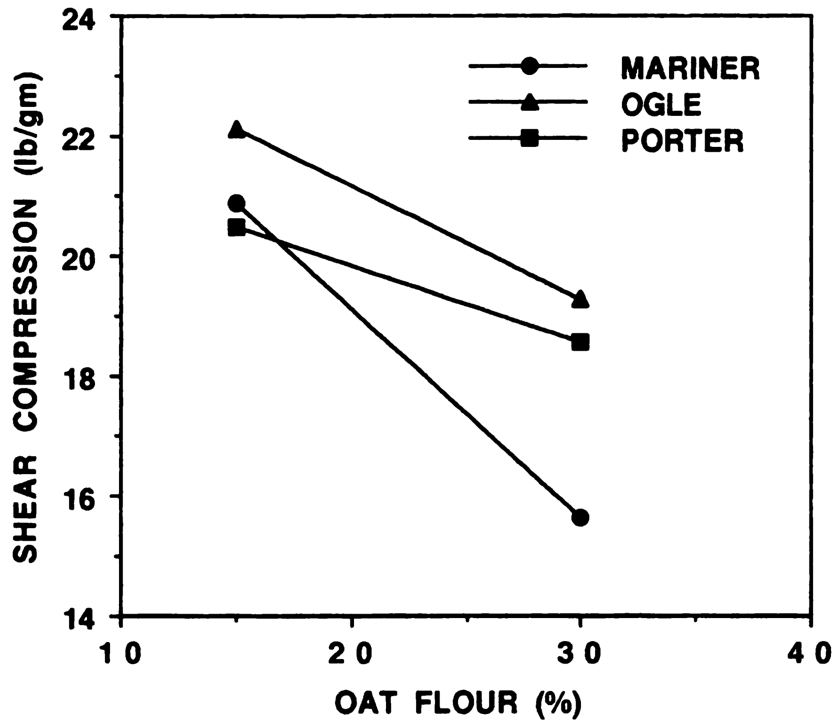


Figure 31. Interaction of oat cultivar x level of hammer and roller milled groat flour substitution for cookie shear compression

Table 45 shows cookies baked from hammer milled groat flours had higher shear compression values than cookies made with roller milled groat flours but the difference was not significant at the $p<0.05$ level. The highest shear compression values were measured for sugar-snap cookies made with Ogle composite flours. The Ogle cookie shear compression values were significantly higher than shear compression values for cookies made with Mariner and Porter composite flours. Cookies made with Ogle composite flours contained the lowest percentage of oat protein and a higher percentage of wheat protein which may have affected shear compression There was no difference between shear compression values for Mariner and Porter cookies. Shear compression values were significantly higher for cookies containing 15 percent oat flours compared to cookies containing 30 percent oat flour.

Table 45. Effect of milling: Means for shear compression of cookies made with oat-wheat composite flours

Main Effect	Classes	n	Shear Compression (lb/gm)	Level of Significance
Mill Type	Hammer	12	19.17^{a}	
	Roller	12	19.30^{a}	ns
Oat Cultivar	Mariner	8	18.26^{b}	
	Ogle	8	20.73^{a}	
	Porter	8	19.52^{ab}	0.01
Oat Flour Percent	15	12	21.17^{a}	
	30	12	17.83^{b}	0.01

Means in the same main effect having a different superscript are significantly different.

There was a significant difference in the breaking strength of cookies made with hammer milled groat flour composites compared to cookies containing roller milled groat flour composites. Sugar-snap cookies made from the three oat composite flours did not differ significantly in breaking strength. More force was required to break cookies containing the smaller percentage of oat flour (15%) than the larger percentage (30%) of oat flour.

Table 46. Effect of milling: Means for breaking strength of cookies made with oat-wheat composite flours

Main Effect	Classes	n	Breaking Strength (lb/cm^2)	Level of Significance
Mill Type	Hammer	12	11.20[a]	
	Roller	12	9.57[b]	0.05
Oat Cultivar	Mariner	8	11.31[a]	
	Ogle	8	10.37[a]	
	Porter	8	9.48[a]	ns
Oat Flour Percent	15	12	11.20[a]	
	30	12	9.57[b]	0.05

Means in the same main effect having a different superscript are significantly different.

The results agreed with findings reported by Vratanina and Zabik (1978) for wheat brans substituted in sugar-snap cookies. As the level of substituted wheat brans increased from 10 to 30 percent, there was an incremental decrease in shear compression and breaking strength. The shear compression and breaking strength values for sugar-snap cookies substituted with navy bean flour also decreased as increasing levels of navy bean flour were blended into the composite (Hoojjat and Zabik, 1984).

Table 47 contains the means and standard deviations for moisture retention, shear compression and breaking strength for the sugar-snap cookies. The large standard deviations influenced the analysis of variance results for moisture retention percentage. Cookies made with 15 percent Porter oat flour had smaller shear compression readings than 15 percent roller milled Porter oat flour. For the other two 15 percent composite flours, cookies made with hammer milled oat flours had larger shear compression readings than roller milled oat flours. Cookies prepared with hammer milled oat composite flours had larger breaking strength measurements than the comparable cookies prepared with roller milled composite flours.

Effect of Processing

The effect of processing on cookie quality was determined by comparing cookies made from oat-wheat composite flours of Caldwell soft wheat flour combined with the hammer milled flours ground from Mariner, Ogle and Porter groats and flakes. The composites contained oat flours substituted by weight at two levels (15 and 30%) for soft wheat flour. The analysis of variance model had three main effects; oat form, oat cultivar and level of oat flour substitution. The ANOVA tables for the dependent variables; cookie diameter, surface color, protein content, ash content, lipid content, moisture retention, shear compression, breaking strength and alkaline water retention capacity of the composite flours are

Table 19. Means and standard deviations of shear compression and breaking strength of cookies measuring the effect of processing on cookie quality[1]

Oat-wheat composite flour	Oat flour (%)	Shear Compression (lb/gm)	Breaking Strength (lb/cm^2)
Groats			
Mariner-Caldwell	30	16.80 ^{ac} ± 3.01	10.64 ^{a} ± 0.27
	15	20.98 ^{ab} ± 0.22	12.96 ^{a} ± 1.88
Ogle-Caldwell	30	18.87 ^{ac} ± 0.71	10.01 ^{a} ± 1.82
	15	21.85 ^{ab} ± 1.07	12.21 ^{a} ± 1.09
Porter-Caldwell	30	19.39 ^{ac} ± 0.26	10.54 ^{a} ± 0.42
	15	20.32 ^{ab} ± 0.07	10.82 ^{a} ± 0.12
Flakes			
Mariner-Caldwell	30	17.36 ^{ac} ± 1.08	10.72 ^{a} ± 3.50
	15	20.25 ^{ab} ± 0.44	12.16 ^{a} ± 1.46
Ogle-Caldwell	30	17.84 ^{ac} ± 2.02	13.25 ^{a} ± 0.35
	15	20.95 ^{ab} ± 0.65	9.78 ^{a} ± 0.89
Porter-Caldwell	30	16.86 ^{ac} ± 1.06	11.47 ^{a} ± 0.31
	15	20.69 ^{ab} ± 3.16	14.26 ^{a} ± 0.01
Caldwell	0	28.50 ± 2.76	13.78 ± 2.90

[1] n=2

Means in the same column having a different superscript are significantly different at $p<0.01$.

located in the Appendix. The correlation matrices for the dependent variables by main effect are located in the Appendix. The Caldwell soft wheat cultivar was chosen for the processing study based on results of a preliminary study using commercial whole oat flour which is provided in the Appendix.

Cookie diameter and top grain scores:

There were no significant interactions for cookie diameter as seen in Table 114. There was a significant difference ($p<0.01$) in the diameter of cookies made with oat flour hammer milled from flakes compared to cookies made with oat flour from groats as shown in Table 48. Cookies made from oat flour milled from flakes had a smaller diameter. The mean diameter of two sugar-snap cookies prepared with 100 percent Caldwell wheat flour was 17.05 cm.

Table 48. Effect of processing: Means for diameters of cookies made with oat-wheat composite flours

Main Effect	Classes	n	Cookie diameter (cm)	Level of Significance
Oat Form	Groat	12	17.61^{a}	
	Flake	12	17.28^{b}	0.01
Oat Cultivar	Mariner	8	17.30^{b}	
	Ogle	8	17.39^{ab}	
	Porter	8	17.64^{a}	0.05
Oat Flour Percent	15	12	17.34^{b}	
	30	12	17.54^{a}	0.05

Means in the same main effect having a different superscript are significantly different.

Viscosity difference observed during pasting oat flours may have contributed to the difference in cookie diameter. As earlier reported in Table 6, oat flours hammer milled from flakes had a significantly lower initial pasting temperature and a higher peak hot viscosity than oat flours hammer milled from groats. An increase in viscosity at a lower temperature may have facilitated setting of the cookie structure at a point where a lesser degree of dough expansion had occurred.

Cookies made from Mariner hammer milled groat and hammer milled flake flour composites were significantly ($p<0.05$) smaller in diameter than cookies from Porter groat and flake flour composites as shown in Table 48. Hammer milled Mariner groat and flake flours had increased in viscosity at a lower temperature during pasting than Ogle or Porter oat flours as shown in Table 6. Viscoamylograph properties of the oat flour did not appear to influence the average diameter of cookies made from Porter oat flour composites as much as cookies made from Mariner oat flours.

Cookies prepared from composites containing 30 percent hammer milled groat and flake flour had significantly larger cookie diameters than cookies made from composites containing 15 percent oat flour at the $p<0.05$ level as seen in Table 48. This is the opposite effect of oat bran which when substituted at the 30 percent level by Jeltema et al (1983) decreased the diameter of sugar-snap cookies.

The mean diameters and top grain scores of cookies made with composites of oat flours ground from groats and oat flours ground from flakes are given in Table 49. With the exception of cookies made from Mariner flours, cookies made from groat flours had larger diameters than cookies made from oat flake flours. This may have been the influence of the lower initial pasting temperature of Mariner oat flours.

Sugar-snap cookies made from hammer milled groat flour composites had slightly higher top grain scores than cookies made with hammer milled oat flake flour. Development of top grain may have been a function of cookie spread during baking, chemical components of oat flours and particle size related properties.

Alkaline water retention capacity:

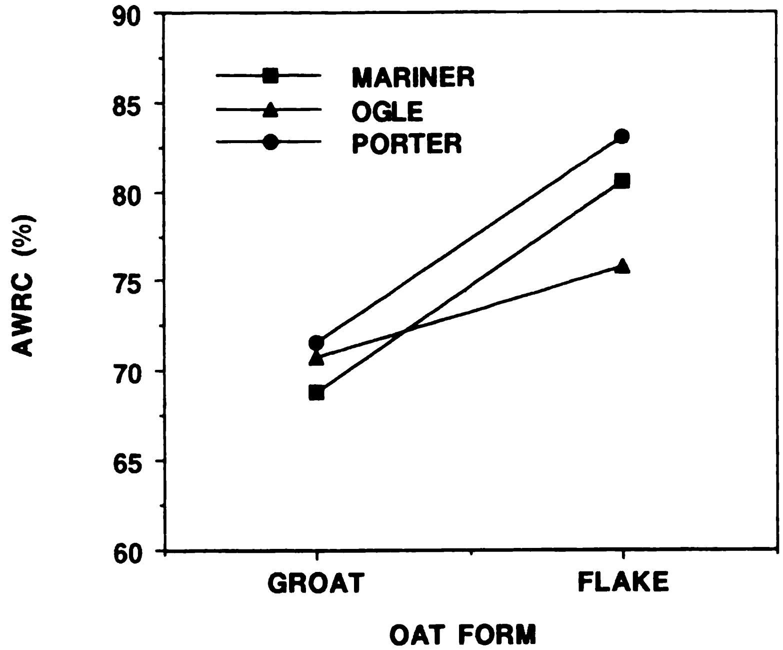
Analysis of variance means for the main effects were influenced by significant interactions between oat cultivar x form and oat cultivar x level as seen in Table 115. The interactions are illustrated in Figure 32a and b. The lines are not parallel and indicate a difference in the level of response to flaking of Ogle flours. The flaking process did not increase the AWRC of Ogle hammer milled flours to the same degree as it did hammer milled flours from Mariner and Porter cultivars. There was also a difference among cultivars in the level of response to doubling the percentage of hammer milled groat or flake flour in the composite. Porter composite flours had the largest increase in AWRC when compared to the two cultivars. Cultivar x form influenced AWRC of the hammer milled composite flours at the $p<0.001$ level while oat cultivar x level influenced AWRC at the $p<0.03$ level.

Table 49. Means and standard deviations of cookie diameter and top grain score measuring the effect of processing on cookie quality.

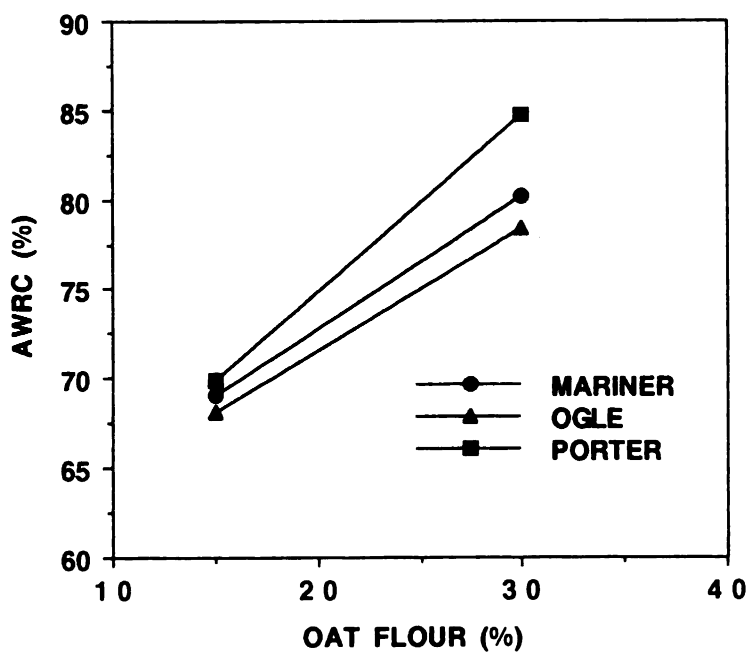
Oat-wheat composite flour	Oat flour (%)	Cookie diameter[1] (cm)	Top Grain Score
Groats			
Mariner-Caldwell	30	17.68 ± 0.26	8.7
	15	17.14 ± 0.03	8.0
Ogle-Caldwell	30	17.81 ± 0.01	8.5
	15	17.41 ± 0.05	8.3
Porter-Caldwell	30	17.88 ± 0.05	9.0
	15	17.72 ± 0.18	8.2
Flakes			
Mariner-Caldwell	30	17.13 ± 0.02	8.5
	15	17.23 ± 0.05	6.8
Ogle-Caldwell	30	17.26 ± 0.27	8.0
	15	17.07 ± 0.49	7.3
Porter-Caldwell	30	17.47 ± 0.00	8.8
	15	17.48 ± 0.26	8.0
Caldwell	0	17.05 ± 0.42	7.0

[1] n=2

Figure 32. Interaction for AWRC of Hammer Milled Groat and Flake Composite Flours. a) Oat Form x Oat Cultivar b) Oat Cultivar x Level of Hammer Milled Groat and Flake Flour Substitution



Oat Cultivar x Form Interaction for AWRC of Composite Flours



Oat Cultivar x Level of Oat Flour Interaction for AWRC of Composite Flours

Table 50 shows the alkaline water retention capacity (AWRC) of hammer milled flake flour composites was significantly higher than that of hammer milled groat flour composites. Hunter Color Difference L-values previously given in Table 5 indicated that oat flours hammer milled from oat flakes had a finer particle size than oat flours hammer milled from groats. This is in agreement with the findings of Nishita and Bean (1982) that rice flour with the finest particle size had the highest alkaline water retention capacity. Kurimoto and Shelton (1988) related flour particle size with the rate at which water penetrates into the core of the particle. A small flour particle was theorized to absorb water faster and more easily form a uniform gel. Scalon et al (1988) reported that the fine fraction of hard spring wheat flour produced by roller milling absorbed a greater amount of water than the coarse fraction.

Composite flours containing oat flour ground from groats or flakes required approximately the same amount to water to be added for desirable dough consistency. Oat-wheat composite flours required less water to be added for desirable dough consistency than the 100% Caldwell soft wheat flour.

There was a highly significant correlation ($r=0.76$, $p<0.003$) between cookie diameter and alkaline water retention capacity for cookies made with hammer milled groat composite flours. The correlation for cookies made with hammer milled flake composite flours was not as strong and not statistically significant ($r=0.26$, $p<0.39$).

Table 50. Effect of processing: Means for alkaline water retention capacity of oat-wheat composite flours

Main Effect	Classes	n	Alkaline water retention[1] (%)	Level of Significance
Oat Form	Groat	12	70.39[b]	
	Flake	12	76.81[a]	0.01
Oat Cultivar	Mariner	8	74.66[ab]	
	Ogle	8	73.26[b]	
	Porter	8	77.37[a]	0.01
Oat Flour Percent	15	12	69.04[b]	
	30	12	81.15[a]	0.01

[1] 14% moisture basis
Means in the same main effect having a different superscript are significantly different.

Cookies made from Porter hammer milled groat and flake flour composites had the largest average cookie diameter while the composite flours had the largest alkaline water retention capacity as seen in Table 50. Alkaline water retention capacity of Porter oat flour composites were significantly larger than AWRC of the other two oat flours composites at the $p<0.05$ level. The correlations between cookie diameter and AWRC by oat cultivar were not strong and not statistically significant. The correlations for Mariner, Ogle and Porter cookie diameters and AWRC were respectively; $r=-0.2$ ($p<0.95$), $r= 0.16$ ($p<0.69$) and $r=-0.37$ ($p<0.36$).

Table 50 also shows that composites of thirty percent oat flours had significantly higher alkaline water retention capacities than composites of fifteen percent oat flour at the $p<0.01$ level.

Chang and Sosulski (1985) reported that oat flour will hydrate 110% of its weight in water compared to a water hydration capacity of 93% for wheat flour. Kissel and Yamazaki (1975) added wheat gluten and soy flour derivatives to sugar snap cookies and concluded that the increased water retention properties of these ingredients competed for the limited free water present in cookie dough and increased dough viscosity. Sugar within the cookie dough system was theorized to not be fully dissolved. Reduced cookie spread and limited top grain formation was the outcome.

Sugar-snap cookie diameter and AWRC were not significantly correlated ($r=-0.009$, $p<0.97$) when hammer milled groat and flake flours were substituted at the 15 percent level. The correlation became stronger and statistically significant ($r=-0.57$, $p<0.05$) when hammer milled groat and flake flours were substituted at the 30 percent level in sugar-snap cookies.

The means and standard deviations of alkaline water retention capacities are given in Table 51. The alkaline water retention capacities of composites containing oat flour ground from flakes were consistently larger than their groat counterparts. Cadden (1987) reported that processes that alter the physical characteristics of certain food fibers can affect the total amount of water held by the fiber and how the water is held. Oat bran that was ground to further reduce particle size had an increased ability to hold water. However, the grinding to reduce particle size eliminated the "multilayer region" where water is loosely held within the pores or matrix structure of the fiber.

Table 51. Means and standard deviations of alkaline water retention capacity measuring the effect of processing on cookie quality.

Oat-wheat composite flour	Oat flour (%)	Alkaline Water Retention[1] (%)
Groats		
Mariner-Caldwell	30	74.58 ± 0.71
	15	63.05 ± 1.17
Ogle-Caldwell	30	75.98 ± 0.25
	15	65.46 ± 0.87
Porter-Caldwell	30	77.08 ± 0.18
	15	66.15 ± 0.77
Flakes		
Mariner-Caldwell	30	85.91 ± 0.39
	15	75.11 ± 0.64
Ogle-Caldwell	30	80.84 ± 0.10
	15	70.77 ± 1.88
Porter-Caldwell	30	92.53 ± 2.05
	15	73.71 ± 0.95
Caldwell	0	58.81 ± 1.05

[1] n=3 14% moisture basis

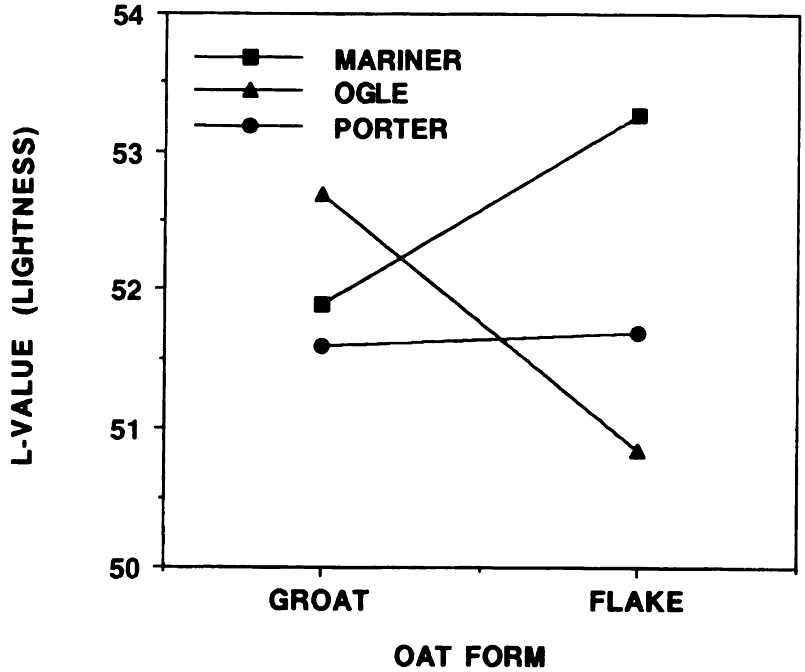
Chang and Morris (1990) heat processed (autoclaved for 15 minutes at 121°C) samples of apple fiber, corn fiber, oat bran and soy fiber and then evaluated physical structural changes in the fibers with a Scanning Electron Microscope. The results were an increase in the surface area of the fibers due to increased furrowing and/or cracking. The oat bran exhibited a rougher and more irregular surface after the heat treatment. The increased water holding capacity of oat flours ground from flakes may have been influenced by the heat processing involved in rolling groats into flakes.

Cookie surface color:

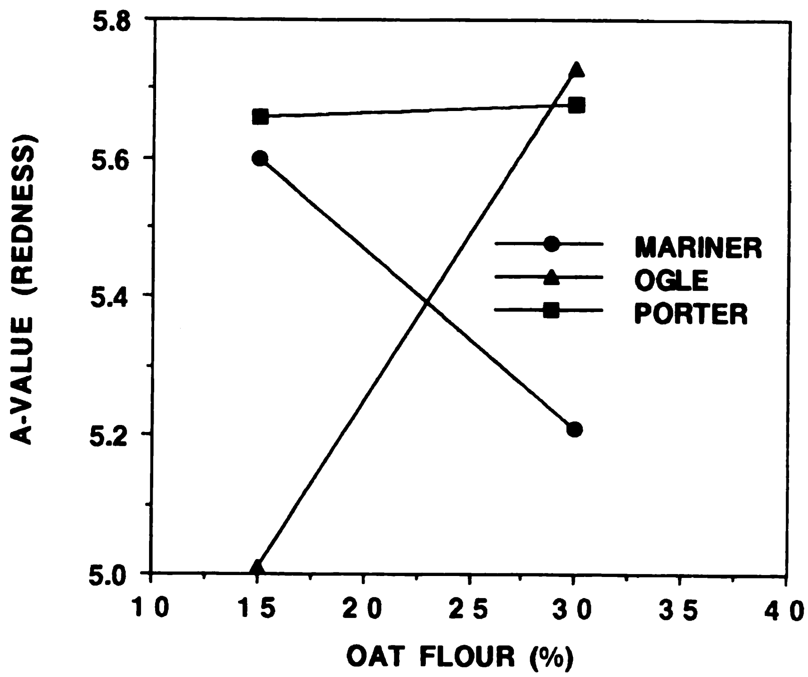
Analysis of variance means were influenced by significant interactions between cultivar x form and cultivar x level. There was a highly significant $p<0.001$ interaction between oat cultivar x form for Hunter L-value which is illustrated in Figure 33a. Processing the groats into flakes appeared to have a different effect on the lightness or L-value of cookies prepared from the composite flours. Cookies made from hammer milled oat flake flour from the Ogle cultivar had darker surfaces than cookies made from hammer milled groat flour. The opposite effect was seen for cookies made with Mariner and Porter oat flours.

The interaction of oat cultivar x level was also significant for a-value of sugar snap cookies and is shown in Figure 33b. Increasing the percent of oat flour two fold in the composite had a different level of response for each cultivar in the resulting redness or a-value of the cookie. Cookies made with Ogle hammer milled groat or flake flour composites had an increased reddish hue while

Figure 33. Interaction for Hunter Color Difference Values for Cookies made with Hammer Milled Groat and Flake Flours.
a) Oat Form x Oat Cultivar Interaction for L-value.
b) Oat Cultivar x Level of Hammer Milled Groat and Flake Flour Substitution for a-value.



Oat Cultivar x Oat Form Interaction for L-value of Cookie



Oat Cultivar x Level of Oat Flour Interaction for a-value cookies made with Mariner composites had a decreased reddish hue. No interactions were significant for b-values. There was no significant difference in a-values (redness).

Table 52 provides the mean Hunter Color Difference L-values of sugar-snap cookies prepared with hammer milled oat flour composites from groats and flakes. There were no significant differences at the $p<0.05$ level in the L-values of oat groat flour composites when compared to oat flake flour composites. The oat cultivar did not appear to effect the L-values of the sugar snap cookies baked with their composite hammer milled groat and flake flours. However, cookies prepared with thirty percent oat groat and flake flour composites had significantly lower Hunter Color Difference L-values (darkness vs lightness) than cookies prepared with fifteen percent oat flour composites.

Table 52. Effect of processing: Means for Hunter Color Difference L-values of cookies made with oat-wheat composite flours

Main Effect	Classes	n	L-value[1]	Level of Significance
Oat Form	Groat	12	52.08[a]	
	Flake	12	51.93[a]	ns
Oat Cultivar	Mariner	8	52.58[a]	
	Ogle	8	51.77[a]	
	Porter	8	51.67[a]	ns
Oat Flour Percent	15	12	52.69[a]	
	30	12	51.35[b]	0.01

[1] L values = 0 (black) to 100 (white)
Means in the same main effect having a different superscript are significantly different.

Cookies made with oat groat flour composites had a more reddish hue than cookies made with oat flake composite flours as seen in Table 53. The difference in a-value (redness) was significant at the p<0.05 level. There were no significant differences at the p<0.05 level in the a-value of cookie surfaces when compared according to oat flour cultivar or level of oat flour in the composite.

Table 53. Effect of processing: Means for Hunter Color Difference a-values of cookies made with oat-wheat composite flours

Main Effect	Classes	n	a-value[1]	Level of Significance
Oat Form	Groat	12	5.63^a	
	Flake	12	5.34^a	0.05
Oat Cultivar	Mariner	8	5.41^a	
	Ogle	8	5.37^a	
	Porter	8	5.67^a	ns
Oat Flour Percent	15	12	5.54^a	
	30	12	5.42^a	ns

[1] a values = positive values indicate redness
Means in the same main effect having a different superscript are significantly different.

There were no significant differences at the p<0.05 level in the b-values (yellowness) of cookies prepared with oat groat flour composites when compared to cookies prepared with oat flake flour composites as seen in Table 54. The oat cultivar did not appear to effect the surface color of the sugar snap cookies. There was no significant difference at the p<0.05 level in b-values. Table 54 shows that cookies prepared with thirty percent oat groat and flake flour composites had significantly lower Hunter Color Difference b-values (yellowness) than cookies prepared with fifteen percent oat flour composites. Sugar-snap cookies prepared with 30 percent oat flours could be described as not as yellow or slightly browner.

Table 54. Effect of processing: Means for Hunter Color Difference b-values of cookies made with oat-wheat composite flours

Main Effect	Classes	n	b-value[1]	Level of Significance
Oat Form	Groat	12	19.13[a]	
	Flake	12	18.99[a]	ns
Oat Cultivar	Mariner	8	19.16[a]	
	Ogle	8	19.22[a]	
	Porter	8	18.81[a]	ns
Oat Flour Percent	15	12	19.35[a]	
	30	12	18.77[b]	0.01

[1] b values = positive values indicate yellowness
Means in the same main effect having a different superscript are significantly different.

Table 55 contains the means and standard deviations of Hunter Color Difference values of cookies prepared with composites of oat flours ground from groats and oat flours ground from flakes. Cookies made with oat flours ground from Mariner groats had smaller L-values than cookies made with oat flours ground from mariners flakes. The opposite trend was seen for cookies made with Ogle composite flours. Cookies made from oat groat composite flours had larger L-values than cookies made from oat flake

Table 55 Means and standard deviations of Hunter Color Difference values of cookies measuring the effect of processing on cookie quality[1]

Oat-wheat composite flour	Oat flour (%)	Hunterlab Color Difference		
		L[2]	a[3]	b[4]
Groats				
Mariner-Caldwell	30	50.82 ± 1.17	5.22 ± 0.32	18.80 ± 0.56
	15	51.97 ± 1.24	5.87 ± 0.67	18.97 ± 0.11
Ogle-Caldwell	30	51.40 ± 0.07	6.02 ± 0.46	18.55 ± 0.07
	15	54.00 ± 0.28	5.20 ± 0.07	19.97 ± 0.03
Porter-Caldwell	30	50.30 ± 0.14	5.80 ± 0.00	18.70 ± 0.07
	15	53.00 ± 0.28	5.65 ± 0.07	19.80 ± 0.21
Flakes				
Mariner-Caldwell	30	52.72 ± 0.03	5.20 ± 0.07	19.12 ± 0.03
	15	53.80 ± 0.07	5.32 ± 0.11	19.72 ± 0.25
Ogle-Caldwell	30	50.40 ± 0.07	5.45 ± 0.35	18.87 ± 0.81
	15	51.27 ± 0.18	4.82 ± 0.11	19.50 ± 0.92
Porter-Caldwell	30	51.47 ± 0.81	5.56 ± 0.33	18.60 ± 0.56
	15	51.90 ± 0.28	5.67 ± 0.32	18.15 ± 0.00
Caldwell	0	56.67 ± 0.18	5.67 ± 0.25	20.15 ± 0.64

[1] n=2

[2] L values = 0 (black) to 100 (white)

[3] a values = positive values indicate redness

[4] b values = positive values indicate yellowness

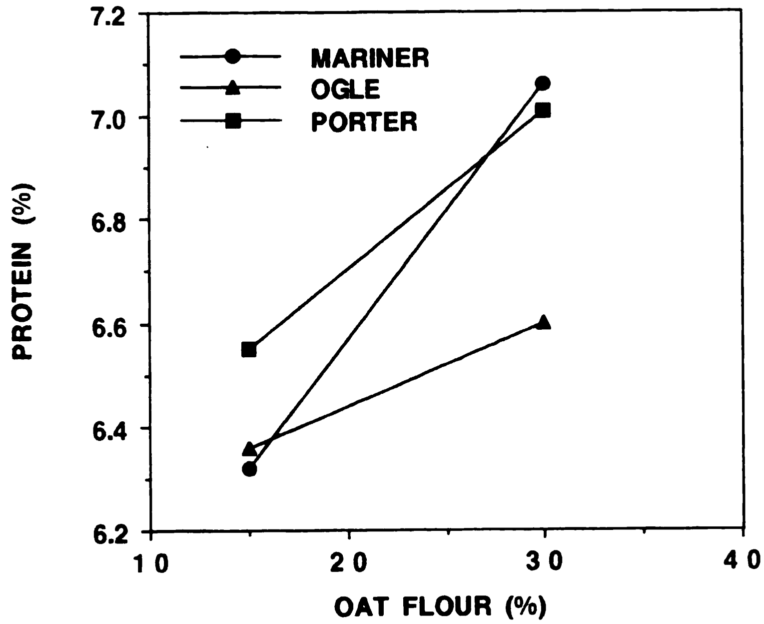
composite flours. With the exception of sugar snap cookies made from 15% Porter groat flour, cookies made from groat composite flours had a stronger reddish hue as measured by a-values. Cookies made from 30% composite flours were less yellow than the cookie containing 15% of the same oat cultivar flour with the exception of Porter oat flake flour.

Cookie Proximate Analyses

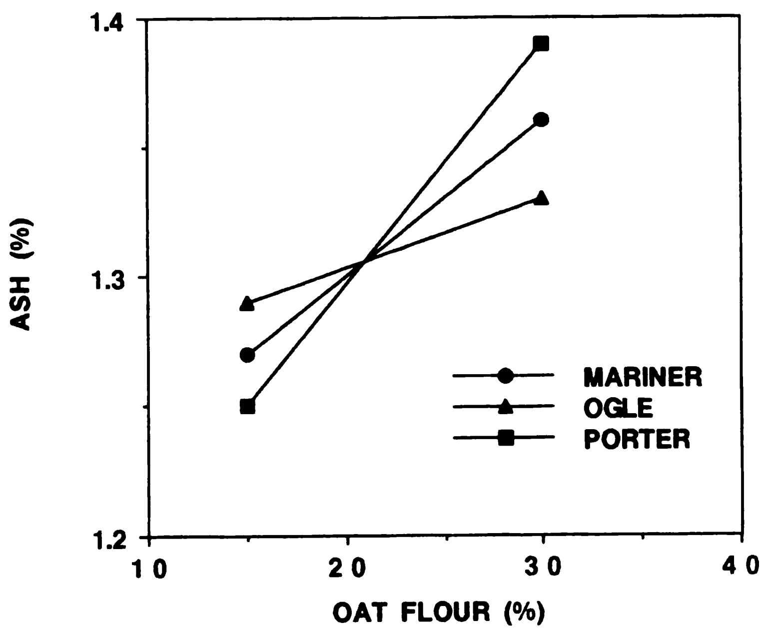
Analysis of variance means were influenced by significant interactions between cultivar x level of oat flour as seen in Tables 119 and 120. The interaction of oat cultivar and level of oat flour was significant for cookie ash content. The interactions for cookie protein and ash content are shown in Figures 34a and b. Cookies made from the high protein oat cultivars, Mariner and Porter, had a greater increase in protein content when twice as much oat flour was included in the composite flours than cookies made from Ogle composite flours. The same effect was seen for ash content of cookies made with Mariner and Porter composite flours.

Table 56 shows there was no significant difference at the $p<0.05$ level for protein percentage when cookies made from oat flour hammer milled from groats were compared to cookies made with oat flour hammer milled from flakes. The correlations between sugar-snap cookie protein content and Hunter Color Difference values for cookie surface color were not significant for cookies prepared with hammer milled groat or hammer milled flake composite flours. The correlations for Hunter L-value, a- value and b-values of cookies made with hammer milled groat composite

Figure 34. Interaction for Protein and Ash Content of Cookies made with Hammer Milled Groat and Flake Flours.
a) Cookie Protein Content b) Cookie Ash Content.



Oat Cultivar x Level of Oat Flour Interaction
for Cookie Protein Content



Oat Cultivar x Level of Oat Flour Interaction
for Cookie Ash Content

flours were respectively; r=-0.54 (p<0.06), r=-0.03 (p<0.90), r=-0.37 (p<0.23).

Table 56. Effect of processing: Means for protein content of cookies made with oat-wheat composite flours

Main Effect	Classes	n	Protein[1] (%)	Level of Significance
Oat Form	Groat	12	6.62[a]	
	Flake	12	6.69[a]	ns
Oat Cultivar	Mariner	8	6.69[ab]	
	Ogle	8	6.48[b]	
	Porter	8	6.78[a]	0.05
Oat Flour Percent	15	12	6.41[b]	
	30	12	6.89[a]	0.01

[1] Dry basis

Means in the same main effect having a different superscript are significantly different.

The sugar-snap cookies made with composite flours of Porter hammer milled groat and flake flours contained a significantly higher percentage of protein than cookies made with composites of Ogle hammer milled groat and flake flours. The percentage of protein in cookies made with composite of Porter hammer milled groat and flake flours was negatively correlated (r=-0.75, p<0.03) with Hunter Color L-values. The same correlation was smaller and not statistically significant (r=-0.54, p<0.15) for cookies made with Ogle composite flours and for cookies made with Mariner composite flours (r=-0.12, p<0.77). The only significant correlation for protein content and a-value (redness) ($r=0.81$, $p<0.01$) was for cookies made with Ogle composite flours. There were no significant correlations between protein content and b-value (yellowness) for cookies made with any of the three oat cultivar composite flours.

Sugar-snap cookies made with 30 percent oat groat and flake composite flours contained a significantly higher percentage of protein than cookies prepared with 15 percent composite flours as shown in Table 56. All of the oat groat and flake flours contained a higher percentage of protein than the Caldwell soft wheat flour that they replaced in the composite flour.

The correlations between sugar-snap cookie protein content and Hunter Color Difference values for cookie surface color were not significant for cookies prepared with 15 percent or 30 percent hammer milled groat or hammer milled flake composite flours. The correlations for Hunter L-value, a- value and b-values of cookies made with 15 percent hammer milled groat or flake composite flours were respectively; $r=0.13$ ($p<0.68$), $r=-0.11$ ($p<0.71$), $r=0.05$ ($p<0.86$). The correlations for Hunter L-value, a- value and b-values of cookies made with 30 percent hammer milled groat or flake composite flours were respectively; $r=0.25$ ($p<0.42$), $r=-0.19$ ($p<0.54$), $r=0.45$ ($p<0.14$). There were also no significant correlations between Hunter Color Values and lipid content.

Table 57 shows there was no significant difference at the $p<0.05$ level for ash percentage when cookies made from oat flour hammer milled from groats were compared to cookies made with oat flour hammer milled from flakes. There was not a significant difference in ash content of cookies made with composites of the three different oat cultivars. Sugar-snap cookies made with 30 percent oat groat and flake composite flours contained a significantly higher percentage of ash than cookies prepared with 15 percent composite flours.

Table 57. Effect of processing: Means for ash content of cookies made with oat-wheat composite flours

Main Effect	Classes	n	Ash[1] %	Level of Significance
Oat form	Groat	12	1.32[a]	
	Flake	12	1.31[a]	ns
Oat Cultivar	Mariner	8	1.32[a]	
	Ogle	8	1.31[a]	
	Porter	8	1.32[a]	ns
Oat Flour Percent	15	12	1.27[b]	
	30	12	1.36[a]	0.01

[1] Dry basis
Means in the same main effect having a different superscript are significantly different.

Table 58 shows there was no significant difference in lipid content when cookies made from oat flour hammer milled from groats were compared to cookies made with oat flour hammer milled from flakes. The large standard deviations for fat content shown in Table 59 affected analysis of variance results. Cookies made with oat flour hammer milled from flakes did contain a higher percentage of lipid than cookies made with oat flour hammer milled from groats. Particle size effect may have influence the lipid results.

The AACC method required the cookie sheets be lightly greased with shortening which also may have influenced the cookie lipid content.

Table 58. Effect of processing: Means for fat content of cookies made with oat-wheat composite flours

Main Effect	Classes	n	Fat[1] %	Level of Significance
Oat Form	Groat	12	17.31^{a}	
	Flake	12	17.74^{a}	ns
Oat Cultivar	Mariner	8	17.76^{a}	
	Ogle	8	17.46^{a}	
	Porter	8	17.35^{a}	ns
Oat Flour Percent	15	12	17.16^{b}	
	30	12	17.89^{a}	0.01

[1] Dry basis
Means in the same main effect having a different superscript are significantly different.

There was not a significant difference in lipid content of cookies made with composite flours of the three different oat cultivars. Sugar-snap cookies made with 30 percent oat groat and flake composite flours contained a significantly higher percentage of lipid than cookies prepared with 15 percent composite flours as shown in Table 58. There were no significant correlations between Hunter Color L-values and lipid content for cookies prepared with hammer milled groat or hammer milled flake composite flours.

Table 59 contains the means and standard deviations for protein, ash and fat content of cookies made with oat flours ground from groats or from flakes. The percent protein was consistently

Table 59. Means and standard deviations of protein, ash, and fat content of cookies measuring the effect of processing on cookie quality[1]

Oat-wheat composite flour	Oat flour (%)	Protein[2] (%)	Ash[2] (%)	Fat[2] (%)
Groats				
Mariner-Caldwell	30	6.99 ± 0.03	1.36 ± 0.05	17.23 ± 0.25
	15	6.16 ± 0.20	1.31 ± 0.00	16.91 ± 0.01
Ogle-Caldwell	30	6.58 ± 0.11	1.33 ± 0.05	18.00 ± 0.82
	15	6.38 ± 0.03	1.29 ± 0.01	16.77 ± 0.82
Porter-Caldwell	30	7.00 ± 0.07	1.40 ± 0.00	17.36 ± 0.05
	15	6.59 ± 0.11	1.24 ± 0.03	17.57 ± 0.49
Flakes				
Mariner-Caldwell	30	7.13 ± 0.37	1.37 ± 0.00	19.23 ± 0.90
	15	6.48 ± 0.15	1.22 ± 0.02	17.68 ± 0.37
Ogle-Caldwell	30	6.62 ± 0.13	1.33 ± 0.01	17.74 ± 0.15
	15	6.32 ± 0.02	1.29 ± 0.01	17.31 ± 0.20
Porter-Caldwell	30	7.02 ± 0.38	1.37 ± 0.01	17.76 ± 0.13
	15	6.51 ± 0.05	1.25 ± 0.02	16.71 ± 0.18
Caldwell	0	6.04 ± 0.03	1.12 ± 0.02	15.81 ± 0.46

[1] n=2   [2] Dry basis

higher in cookies prepared from oat flour ground from flakes. Proximate analysis results had previously reported a significantly higher percentage of protein in oat flake flours.

Fat content of cookies made with oat-wheat composite flours was higher than the 100 percent Caldwell soft wheat cookies. Cookies prepared with 30 percent oat-wheat composites contained a higher percentage of fat than cookies made with 15 percent oat wheat composite flours with the exception of Porter-Caldwell hammer milled groat cookies. The large standard deviations for fat content affected analysis of variance results.

Moisture retention:

Moisture retention percent was calculated by dividing the percent moisture in cookie crumbs by the percent moisture in the respective cookie dough. There were no significant interactions for the characteristic of moisture retention.

Table 60 contains analysis of variance means which indicated there were no significant differences in the attribute of moisture retention when cookies made from oat hammer milled flake composite flours were compared to cookies made from hammer milled groat composite flours. Oat cultivar also did not appear to influence the moisture retention capability of sugar-snap cookies prepared with hammer milled groat and flake flour composites.

Moisture retention was higher for cookies made from thirty percent hammer milled groat or flake flour composites than cookies made from fifteen percent oat flour composites but the difference was not significant. Moisture retention had large standard deviations from the means. There was a time related trend observed during baking in the moisture retention percentage that was thought to be caused by undefinable experimental conditions.

Table 60. Effect of processing: Means for moisture retention of cookies made with oat-wheat composite flours

Main Effect	Classes	n	Moisture Retention (%)	Level of Significance
Oat Form	Groat	12	19.60[a]	
	Flake	12	18.59[a]	ns
Oat Cultivar	Mariner	8	18.97[a]	
	Ogle	8	19.11[a]	
	Porter	8	19.20[a]	ns
Oat Flour Percent	15	12	18.92[a]	
	30	12	19.27[a]	ns

[1] Dry basis
Means in the same main effect having a different superscript are significantly different.

Shear compression and breaking strength:

There were no significant interactions for the characteristics of shear compression or breaking strength as shown in Table 123 and 124. Analysis of variance indicated there were no significant differences in the mean values of shear compression when cookies made from oat hammer milled flake composite flours were compared to cookies made from hammer milled groat composite flours as seen in Table 61. The size of the standard deviations for shear compression influenced analysis of variance results. There was no significant difference between cookies made from composites of the three different oat cultivars at the $p<0.05$ level in shear compression.

Table 61. Effect of processing: Means for shear compression of cookies made with oat-wheat composite flours

Main Effect	Classes	n	Shear Compression (lb/gm)	Level of Significance
Oat Form	Groat	12	19.71[a]	
	Flake	12	18.99[a]	ns
Oat Cultivar	Mariner	8	18.85[a]	
	Ogle	8	19.88[a]	
	Porter	8	19.32[a]	ns
Oat Flour Percent	15	12	20.84[a]	
	30	12	17.86[b]	0.01

Means in the same main effect having a different superscript are significantly different.

Analysis of variance results provided in Table 61 indicated there was a significant difference in shear compression or tenderness at the $p<0.01$ level between cookies containing 15 and 30 percent oat flour. Increased levels of hammer milled groat or flake flours increased the tenderness of the cookies or decreased the pounds/gram required to shear the sample. This was in agreement with results reported by Vratanina and Zabik (1978), Jeltema et al (1983), and Hoojjat and Zabik (1984). Red and white wheat brans substituted at the 10, 20 and 30 percent level progressively increased cookie tenderness (Vratanina and Zabik,1978) Jeltema et al (1983) substituted 20 percent oat bran in sugar-snap cookies and increased the tenderness. Substitution of 20 and 30 percent navy bean flour increased tenderness of sugar snap cookies (Hoojjat and Zabik,1984).

Comparison of mean breaking strength of cookies made from hammer milled flake composite flours with cookies made from hammer milled groat composite flours found no significant difference as seen in Table 62. There also was no significant difference between cookies made from composites of the three different oat cultivars at the $p<0.05$ level in the breaking strength of the cookies. There was a wide variation in these three values which contributed to the lack of a statistically significant difference.

Table 62. Effect of processing: Means for breaking strength of cookies made with oat-wheat composite flours

Main Effect	Classes	n	Breaking Strength (lb/cm^2)	Level of Significance
Oat Form	Groat	12	11.20^a	
	Flake	12	11.94^a	ns
Oat Cultivar	Mariner	8	11.62^a	
	Ogle	8	11.31^a	
	Porter	8	11.77^a	ns
Oat Flour Percent	15	12	12.03^a	
	30	12	11.11^a	ns

Means in the same main effect having a different superscript are significantly different.

There was no significant difference in breaking strength for cookies prepared with the two levels of hammer milled groat or flake flour. Vratanina and Zabik (1978) reported that increasing red and white wheat bran in sugar-snap cookies reduced breaking strength or cookie crispness. That trend was also found for navy bean flour (Hoojjat and Zabik,1984)

Table 63 contains the means and standard deviations for moisture retention, shear compression and breaking strength of cookies made with hammer milled groat and flake composite flours. All three attributes had large standard deviations which influenced analysis of variance results. No clear trend in the effect of oat form, oat cultivar or level of oat flour was demonstrated. There was a time related trend in the moisture retention percentage that was thought to be caused by undefinable experimental conditions.

Interaction with Wheat Cultivars

The effect of wheat cultivar on cookie quality was determined by comparing cookies made from oat-wheat composite flours of Becker, Caldwell and Compton soft wheat cultivars combined with the hammer milled oat flours of Mariner, Ogle and Porter groats. The composites contained oat flours substituted by weight at two levels (15 and 30%) for soft wheat flour. The experimental design was outlined in Figure 4. The analysis of variance model had three main effects; wheat cultivar, oat cultivar and level of oat flour substitution. The ANOVA Tables for the dependent variables; cookie diameter, surface color, protein content, ash content, lipid content, moisture retention, shear compression, breaking strength and

Table 63 Means and standard deviations of moisture retention, shear compression and breaking strength of cookies measuring the effect of processing on cookie quality[1]

Oat-wheat composite flour	Oat flour (%)	Moisture retention (%)	Shear Compression (lb/gm)	Breaking Strength (lb/cm^2)
Groats				
Mariner-Caldwell	30	19.70 ± 3.44	16.80 ± 3.01	10.64 ± 0.27
	15	21.12 ± 8.77	20.98 ± 0.22	12.96 ± 1.88
Ogle-Caldwell	30	20.08 ± 1.51	18.87 ± 0.71	10.01 ± 1.82
	15	14.68 ± 0.10	21.85 ± 1.07	12.21 ± 1.09
Porter-Caldwell	30	22.67 ± 8.37	19.39 ± 0.26	10.54 ± 0.42
	15	19.33 ± 3.31	20.32 ± 0.07	10.82 ± 0.12
Flakes				
Mariner-Caldwell	30	13.42 ± 1.38	17.36 ± 1.08	10.72 ± 3.50
	15	21.65 ± 4.55	20.25 ± 0.44	12.16 ± 1.46
Ogle-Caldwell	30	20.70 ± 0.00	17.84 ± 2.02	13.25 ± 0.35
	15	20.97 ± 3.46	20.95 ± 0.65	9.78 ± 0.89
Porter-Caldwell	30	19.02 ± 1.68	16.86 ± 1.06	11.47 ± 0.31
	15	15.77 ± 0.50	20.69 ± 3.16	14.26 ± 0.01
Caldwell	0	21.23 ± 0.65	28.50 ± 2.76	13.78 ± 2.90

[1] n=2

alkaline water retention capacity of the composite flours are located in the Appendix. The correlation matrices for the dependent variables by main effect are located in the Appendix.

The U.S.D.A. Soft Wheat Quality Laboratory at Wooster, Ohio provided the chemical and physical analyses results listed in Table 64. Becker, a red soft wheat cultivar, had been milled into a flour that contained the highest percentage of protein, the smallest average particle size and the lowest percentage of damaged starch among the three soft wheat flours. Compton, also a red soft wheat cultivar, had the lowest percentage of protein, the highest percentage of ash, the largest average particle size and the highest percentage of damaged starch. Caldwell, a white soft wheat cultivar, had the lowest percent of ash. Starch damage is an indicator of wheat kernel hardness and severity of milling (Abboud et al, 1985b). Starch damage increases water absorption thereby influencing baking quality of soft wheat flours.

Table 64 Chemical analysis and particle size of soft wheat flours as furnished by Soft Wheat Quality Lab[1]

Cultivar	Protein[2] (%)	Ash[2] (%)	Particle Size (microns)	Starch Damage[2] (%)
Becker	10.1	0.43	48.8	3.0
Caldwell	9.3	0.40	49.0	3.2
Compton	8.6	0.49	52.3	3.9

[1] Number of determinations and standard deviations were not provided

[2] 14% moisture basis

Cookie diameter and top grain score:

There were no significant interactions between main effects for cookie diameter. Sugar-snap cookies made with oat-wheat composites of Caldwell soft wheat had the smallest average diameter as shown in Table 65. Analysis of variance indicated their diameter was significantly ($p<0.05$) smaller than the diameter of cookies from Becker soft wheat flour composites. The mean diameter of two sugar-snap cookies made with 100 percent Caldwell wheat flour was 17.05 cm. Cookies prepared with composites of Becker soft wheat had the largest average diameter. The mean diameter of two sugar-snap cookies made with 100 percent Becker soft wheat flour was also 17.05 cm.

Table 65. Effect of wheat cultivar: Means for diameters of cookies made with oat-wheat composite flours

Main Effect	Classes	n	Cookie diameter (cm)	Level of Significance
Wheat Cultivar	Becker	12	17.89^{a}	
	Caldwell	12	17.61^{b}	
	Compton	12	17.71^{ab}	0.05
Oat Cultivar	Mariner	12	17.65^{b}	
	Ogle	12	17.64^{b}	
	Porter	12	17.93^{a}	0.05
Oat Flour Percent	15	18	17.56^{b}	
	30	18	17.91^{a}	0.01

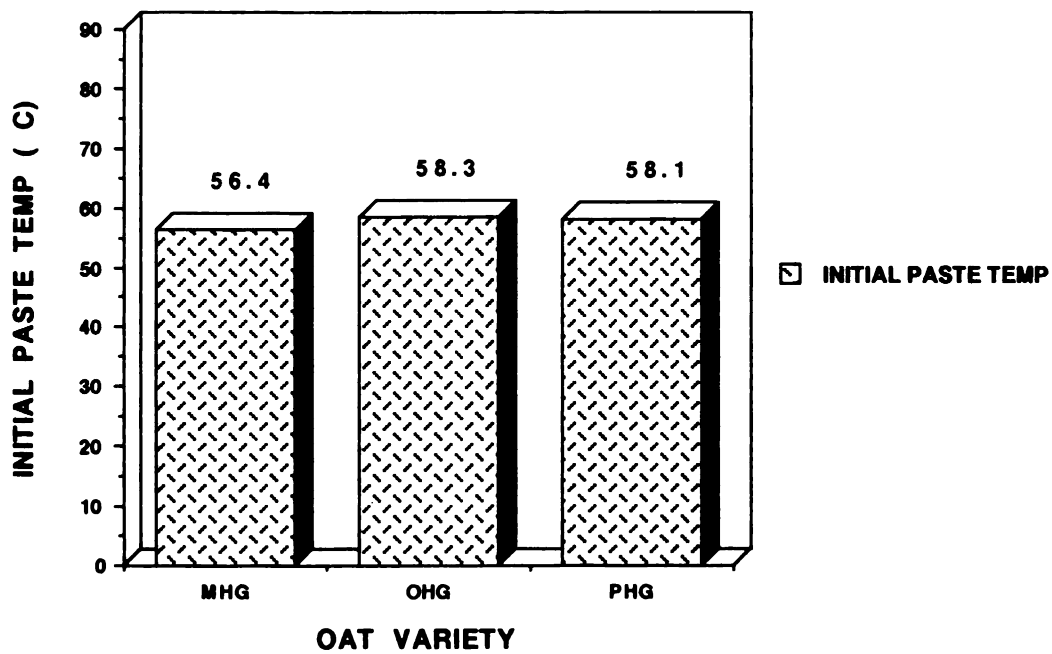
Means in the same main effect having a different superscript are significantly different.

Substitution of oat flour hammer milled from groats increased the diameter of sugar-snap cookies prepared from the composite flours. The largest increase in cookie diameter was for cookies made from composites of Compton soft wheat flour. The mean diameter of two sugar-snap cookies made with 100% Compton soft wheat was 16.72 cm and was increased in oat-wheat composite cookies to 17.71 cm. The level of damaged starch in Compton soft wheat flour probably contributed to the relatively small cookie diameter.

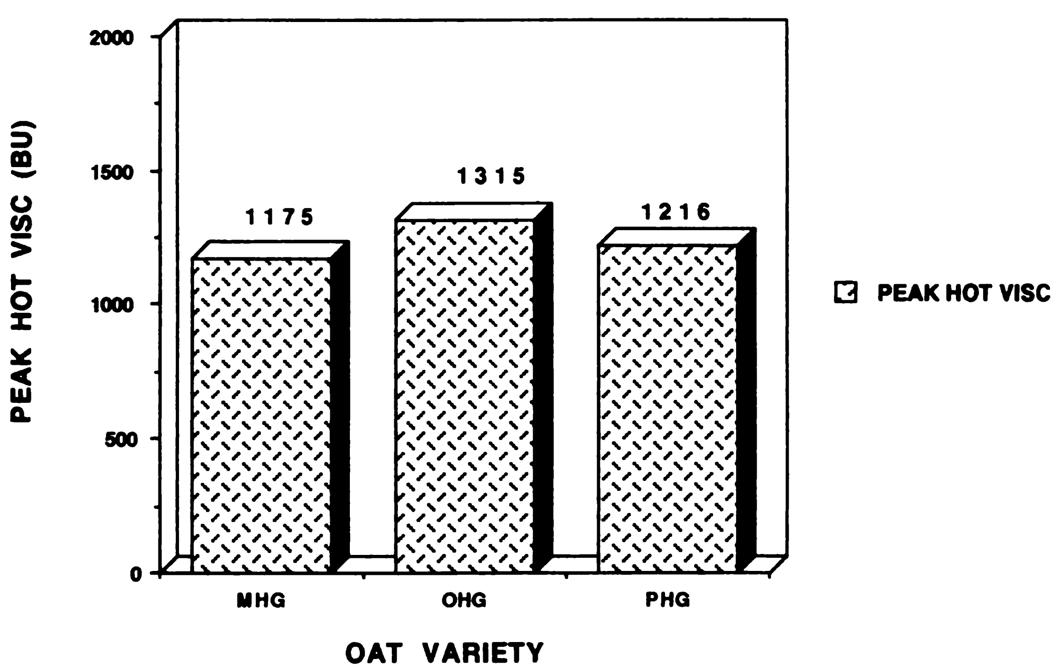
Table 65 also shows that sugar-snap cookies made with composites containing Porter oat flour had a significantly larger mean diameter than cookies made with composites of the other two oat cultivars. There was no significant difference in the diameter of cookies made with Mariner hammer milled groat oat flour and Ogle hammer milled groat oat flour.

Abboud et al (1985a) theorized that cookie diameter is a function of the rate of cookie dough spread and the setting time of the cookie dough. The influence of viscoamylograph properties on diameter of sugar-snap cookies prepared with oat wheat composite flours is not clear. Figure 35 shows that among hammer milled groat flours, Mariner groat flour did have the lowest initial pasting temperature which could have contributed to increased dough viscosity at an early stage of the baking process. There was no difference in the initial pasting temperatures of Ogle and Porter hammer milled groat flours. However, Ogle hammer milled groat flours did have the highest peak hot viscosity of the three flours and the ability to entrap a high percentage of free water may have

Figure 35. Viscoamylograph Properties of Hammer Milled Groat Flours. a) Initial Paste Temperature of Oat Flour Slurries. b) Peak Hot Viscosity of Oat Flour Slurries..



Initial Paste Temperature of Oat Flour Slurries (11% db)



Peak Hot Viscosity of Oat Flour Slurries (11% db) contributed to cookie dough viscosity at later point in the baking process.

The Abboud et al (1985a) study had conclusions that could support this theory. One conclusion was that a change occurs at low temperatures (30-40°C) in cookie doughs made from hard wheat flour that make the hard wheat cookie doughs set at a lower temperature than the soft wheat flours. The second conclusion was that cookie diameter increases linearly with baking time in the early and middle stages of baking. After 8.5 minutes into the baking period, cookie diameter was fixed and no changes could be measured by time lapse photography. Sugar-snap cookies made with oat-wheat composite flours exhibited a greater degree of dough expansion at the end of the eleven minute baking period. The cookie surface was not set and tended to collapse after removal from the oven.

Table 65 shows that addition of increasing levels of oat flour significantly increased the diameters of sugar-snap cookies. Each level of oat flour addition produced cookies with significantly different diameters. Sugar-snap cookies made with oat-wheat composite flours had larger diameters than the 100 percent soft wheat flour cookie.

Table 66 contains the means and standard deviations of cookie diameter and top grain scores. Substitution of hammer milled groat flour at the 15 and 30 percent level improved the top grain scores of cookies when compared to controls with few exceptions. The top grain score of a cookie prepared with 15 percent Mariner-Becker was less than the control despite having an increased diameter. The

Table 66 Means and standard deviations of cookie diameter and top grain scores of cookies measuring the effect of wheat cultivar on cookie quality

Oat-wheat composite flour	Oat flour (%)	Cookie diameter[1] (cm)	Top Grain Score
Mariner-Becker	30	18.17 ± 0.25	8.0
	15	17.66 ± 0.01	6.0
Ogle-Becker	30	17.96 ± 0.01	7.0
	15	17.38 ± 0.16	7.0
Porter-Becker	30	18.15 ± 0.12	8.2
	15	18.02 ± 0.03	7.5
Mariner-Caldwell	30	17.68 ± 0.26	8.7
	15	17.14 ± 0.03	8.0
Ogle-Caldwell	30	17.81 ± 0.01	8.5
	15	17.41 ± 0.06	8.3
Porter-Caldwell	30	17.88 ± 0.05	9.0
	15	17.72 ± 0.18	8.2
Mariner-Compton	30	17.67 ± 0.67	8.0
	15	17.55 ± 0.28	8.0
Ogle-Compton	30	17.74 ± 0.32	8.7
	15	17.52 ± 0.25	7.7
Porter-Compton	30	18.15 ± 0.00	8.5
	15	17.62 ± 0.13	7.5
Becker	0	17.05 ± 0.07	7.0
Caldwell	0	17.05 ± 0.42	7.0
Compton	0	16.72 ± 0.14	6.0

[1] n=2

independence of top grain and diameter is also seen in cookies made with Ogle-Becker composite flours. The top grain scores of 15 and 30 percent Ogle-Becker cookies were the same as the control. Only composites of Porter hammer milled groat flour were able to produce cookies with better top grain scores than the Becker control. Incorporation of Porter hammer milled groat flour into a oat-wheat composite flour consistently improved top grain scores of sugar-snap cookies.

Alkaline Water Retention Capacity:

Analysis of variance means for the main effects were influenced by the interaction between wheat cultivar and level of oat flour. There was a significant interaction for alkaline retention capacity of composite flour for wheat cultivar x level of oat flour as shown in Table 126 and illustrated in Figure 36. Increasing the level of oat flour in the composite from 15 to 30 percent had a lesser effect on oat-wheat composites containing Becker soft wheat flours. The lines appear to be parallel for composites of Caldwell and Compton soft wheat.

Table 67 shows the alkaline water retention capacity (AWRC) of Becker composite flours was significantly ($p<0.05$) higher than AWRC of Caldwell composite flours. The Becker composite flours had the highest AWRC and produced cookies with the largest diameters. The Caldwell composite flours had the smallest alkaline water retention capacities and prepared cookies with the smallest diameters.

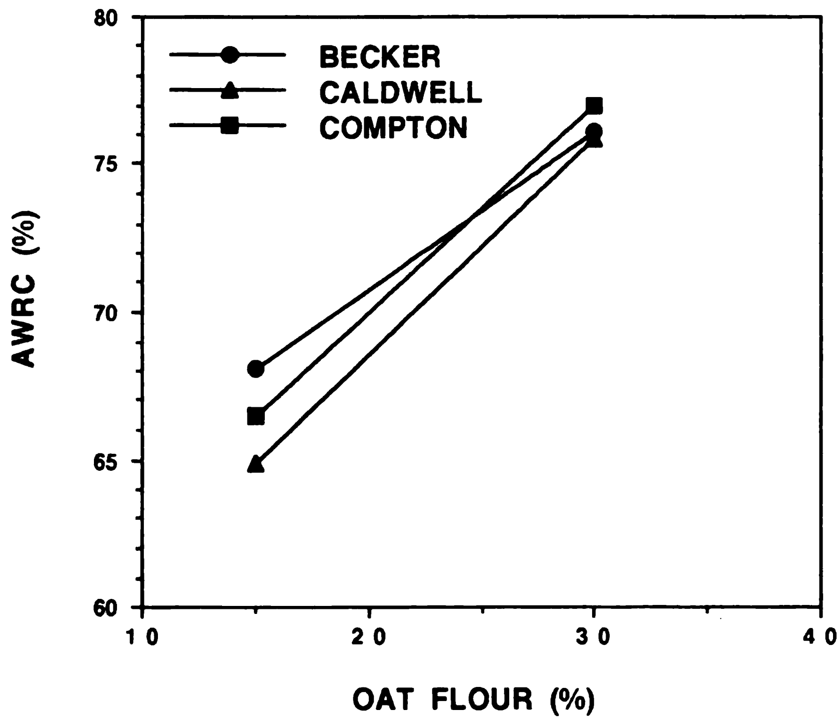


Figure 36. Interaction of Wheat Cultivar and Level of Oat Flour for Alkaline Water Retention Capacity of Composite Flours of Becker, Caldwell and Compton.

Table 67. Effect of wheat cultivar: Means for alkaline water retention capacity of oat-wheat composite flours

Main Effect	Classes	n	Alkaline water retention[1] (%)	Level of Significance
Wheat Cultivar			72.07[a]	
	Becker	12		
	Caldwell	12	70.38[b]	
	Compton	12	71.71[ab]	0.05
Oat Cultivar	Mariner	12	71.46[ab]	
	Ogle	12	69.62[b]	
	Porter	12	73.08[a]	0.01
Oat Flour Percent	15	18	66.48[b]	
	30	18	76.29[a]	0.01

[1] 14% moisture basis
Means in the same main effect having a different superscript are significantly different.

Abboud et al (1985b) prepared sugar-snap cookies with flours from forty-four wheat cultivars with the objective of determining why flour from one cultivar produces larger cookies than flour from another cultivar. The alkaline water retention capacities of the wheat flours ranged from 53.8 to 67.8% for the samples. Yamazaki (1953) had reported a high negative correlation (r= -0.85) between cookie diameter and AWRC of 100% wheat flours. Abboud et al (1985b) did not find as high a correlation (r= -0.63 to -0.78) but did conclude AWRC gave a better correlation than protein percent, starch damage percent, pentosan percent or MacMichael viscosity. Yamazaki (1959) had earlier concluded that flour factors other than granularity were more influential in determining cookie spread or diameter.

The correlations between cookie diameter and alkaline water retention capacity for the oat-wheat composite flours were all positive with a minimum level of significance of $p<0.06$. Figure 37 illustrates the correlations by wheat cultivar for cookie diameter and alkaline water retention capacity.

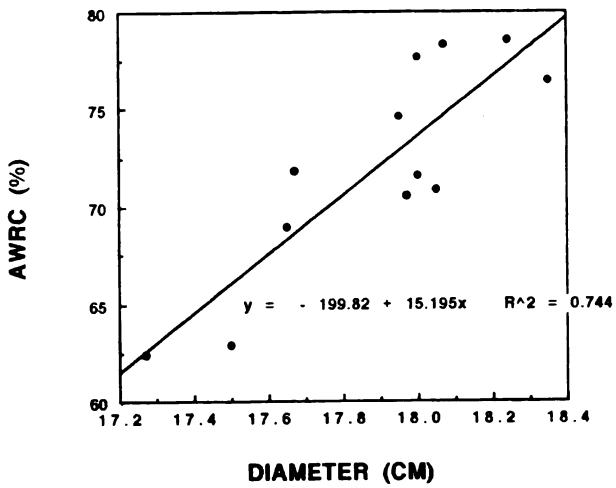
Table 67 shows Porter oat-wheat composite flours had the highest mean alkaline water retention capacity. It was not significantly different from the AWRC of Mariner oat-wheat composite flours at the $p<0.01$ level but it was significantly different at the $p<0.05$ level. The AWRC of Porter composite flours was also significantly different at the $p<0.01$ level from the mean alkaline water retention capacity of Ogle oat-wheat composite flours. The relative degree of AWRC of the composite flours was identical to that measured for the oat flours which indicated the influence of oat cultivar on the composite flour.

The correlation between cookie diameter of Porter composite cookies and alkaline water retention capacity was $r=0.80$ ($p<0.01$). The correlations for the two other oat flour composites were also positive and were respectively for Mariner $r=0.69$ ($p<0.02$) and for Ogle $r=0.74$ ($p<0.01$).

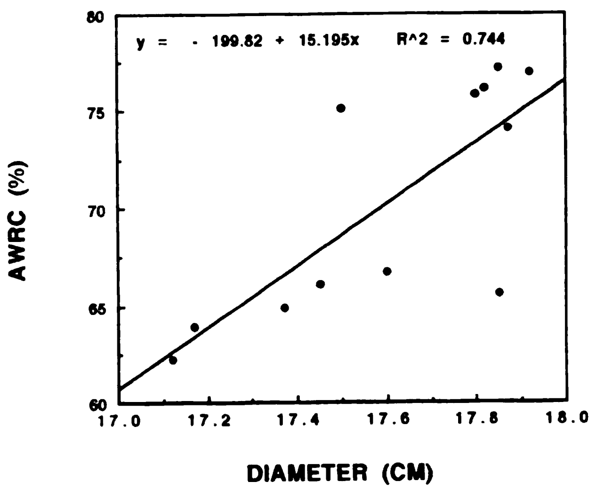
Table 67 also shows the mean alkaline water retention capacity of the composite flours significantly increased as increasing amounts of oat flours were added to the composites. The cookie doughs prepared with 30 percent oat flours had a lower

Figure 37. Correlation by Wheat Cultivar of Cookie Diameter and Alkaline Water Retention Capacity

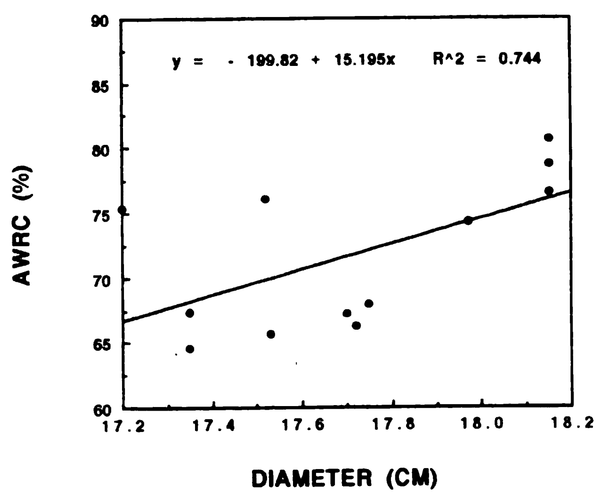
BECKER COOKIES



CALDWELL COOKIES



COMPTON COOKIES



requirement for added water to obtain the desirable dough consistency.

Chang and Sosulski (1985) reported that oat flour will hydrate 110 percent of its weight in water. The alkaline water retention capacities of hammer milled groat flours of the three cultivars used in this study were previously reported in Table 9 and ranged from 111.6 to 132.6 percent.

Materials that are capable of absorbing large amounts of water generally reduce sugar-snap cookie diameter. Yamazaki (1955) studied purified tailings and Sollars (1959) reported that the straight grade wheat flour non-starchy polysaccharides with a high pentose content would greatly reduce cookie diameter.

Kissel and Yamazaki (1975) added chemically modified and toasted soy flour to sugar-snap cookies. The alkaline water retention capacities of these soy derivatives ranged from 178-188 percent and contained about 51 percent protein. The conclusion was that increased water retention properties of these ingredients contributed to a reduction in cookie diameter. Jeltema et al (1983) substituted 20 percent oat bran in sugar-snap cookies and reported a significant decrease in cookie diameter. The sugar-snap cookie dough system is characterized as containing a limited amount of free water for which sugar and wheat flour compete.

The correlation between cookie diameter and alkaline water retention capacity was positive and highly significant for composites containing 15 percent oat flour ($r = 0.77$, $p<0.001$), However, the correlation between the same two parameters was greatly reduced and insignificant for cookies made with 30 percent composite flours.

Table 68 contains the means and standard deviations of alkaline water retention capacity for composite flours of each of the three soft wheat cultivars combined with each of the three oat cultivars. Oat wheat composite flours containing 30 percent hammer milled groat flour always had a higher alkaline water retention capacity than composites containing 15 percent oat flour. Soft wheat flours from all three cultivars had the highest alkaline water retention capacity when combined with Porter hammer milled groat flour.

Cookie surface color:

There were no significant interactions between the main effects for cookie surface color. Table 69 contains the Hunter Color Difference L-values of cookies. Sugar-snap cookies made with Compton composite flours had significantly higher L-values (lightness vs darkness) than cookies made with Becker composite flours. L-values for cookies made with Caldwell composite flours were not significantly different at the $p<0.01$ level from those determined for Becker or Compton cookies. There was no significant difference in Hunter color difference L-values for cookies made with any of the three oat-wheat composites. Porter oat-wheat composite cookies had the lowest L-values while Ogle oat-wheat composite flours had the highest L-values.

As the percentage of oat flour increased in sugar-snap cookies, there was a significant difference in Hunter color difference L-

Table 68 Means and standard deviations of alkaline water retention capacity measuring the effect of wheat cultivar on cookie quality

Oat-wheat composite flour	Oat flour (%)	Alkaline Water Retention[1] (%)
Mariner-Becker	30	77.08 ± 0.81
	15	70.41 ± 2.02
Ogle-Becker	30	72.60 ± 2.92
	15	62.62 ± 0.34
Porter-Becker	30	78.45 ± 0.15
	15	71.24 ± 0.52
Mariner-Caldwell	30	74.58 ± 0.71
	15	63.05 ± 1.16
Ogle-Caldwell	30	75.98 ± 0.25
	15	65.46 ± 0.87
Porter-Caldwell	30	77.08 ± 0.18
	15	66.15 ± 0.77
Mariner-Compton	30	75.98 ± 0.83
	15	67.62 ± 0.37
Ogle-Compton	30	75.17 ± 1.34
	15	65.88 ± 1.87
Porter-Compton	30	79.68 ± 1.38
	15	65.90 ± 0.42
Becker	0	57.64 ± 0.42
Caldwell	0	58.81 ± 1.05
Compton	0	60.48 ± 0.76

[1] n= 3 14% moisture basis

values (darkness to lightness) as shown in Table 69. Cookies from 15 percent oat-wheat composite flours had significantly higher L-values (lighter) than cookies containing 30 percent oat-wheat composite flours.

Table 69. Effect of wheat cultivar: Means for Hunter Color Difference L-values of cookies made with oat-wheat composite flours

Main Effect	Classes	n	L-value[1]	Level of Significance
Wheat Cultivar	Becker	12	50.89^{b}	
	Caldwell	12	52.08^{ab}	
	Compton	12	52.64^{a}	0.01
Oat Cultivar	Mariner	12	51.92^{a}	
	Ogle	12	52.14^{a}	
	Porter	12	51.55^{a}	ns
Oat Flour Percent	15	12	52.87^{a}	
	30	12	50.87^{b}	0.01

[1] L values = 0 (black) to 100 (white)
Means in the same main effect having a different superscript are significantly different.

Table 70 shows there was no significant difference in a-values (redness) among cookies made with the three wheat cultivars. Analysis of variance of a-values of cookies made with the three different oat cultivars indicated there was no significant difference between the means. As the percentage of oat flour increased in sugar-snap cookies, there was no significant difference in a-values or redness when the cookies were compared.

Table 70. Effect of wheat cultivar: Means for Hunter Color Difference a-values of cookies made with oat-wheat composite flours

Main Effect	Classes	n	a-value[1]	Level of Significance
Wheat Cultivar	Becker	12	5.82[a]	
	Caldwell	12	5.63[a]	
	Compton	12	5.91[a]	ns
Oat Cultivar	Mariner	12	5.73[a]	
	Ogle	12	5.74[a]	
	Porter	12	5.88[a]	ns
Oat Flour Percent	15	18	5.74[a]	
	30	18	5.83[a]	ns

[1] a values = positive values indicate redness
Means in the same main effect having a different superscript are significantly different.

There was no significant difference in b-values (yellowness) among cookies made with the three wheat cultivars as shown by Table 71. There were also no significant differences in any of the Hunter color difference values for cookies made with any of the three oat-wheat composites. The b-values (yellowness) of cookies made from 15 percent oat-wheat composite flours were significantly more yellow than cookies made with 30 percent oat-wheat composite flours.

The same effect on Hunter L- and b-values was reported for cookies made with oat bran (Jeltema et al, 1983). The L-value or lightness of the cookie was significantly reduced by the addition of 20 percent oat bran. The yellowness or b-value of cookies was significantly reduced by addition of oat bran. However, oat bran also effected the a-value or redness of sugar-snap cookies.

Table 71. Effect of wheat cultivar: Means for Hunter Color Difference b-values of cookies made with oat-wheat composite flours

Main Effect	Classes	n	b-value[1]	Level of Significance
Wheat Cultivar	Becker	12	19.17[a]	
	Caldwell	12	19.19[a]	
	Compton	12	19.81[a]	ns
Oat Cultivar	Mariner	12	19.16[a]	
	Ogle	12	19.19[a]	
	Porter	12	19.14[a]	ns
Oat Flour Percent	15	18	19.60[a]	
	30	18	18.73[b]	0.01

[1] b values = positive values indicate yellowness
Means in the same main effect having a different superscript are significantly different.

Table 72 contains the means and standard deviations of color difference of cookie surfaces measuring the effect of wheat cultivar on cookie quality. Cookies made with oat flour composites containing 30 percent oat flour were consistently darker (smaller L-values) than cookies containing 15 percent oat flour. The same relationship was seen for b-values (yellowness) when cookies containing 30 percent oat flour were compared to cookies containing 15 percent oat flour.

Table 72. Means and standard deviations of Hunter color difference values of cookies measuring effect of wheat cultivar on cookie quality [1]

Oat-wheat composite flour	Oat flour (%)	Hunterlab Color Difference		
		L	a	b
Mariner-Becker	30	50.07 ± 1.92	5.73 ± 0.44	18.65 ± 1.22
	15	51.91 ± 0.20	5.77 ± 0.18	19.28 ± 0.37
Ogle-Becker	30	50.07 ± 0.11	5.85 ± 0.07	18.36 ± 0.93
	15	51.93 ± 0.47	5.78 ± 0.21	18.93 ± 0.80
Porter-Becker	30	48.97 ± 0.46	6.15 ± 0.42	18.06 ± 0.65
	15	52.38 ± 1.46	5.63 ± 0.30	19.38 ± 0.97
Mariner-Caldwell	30	51.82 ± 1.17	5.22 ± 0.32	18.80 ± 0.56
	15	51.97 ± 1.24	5.87 ± 0.67	18.97 ± 0.11
Ogle-Caldwell	30	51.40 ± 0.07	6.02 ± 0.46	18.55 ± 0.07
	15	54.00 ± 0.28	5.20 ± 0.07	19.97 ± 0.03
Porter-Caldwell	30	50.30 ± 0.14	5.80 ± 0.00	18.70 ± 0.07
	15	53.00 ± 0.28	5.65 ± 0.07	19.80 ± 0.21
Mariner-Compton	30	52.26 ± 0.30	5.77 ± 0.49	19.31 ± 0.27
	15	53.51 ± 0.37	6.02 ± 0.07	20.17 ± 0.35
Ogle-Compton	30	51.61 ± 1.00	5.87 ± 0.35	19.27 ± 0.32
	15	53.85 ± 1.41	5.72 ± 0.07	20.07 ± 0.14
Porter-Compton	30	51.31 ± 2.32	6.01 ± 0.34	19.02 ± 0.67
	15	53.31 ± 0.44	6.09 ± 0.30	19.85 ± 0.49
Becker	0	54.96 ± 0.13	5.78 ± 0.23	20.71 ± 0.01
Caldwell	0	56.67 ± 0.18	5.67 ± 0.25	20.15 ± 0.64
Compton	0	55.72 ± 0.18	6.12 ± 0.11	20.98 ± 0.16

[1] n= 2

Proximate analyses of cookies:

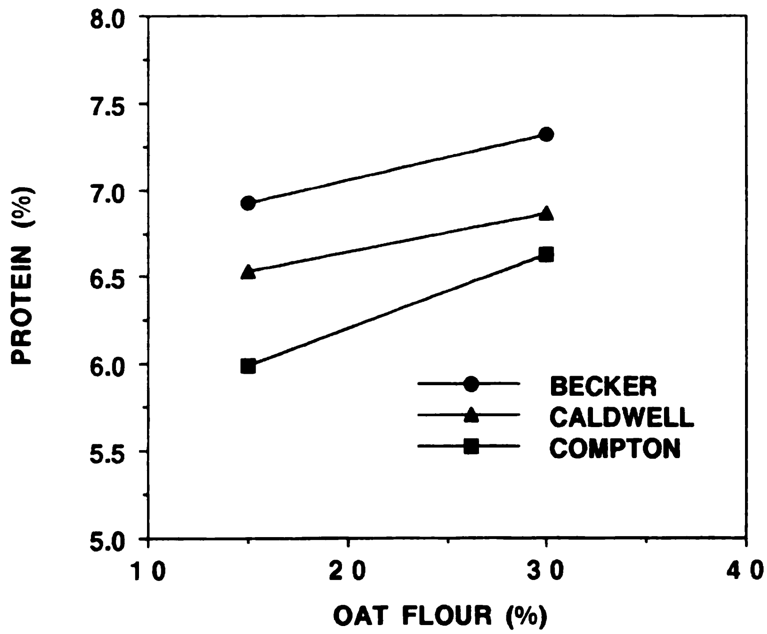
Analysis of variance means for the main effects were influenced by the interaction of wheat cultivar x level of oat flour and oat cultivar x level of oat flour. From Table 130 and Figure 38a it can be seen that the interaction of wheat cultivar x level of oat flour was significant for cookie protein content. Incorporation of an addition 15 percent oat flour had a greater influence on protein content of cookies made with Compton composite flours. Compton soft wheat flour did contain the lowest percentage of protein among the wheat flours used in this study.

The interaction of oat cultivar and level of oat flour was significant for cookie protein content as shown in Figure 38b. The lines appear parallel and the slopes are steeper for cookies made with the two high protein oat cultivars, Mariner and Porter. The incorporation of high protein hammer milled groat flours had a greater effect on the protein content of cookies made from the composite flours than of oat flour containing a significantly lower percentage of protein.

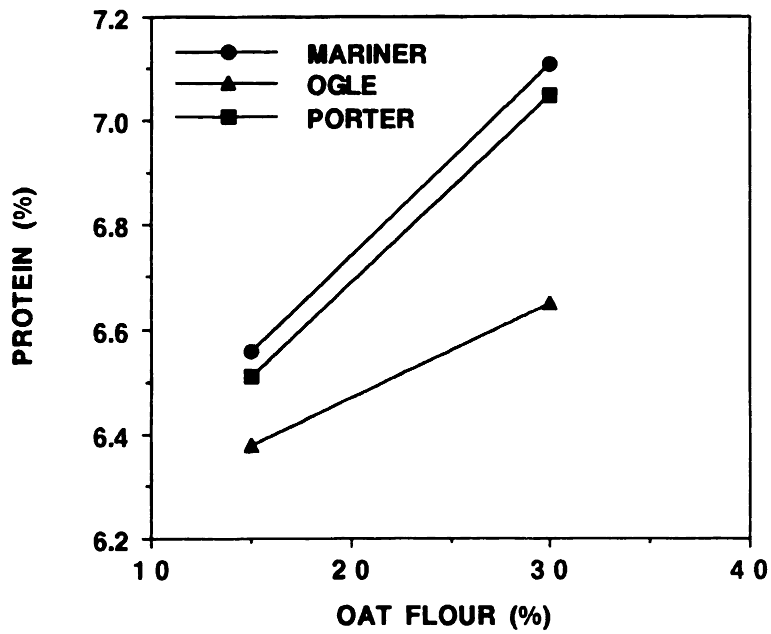
Cookie ash had a significant interaction for wheat cultivar x level of oat flour as shown in Table 131 and illustrated in Figure 39. The steeper slope for cookie ash content of cookies made with Compton composites is due to the fact that Compton contained the highest percent of ash.

Analysis of variance results for protein, ash and fat content of cookies by wheat cultivar are contained in Tables 73-75. Cookies prepared with the three soft wheat flour composites contained significantly different levels of protein. The Becker composites

Figure 38. Interactions of Wheat Cultivar, Oat Cultivar and Level of Oat Flour for Cookie Protein Content.



Wheat Cultivar x Level of Oat Flour Interaction for Cookie Protein Content



Oat Cultivar x Level of Oat Flour Interaction for Cookie Protein Content

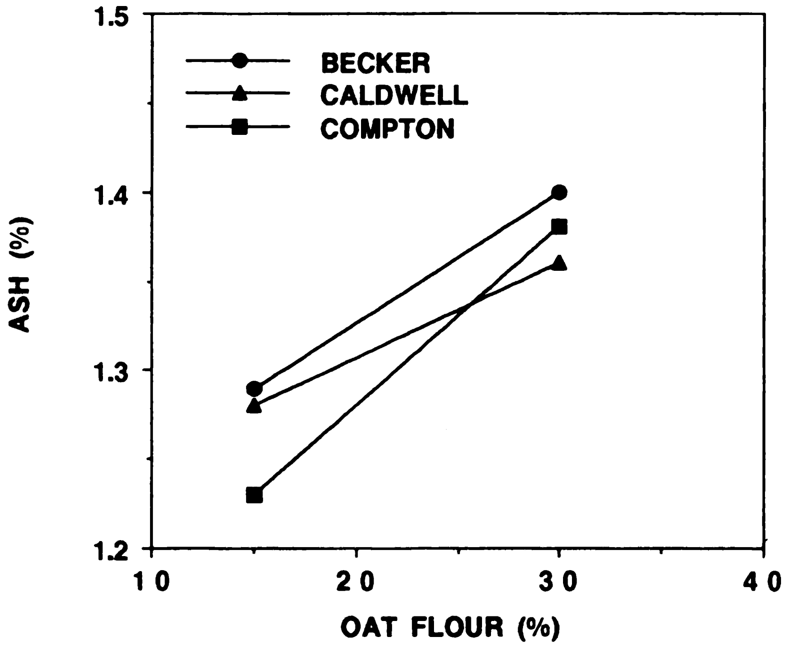


Figure 39. Interaction of Wheat Cultivar and Level of Oat Flour for Cookie Ash Content.

contained the highest percentage and Compton composites contained the lowest percentage of protein. Cookies prepared with composites of Mariner and Porter oat flours contained a significantly higher percentage of protein than cookies made from composites of Ogle oat flour. The percentage of protein significantly increased in sugar-snap cookies as increasing levels of oat flours were incorporated into the composites.

Table 73. Effect of wheat cultivar: Means for protein content of cookies made with oat-wheat composite flours

Main Effect	Classes	n	Protein[1] (%)	Level of Significance
Wheat Cultivar	Becker	12	7.13^a	
	Caldwell	12	6.70^b	
	Compton	12	6.30^c	0.01
Oat Cultivar	Mariner	12	6.83^a	
	Ogle	12	6.51^b	
	Porter	12	6.78^a	0.01
Oat Flour Percent	15	18	6.49^b	
	30	18	6.93^a	0.01

[1] Dry basis
Means in the same main effect having a different superscript are significantly different.

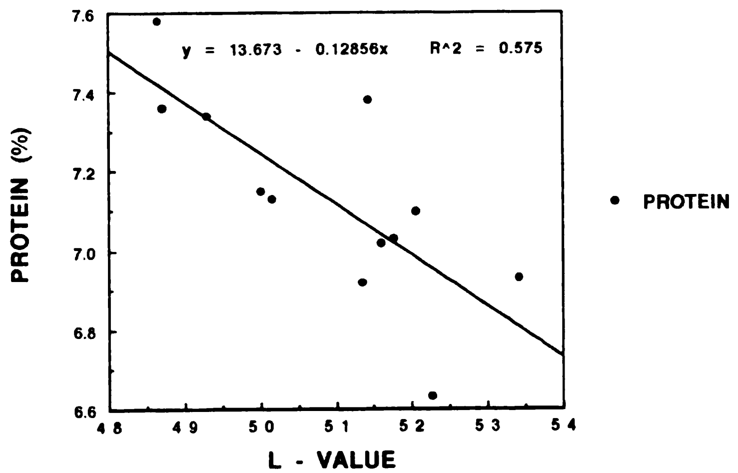
Hunter color values for sugar-snap cookies may have been influenced by composite flour protein content along with other factors. The correlation between L-value and cookie protein content for Becker composite cookies was r=-0.75 with p<0.01. The correlation for cookies made with Caldwell soft wheat composites was $r=-0.74$ with $p<0.01$ and comparable to the values for Becker cookies However, the correlation was neither strong nor significant for cookies made with Compton composite flours. These correlations are illustrated in Figure 40.

The correlations between protein content and Hunter difference L-values for Mariner, Ogle and Porter composite cookies were respectively $r=-0.73$ ($p<0.01$); $r=-0.71$ ($p<0.01$); $r=-0.72$ ($p<0.01$) and are illustrated in Figure 41. When compared with the same correlations by wheat cultivar as shown in Figure 40, it could be concluded that oat protein may have influenced sugar-snap cookie color more than wheat protein.

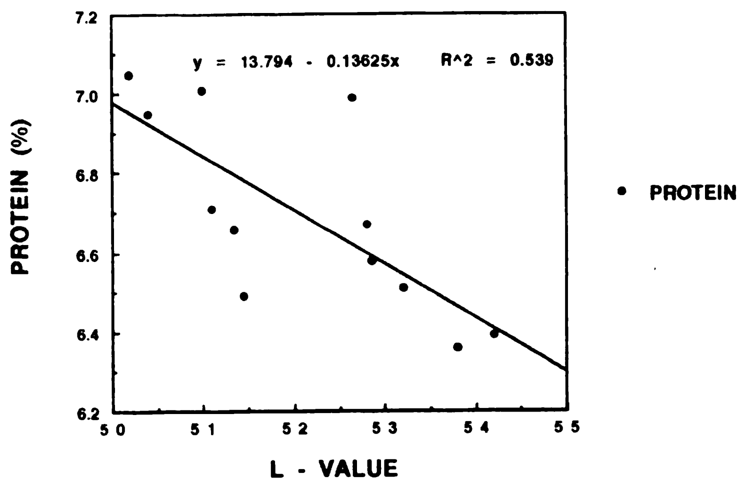
The correlations between protein content and Hunter Color Difference L- and b-values are negative and statistically significant for both levels of hammer milled groat flour substitution. The Pearson correlation coefficients between protein content and L- and b-values for cookies made with 15 percent oat-wheat composite flours are respectively; $r= -0.69$ ($p<0.001$) and $r= -0.56$ ($p<0.01$). The correlation coefficients between protein content and L- and b-values for cookies made with 30 percent oat wheat composite flours are respectively; $r=-0.50$ ($p<0.03$) and $r=-0.48$ ($p<0.04$).

Table 74 shows Becker composite cookies contained significantly higher levels of ash than cookies made with Compton soft wheat composite flours. Ash or mineral content indicates the level of areas of the kernel adjacent to the bran and bran coat that were incorporated into the flour during milling (Mailhot and Patton, 1988). Becker soft wheat flour did not contain the highest

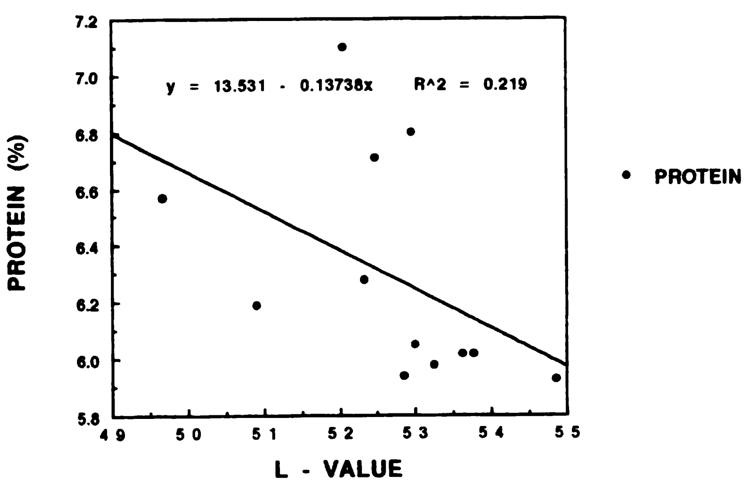
Figure 40. Correlation between Protein Content and Hunter Color Difference L-values for Cookies Made with Composites of Becker, Caldwell and Compton Soft Wheat Flours



Correlation Between Protein Content and Hunter Color
L-value of Becker Cookies

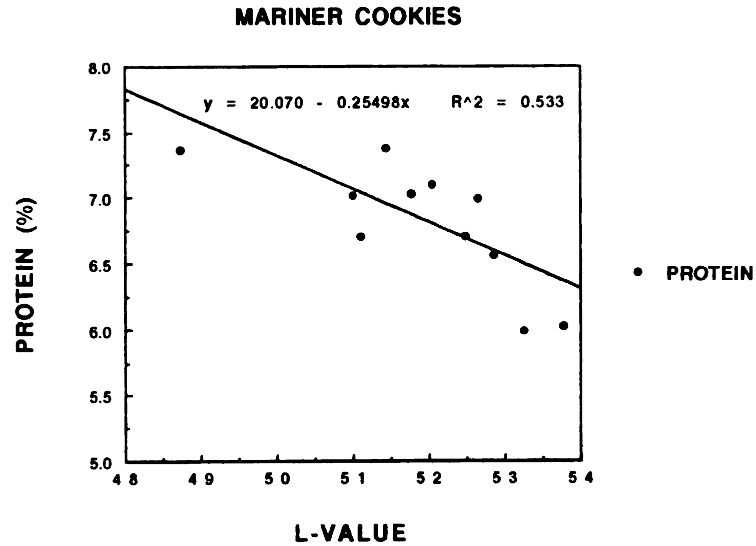


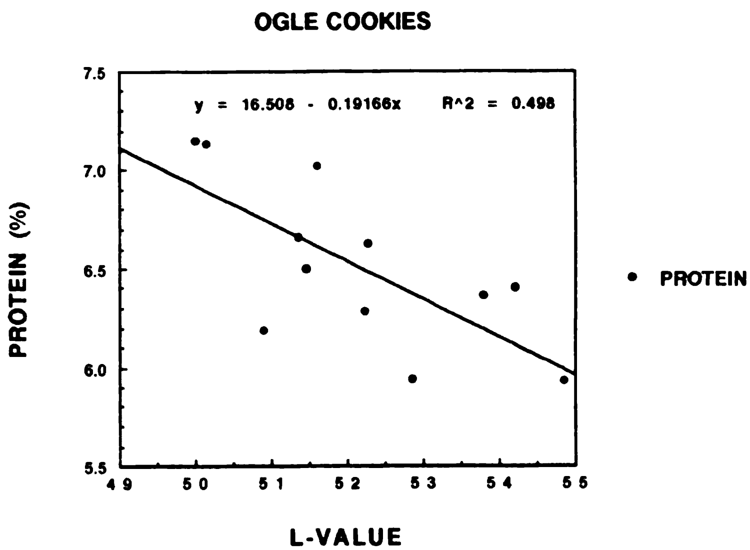
Correlation Between Protein Content and Hunter Color
L-value of Caldwell Cookies

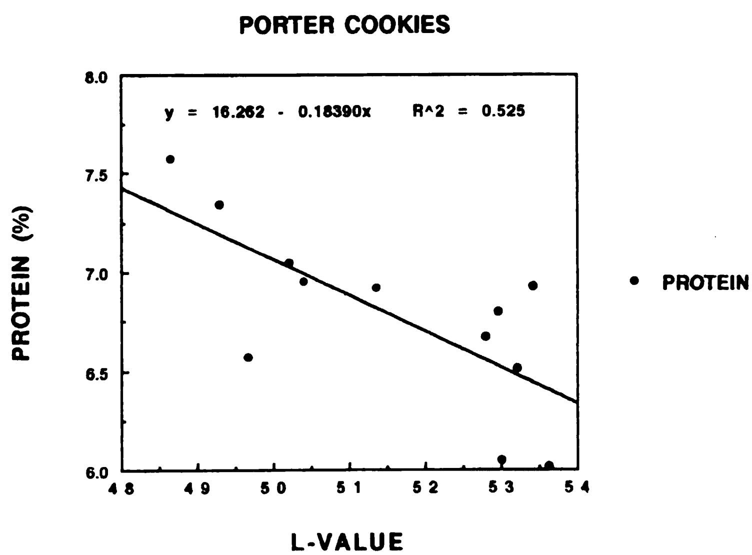


Correlation Between Protein Content and Hunter Color
L-value of Compton Cookies

Figure 41. Correlation between Protein Content and Hunter Color Difference L-Values for Cookies made With Composites of Mariner, Ogle and Porter Hammer Milled Groat Flours


MARINER COOKIES
y = 20.070 - 0.25498x
R^2 = 0.533
PROTEIN (%)
L-VALUE
PROTEIN


OGLE COOKIES
y = 16.508 - 0.19166x
R^2 = 0.498
PROTEIN (%)
L-VALUE
PROTEIN


PORTER COOKIES
y = 16.262 - 0.18390x
R^2 = 0.525
PROTEIN (%)
L-VALUE
PROTEIN

percentage ash but substitution of oat flour for the wheat flour markedly increased ash content of the resulting composite. There was not a significant difference in percentage of ash when cookies made from flours of the three oat cultivars were compared. The percentage of ash significantly increased in sugar-snap cookies as increasing levels of oat flours were incorporated into the composites.

Table 74. Effect of wheat cultivar: Means for ash content of cookies made with oat-wheat composite flours

Main Effect	Classes	n	Ash[1] %	Level of Significance
Wheat Cultivar	Becker	12	1.34[a]	
	Caldwell	12	1.32[ab]	
	Compton	12	1.30[b]	0.01
Oat Cultivar	Mariner	12	1.33[a]	
	Ogle	12	1.31[a]	
	Porter	12	1.32[a]	ns
Oat Flour Percent	15	18	1.26[b]	
	30	18	1.38[a]	0.01

[1] Dry basis
Means in the same main effect having a different superscript are significantly different.

Cookies made with Caldwell composite flours contained a significantly higher percentage of lipid than cookies made with Becker composite flours as seen in Table 75. There was no significant difference in lipid content of cookies made from composites of the three oat cultivars. The percentage of lipid significantly increased in sugar-snap cookies as increasing levels of oat flours were incorporated into the composites.

Table 75. Effect of wheat cultivar: Means for fat content of cookies made with oat-wheat composite flours

Main Effect	Classes	n	Fat[1] %	Level of Significance
Wheat Cultivar	Becker	12	16.37[b]	
	Caldwell	12	17.31[a]	
	Compton	12	17.10[ab]	0.01
Oat Cultivar	Mariner	12	16.82[a]	
	Ogle	12	16.94[a]	
	Porter	12	17.02[a]	ns
Oat Flour Percent	15	18	16.67[b]	
	30	18	17.19[a]	0.01

[1] Dry basis
Means in the same main effect having a different superscript are significantly different.

Table 76 contains the means and standard deviations for protein, ash and fat content for cookies prepared with composites of the three wheat cultivars and three oat cultivars. Cookies prepared with oat-wheat composite flours had significantly higher protein content than the 100 percent soft wheat flour control. The ash or mineral content of sugar-snap cookies was also increased by substitution of hammer milled groat flours at the 15 and 30 percent level. The increased lipid content of cookies made with composite flours was expected to be related to levels of oat flour substitution. However, a higher percent of lipid was not always extracted from

Table 76. Means and standard deviations of protein, ash and fat content of cookies measuring the effect of wheat cultivar on cookie quality.[1]

Oat-wheat composite flour	Oat flour (%)	Protein[2,3] (%)	Ash[2] (%)	Lipid [2] (%)
Mariner-Becker	30	7.37 ± 0.01	1.44 ± 0.01	17.09 ± 0.49
	15	7.06 ± 0.05	1.29 ± 0.03	14.81 ± 0.67
Ogle -Becker	30	7.14 ± 0.01	1.39 ± 0.02	16.10 ± 1.01
	15	6.82 ± 0.27	1.30 ± 0.04	16.70 ± 0.24
Porter-Becker	30	7.46 ± 0.17	1.36 ± 0.01	16.14 ± 0.84
	15	6.92 ± 0.01	1.27 ± 0.01	17.36 ± 0.54
Mariner-Caldwell	30	7.00 ± 0.02	1.36 ± 0.06	17.23 ± 0.25
	15	6.63 ± 0.11	1.31 ± 0.00	16.91 ± 0.01
Ogle-Caldwell	30	6.58 ± 0.11	1.33 ± 0.05	18.00 ± 0.82
	15	6.38 ± 0.03	1.29 ± 0.01	16.77 ± 0.82
Porter-Caldwell	30	7.00 ± 0.07	1.40 ± 0.00	17.36 ± 0.05
	15	6.59 ± 0.11	1.24 ± 0.03	17.57 ± 0.49
Mariner-Compton	30	6.95 ± 0.27	1.38 ± 0.01	18.06 ± 0.59
	15	6.00 ± 0.03	1.25 ± 0.01	16.80 ± 0.18
Ogle-Compton	30	6.23 ± 0.06	1.36 ± 0.02	17.27 ± 0.30
	15	5.93 ± 0.01	1.21 ± 0.01	16.83 ± 0.05
Porter-Compton	30	6.68 ± 0.16	1.39 ± 0.01	17.40 ± 0.20
	15	6.03 ± 0.02	1.23 ± 0.00	16.26 ± 0.24
Becker	0	6.63 ± 0.02	1.24 ± 0.01	15.31 ± 0.02
Caldwell	0	6.04 ± 0.03	1.12 ± 0.02	15.81 ± 0.46
Compton	0	5.62 ± 0.12	1.23 ± 0.00	14.02 ± 0.69

[1] n= 2

[2] Dry basis [3] (N x 6.25)

Means in the same column having a different superscript are significantly different at $p<0.01$

cookies containing 30 percent composite flours compared to cookies containing 15 percent composite flours.

Moisture Retention:

Moisture retention percent was calculated by dividing the percent moisture in cookie crumbs by the percent moisture in the respective cookie dough. There were no significant interactions among the main effects for moisture retention. There was no significant difference in moisture retention percentage among cookies made with composite flours of the three soft wheat cultivars as seen in Table 77. The large standard deviations in moisture retention percentage influenced analysis of variance results.

The difference in moisture retention was not significant at the $p<0.05$ level between the oat flour composite cookies. Cookies made with Ogle composite flours retained a higher percentage of moisture than cookies made with other composite flours.

There was no significant difference at the $p<0.05$ level between means of cookies made with 15 and 30 percent oat-wheat composite flour for moisture retention as shown in Table 77. Cookies that were made of 30 percent oat-wheat composite flours had the highest moisture retention. Less water was required to obtain optimum dough consistency with 30 percent oat-wheat composite flours than for 15 percent oat-wheat composite flour. The sugar-snap cookie formula contains a high percentage of sugar (60 percent of flour weight) and a relatively low percentage of water (depending on flour about 23 percent of flour weight). The added water may have been more tightly held by hydrophillic materials and sites within cookie doughs containing 30 percent hammer milled groat flours.

Table 77. Effect of wheat cultivar: Means for moisture retention of cookies made with oat-wheat composite flours

Main Effect	Classes	n	Moisture Retention (%)	Level of Significance
Wheat Cultivar	Becker	12	19.86[a]	
	Caldwell	12	19.60[a]	
	Compton	12	20.26[a]	ns
Oat Cultivar	Mariner	12	18.86[a]	
	Ogle	12	20.62[a]	
	Porter	12	20.24[a]	ns
Oat Flour Percent	15	18	19.43[a]	
	30	18	20.39[a]	ns

[1] Dry basis
Means in the same main effect having a different superscript are significantly different.

<u>Shear compression and breaking strength:</u>

There were no significant interactions between the main effects for shear compression or breaking strength. Cookies made with Becker soft wheat composite flours did have significantly higher shear compression values than cookies made from composites of Caldwell and Compton flour as seen in Table 78. The most force was required to shear cookies made with Becker composite flours while the least amount of force was required to shear cookies made with Caldwell composite flours.

Table 78 shows the mean shear compression value of cookies made with Ogle composite flours was significantly higher than those for cookies made from Mariner composite flours. Mariner composite cookies had the lowest mean shear compression score but it was not significantly different from Porter cookies.

Table 78. Effect of wheat cultivar: Means for shear compression of cookies made with oat-wheat composite flours

Main Effect	Classes	n	Shear Compression (lb/gm)	Level of Significance
Wheat Cultivar	Becker	12	22.51^{a}	
	Caldwell	12	19.71^{b}	
	Compton	12	21.45^{a}	0.01
Oat Cultivar	Mariner	12	20.68^{b}	
	Ogle	12	22.14^{a}	
	Porter	12	20.84^{ab}	0.01
Oat Flour Percent	15	12	22.39^{a}	
	30	12	20.03^{b}	0.01

Means in the same main effect having a different superscript are significantly different.

Shear compression was used as an indicator of cookie tenderness. Table 78 also contains mean shear compression values for cookies made with hammer milled groat flours substituted at the two levels. Incorporation of increasing higher levels of oat flours in sugar-snap cookies significantly decreased the shear compression values or increased cookie tenderness. Each levels of oat flour substitution had significantly different shear compression values.

Breaking strength was an indicator of cookie crispness. Cookies made with Becker composites had breaking strength scores close in value to the 100 percent Becker soft wheat cookie. Cookies made with Caldwell composite flours had a significantly higher mean breaking strength or were more crisp than cookies made with Compton composite flours as seen in Table 79. There was no significant difference in breaking strength scores of cookies made with composite oat-wheat flours of the three oat cultivars. There was also no significant difference for breaking strength or crispness of cookies made with the two levels of oat flour.

Table 79. Effect of wheat cultivar: Means for breaking strength of cookies made with oat-wheat composite flours

Main Effect	Classes	n	Breaking Strength (lb/cm^2)	Level of Significance
Wheat Cultivar	Becker	12	10.03^{ab}	
	Caldwell	12	11.20^{a}	
	Compton	12	9.65^{b}	0.05
Oat Cultivar	Mariner	12	10.65^{a}	
	Ogle	12	10.19^{a}	
	Porter	12	10.04^{a}	ns
Oat Flour Percent	15	18	10.35^{a}	
	30	18	10.23^{a}	ns

Means in the same main effect having a different superscript are significantly different.

Jeltema et al (1983) reported that substitution of 20 percent oat bran in sugar-snap cookies did not significantly effect the shear compression or breaking strength. Sugar-snap cookies made from 20 and 30 percent navy bean flour became more tender as higher amounts of navy bean flour was substituted in the composite (Hoojjat and Zabik, 1984). Vratanina and Zabik (1978) incorporated red and white wheat brans into sugar-snap cookies to increase fiber content. The cookies became more tender as wheat bran levels were increased from 10 to 20 to 30 percent.

Table 80 contains the means and standard deviations moisture retention percentage, shear compression and breaking strength of cookies measuring the effect of wheat cultivar. The large standard deviations in moisture retention percentage influenced analysis of variance results. Cookies made with Becker soft wheat flours had a wide range in moisture retention so no meaningful comparison could be made with composite cookies. Moisture retention percent of Caldwell composites had large standard deviations at the 15 percent level for Mariner composites and the 30 percent level for Porter composites. Among cookies containing Compton soft wheat flour, only Ogle-Compton 30 percent composite cookies had a wide range of moisture retention. Cookies prepared from the other Compton composites were comparable in moisture retention to the control cookies.

Substitution of 15 and 30 percent hammer milled groat flour into sugar-snap cookies increased the tenderness or lowered the shear compression of the oat-wheat composite cookies compared to cookies made with 100 percent soft wheat flour. Breaking strength

Table 80 Means and standard deviations of moisture retention, shear compression and breaking strength of cookies measuring the effect of wheat cultivar[1]

Oat - wheat composite flour and mill	Oat flour (%)	Moisture Retention (%)	Shear Compression lb/g	Breaking Strength lb/cm^2
Mariner-Becker	30	18.05 ± 6.21	20.72 ± 0.85	11.38 ± 2.75
	15	17.82 ± 7.16	23.22 ± 0.30	8.38 ± 0.62
Ogle-Becker	30	24.85 ± 3.96	22.51 ± 0.11	10.23 ± 0.00
	15	17.57 ± 0.19	24.65 ± 1.54	10.65 ± 0.64
Porter-Becker	30	21.27 ± 2.37	21.40 ± 0.99	9.00 ± 0.30
	15	19.65 ± 2.33	22.54 ± 0.13	10.52 ± 0.52
Mariner-Caldwell	30	19.70 ± 3.44	16.80 ± 3.01	10.64 ± 0.27
	15	21.12 ± 8.77	20.98 ± 0.22	12.96 ± 1.88
Ogle-Caldwell	30	20.08 ± 1.51	18.87 ± 0.71	10.01 ± 1.82
	15	14.68 ± 0.10	21.86 ± 1.07	12.21 ± 1.09
Porter-Caldwell	30	22.67 ± 8.37	19.39 ± 0.26	10.54 ± 0.42
	15	19.33 ± 3.31	20.32 ± 0.07	10.83 ± 0.12
Mariner-Compton	30	13.50 ± 0.68	19.93 ± 0.43	11.63 ± 0.38
	15	23.00 ± 0.61	22.45 ± 1.09	8.88 ± 0.53
Ogle-Compton	30	23.97 ± 10.98	21.34 ± 0.73	8.37 ± 0.18
	15	22.59 ± 3.62	23.58 ± 2.00	9.64 ± 1.02
Porter-Compton	30	19.43 ± 3.99	19.33 ± 0.11	10.25 ± 1.56
	15	19.06 ± 1.42	22.05 ± 0.06	9.10 ± 0.90
Becker	0	25.02 ± 10.22	31.69 ± 2.77	10.79 ± 0.17
Caldwell	0	21.23 ± 0.65	28.50 ± 2.76	13.60 ± 2.90
Compton	0	23.39 ± 1.19	25.24 ± 2.11	15.72 ± 2.13

[1] n = 2

scores or crispness did not have a similar trend. Cookies made with Becker composites had breaking strength scores close to the value of the 100 percent Becker soft wheat cookie. At the 15 percent level of substitution, cookies made with Caldwell soft wheat flour had scores close in value to the control with the exception of Caldwell-Porter cookies. Sugar-snap cookies made with Compton composites at both levels of substitution were significantly less crisp than the 100 percent Compton soft wheat flour cookie.

SUMMARY AND CONCLUSIONS

The objective of the study was to observe the functionality of oat-wheat composite flours in sugar-snap cookies. The study was divided into three parts. Part one was the production of whole grain oat flour from three oat cultivars; Mariner, Ogle and Porter. Part two was the evaluation of chemical and physical properties of the oat flours. Part three was measuring the functionality of oat flours in sugar-snap cookies when substituted at two levels for soft wheat flours from three wheat cultivars; Becker, Caldwell and Compton.

Half of the groats from each oat cultivar were steamed and flaked into rolled oats. The groats and flakes from each oat cultivar were divided in half and separately milled into flour by hammer milling and by roller milling.

There were mill related differences in the proximate analyses results, flour particle size, alkaline water retention capacity of oat flour, viscoamylograph properties of flour and starch. Roller milled oat flours contained a significantly lower percentage of protein than hammer milled oat flours. Hammer milled oat flours had a significantly lower moisture content than roller milled oat flours. A higher percentage of fat was extracted from roller milled oat flours than from hammer milled oat flours. A higher percentage of total dietary fiber was measured for roller milled oat flours than for hammer milled oat flours.

Particle sizing of oat flours by Particle Size Index and Hunter Color Difference values (L-, a- and b-values) for oat flour color indicated that roller milling produced a higher percentage of finer oat flour particles than hammer milling. The Hunter Color Difference values measured for oat flours were influenced by the mill type interacting with oat form. Roller milled oat flours had significantly higher alkaline water retention capacities (AWRC) and lower initial pasting temperatures than hammer milled oat flours. These functional results agreed with the physical measures of relative particle size that roller milled oat flours had a finer average particle size.

Alkaline extracted oat starches from hammer milled flours had higher initial pasting temperatures than oat starches from roller milled flours but the difference was not statistically significant. Oat starches from hammer milled oat flours also had significantly higher 30 minute hot viscosities and peak cold viscosities than starches from rolled milled flours.

There were oat form related differences in proximate analyses, flour particle size, alkaline water retention capacity of oat flours and viscoamylograph properties of flour. The protein content of oat flours milled from oat flakes was significantly higher than oat flours milled from oat groats. There was no significant difference between ash content of oat flours milled from groats and from flakes. A higher percentage of fat was extracted from oat flours milled from flakes than from oat flours milled from groats. Oat flours milled from flakes were determined to contain a higher percentage of total dietary fiber than oat flours milled from groats.

There was no significant difference in particle size index when oat flours milled from groats were compared to oat flours milled from flakes. Hunter Color Difference L-, a- and b-values indicated oat flours milled from flakes contained a higher percentage of fine flour particles than oat flours milled from groats. Oat flours milled from flakes had significantly higher AWRC than oat flours milled from groats.

Oat flours milled from groats had an higher initial paste temperature than oat flours milled from flakes. There was no significant difference in peak hot viscosity, 15 minute viscosity or peak cold viscosity between flours milled from groats or flakes. There was no significant difference between the viscoamylograph properties of oat starch extracted from oat flours milled from groats or flakes. Scanning electron micrographs showed alkali extracted oat starches contained compound starch granules with varying degrees of individual granule loss. Oat starches extracted from oat flours milled from flakes contained a significantly higher percentage of protein than oat starches extracted from flours milled from groats.

There were oat cultivar related differences in proximate analyses, flour particle size, alkaline water retention capacity of oat flour, viscoamylograph properties of oat flour and starch. Mariner and Porter oat flours were higher in protein and ash content than Ogle oat flours. Each of the three oat cultivars contained a significantly different percentage of fat. Porter oat flours contained the highest percentage of fat. There were no significant differences between oat cultivars for any of the three classes of lipids. Porter oat flours contained a significantly higher percentage of β-glucan than oat flours from the two other oat cultivars.

There was no significant difference in particle size index among the three oat cultivars. Hunter Color Difference values indicated Ogle flours had a finer average particle size than flour from the two other cultivars. The Hunter Color Difference values for oat flours were influenced by oat cultivar interacting with oat form. There was a significant difference in AWRC among the three oat cultivars. Porter had the highest AWRC while Ogle had the lowest AWRC. The functional results disagreed with the physical measures of Particle Size Index and Hunter L-values (lightness). The AWRC of the Porter cultivar may have been influenced by the presence of an intact aleurone layer in the coarse flour fraction that trapped additional water inside the physical structure.

Ogle oat flours had a significantly higher initial paste temperature and 15 minute viscosity than flours from Mariner or Porter oats. Oat flours from the Mariner cultivar had a significantly lower 15 minute viscosity and peak cold viscosity than flours from Ogle and Porter oats. Oat starches from Ogle flours had significantly lower initial pasting temperatures than oat starches from Mariner and Porter flours. Mariner oat starches had significantly lower 30 minute viscosities than Ogle and Porter starches. There was a significant difference in peak cold viscosities among the oat starches.

Oat flour protein content was influenced by interactions between all three of the main effects; mill x form, mill x cultivar, cultivar x form. Oat flour ash content was effected by the interactions between oat form and oat cultivar and between mill type and oat form. The percentage of lipid extracted from oat flours was influenced by mill type and oat form. The oat flour moisture content was effected by the oat form and the mill type.

The method of milling effected oat flour properties primarily because of particle size related factors. The difference in proximate analyses results were most likely due to the flour particle size produced by roller milling or hammer milling. Reduction of flour particle size by roller milling most likely facilitated the loss of the spherical oat protein bodies located along aleurone and endosperm cell walls. The fat determination method was based on the ability of solvents to penetrate and form bonds with chemical components in the oat flour. Flour particle size influenced the ability of heated water in the viscoamylograph and alkaline water at room temperature to hydrate oat flour.

The processing of oat groats into oat flakes subjected the chemical constituents to elevated temperatures and pressures. The bond between the oat protein bodies and the cell wall material may have been modified by the steam treatment prior to rolling into flakes. The pressure of heated rollers during the flaking process probably reduced the resistance of oat cell wall materials to impact forces during hammer milling.

The effect of milling and processing groats into flakes was not the same on the three oat cultivars used in the study. Flours from the three separate oat cultivars appeared to have different particle size ranges. Scanning electron micrographs indicated the aleurone cell walls of Porter oats may have been more resistant to milling forces. Chemical constituents such as total dietary fiber and β-glucan may have also contributed to viscosity and hydration capacity in oat flours from different cultivars.

Milling Summary

The effect of milling on cookie quality was determined by comparing cookies made from oat-wheat composite flours of Caldwell soft wheat combined with hammer and roller milled flours of Mariner, Ogle and Porter groats. There were mill related differences in cookie diameter, alkaline water retention capacity of composite flours, Hunter Color Difference L- and a-values, protein content and breaking strength of cookies.

Sugar-snap cookies made from hammer milled groat (HMG) flours had significantly larger diameters than cookies made from roller milled groat flours (RMG). Composite flours containing hammer milled groat flours had significantly lower alkaline water retention capacities (AWRC) than composites of roller milled groat flours. The correlation between cookie diameter and AWRC was positive and highly significant for cookies made with composite flours containing HMG flours.

Hunter Color Difference L-values (lightness) were significantly higher for cookies made with hammer milled groat composite flours compared to cookies made with roller milled groat composite flours. Cookies made with RMG composite flours had significantly larger a-values (redness) than cookies made with HMG composite flours.

Protein content of cookies made from hammer milled groat composite flours was significantly higher than protein content of cookies made from roller milled groat composite flours. The correlation between protein content and Hunter Color Difference L-values was negative and highly significant for cookies made with both types of composite flours. Breaking strength or crispness was significantly higher for cookies made with HMG composite flours than cookies made with RMG composite flours.

There were cultivar related differences in cookie diameter, alkaline water retention capacity of composite flours, Hunter Color Difference L-values (lightness), protein content and shear compression. Composite flours containing hammer and roller milled groat flours of the Porter cultivar made cookies with significantly larger diameters than cookies made with Ogle composite flours. Porter composite flours also had a significantly higher alkaline water retention capacity (AWRC) than composite flours of the two other oat cultivars.

Hunter Color Difference L-values (lightness) were significantly higher for cookies made with Ogle composite hammer and roller milled groat flours than cookies made with composite flours of the two other oat cultivars. Protein content was significantly higher in cookies made from composites of Mariner and Porter flours than in cookies made with Ogle composite flours. Shear compression was significantly higher for cookies made from Ogle hammer and roller milled groat composite flour than for cookies made with composite flours of Mariner and Porter groat flours.

There were level of oat flour related differences in cookie diameter, alkaline water retention capacity of composite flours, Hunter Color Difference L- and b-values, protein content, ash content, moisture retention, shear compression and breaking strength of cookies. The response of cookie diameter to increasing the level of oat flour substitution in sugar-snap cookies depended on the method of milling. Composite flours containing 30 percent hammer or roller milled groat flours did have a significantly higher alkaline water retention capacity (AWRC) than composites containing 15 percent oat flours.

Hunter Color Difference values were higher and statistically significant for L-values (lightness) and b-values (yellowness) when cookies made with 15 percent oat-wheat composite flours were compared to cookies made with 30 percent oat-wheat composite flours. The type of oat cultivar and level of oat flour substitution interacted to influence the Hunter L-, a- and b-values for surface color of cookies made with composites of hammer or rolled milled groat flours. Protein and ash content was significantly higher in sugar-snap cookies prepared from 30 percent oat-wheat hammer or roller milled groat composite flours than in cookies made from 15 percent composite flours. The oat cultivar and level of substitution influenced cookie ash content.

Moisture retention was significantly higher for cookies made from 30 percent oat-wheat hammer or roller milled groat composite flours than for cookies made from 15 percent composite flours. Shear compression and breaking strength was significantly higher for cookies made with 15 percent oat-wheat hammer or roller milled groat composite flours compared to cookies made with 30 percent composite flours. The oat cultivar and level of substitution influenced shear compression.

Processing Summary

The effect of processing on cookie quality was determined by comparing cookies made with oat-wheat composite flours of Caldwell soft wheat flour combined with the hammer milled flours ground from Mariner, Ogle and Porter groats and flakes. There were oat form related differences in cookie diameter, alkaline water retention capacity of composite flours and Hunter a-value.

Cookies made from oat-wheat composites containing oat flour hammer milled from flakes (HMF) had significantly smaller diameters than cookies made from oat-wheat composites containing oat flour hammer milled from groats (HMG). Alkaline water retention capacity (AWRC) of hammer milled flake composites was significantly higher than AWRC of hammer milled groat composite flours. The correlation between cookie diameter and AWRC was positive and highly significant for cookies made with HMG composite flours.

There was a significant difference in the Hunter Color Difference a-value (redness) when sugar-snap cookies made with the two types of composite flours were compared. Cookies made with hammer milled groat composite flours had a significantly stronger reddish hue than cookies made with hammer milled flake composite flours.

There were oat cultivar related differences in cookie diameter, alkaline water retention capacity of composite flours and protein content. Sugar-snap cookies made from Mariner hammer milled groat and hammer milled flake composite flours had significantly smaller diameters than cookies made from Porter composite flours. Cookies made from Porter HMG and HMF composite flours had the largest mean cookie diameter and the largest mean alkaline water retention capacity. Alkaline water retention capacity of Porter oat flour composites was significantly larger than AWRC of composite flours of the other two oat cultivars. The oat form from which the flour was milled in combination with the oat cultivar effected alkaline water retention capacity of the composite flours.

Protein content of cookies made with hammer milled groat or hammer milled flake flours from the Porter cultivar was significantly higher than protein content of cookies made from Ogle composite flours. The correlation between cookie protein content and Hunter Color Difference values was not the same for all oat cultivars. There was a negative highly significant correlation between cookie protein content and L-value for cookies made with Porter composite flours. The correlations were negative but not statistically significant for cookies made with Mariner and Ogle composite flours.

Oat form in combination with oat cultivar had a significantly different effect on Hunter L-value for cookies made with composites of hammer milled groat or flake flours. The a-value or redness of cookies made with Ogle composite flours was large and significant.

When the main effect of level of oat flour substitution was averaged over oat form and oat cultivar, there were level of oat flour substitution related differences in cookie diameter, alkaline water retention capacity of composite flours, protein content and shear compression. Sugar-snap cookies made from composites of 30 percent hammer milled groat or flake flours had a significantly larger mean diameter and alkaline water retention capacity than cookies made from 15 percent composite flours. Oat cultivar in combination with level of oat flour substitution also effected AWRC of composite flours. The correlation between cookie diameter and AWRC was negative and statistically significant for cookies made with composites of 30 percent hammer milled groat or flake flours.

Hunter Color Difference L- and b-values were significantly lower for cookies made with composites of 30 percent hammer milled groat or flake flours. Oat cultivar in combination with level of oat flour substitution had a significantly different effect on a-value (redness) of cookies.

Protein, ash and fat content were significantly higher in cookies made with 30 percent HMG or HMF flours compared to cookies made with 15 percent composite flours. Oat cultivar in combination with level of oat flour substitution had a significantly different effect on protein content and ash content of cookies.

Cookies containing 30 percent HMG or HMF flours had significantly lower shear compression than cookies containing 15 percent percent hammer milled groat or flake flours. There was no significant difference in breaking strength between cookies containing the two levels of HMG or HMF flours.

Wheat Cultivar Summary:

The effect of wheat cultivar on cookie quality was determined by comparing cookies made from oat-wheat composite flours of Becker, Caldwell and Compton soft wheat cultivars combined with the hammer milled groat flours of Mariner, Ogle and Porter oat cultivars. There were wheat cultivar related differences in cookie diameter, alkaline water retention capacity of composite flours, Hunter Color Difference L-values, protein content, ash content, fat content, shear compression and breaking strength of cookies.

Cookies made with Becker soft wheat composite flours had a significantly larger mean cookie diameter than cookies made with Caldwell composite flours. Cookies made with Caldwell soft wheat composites had the smallest average diameter. Becker soft wheat composite flours had a significantly higher alkaline water retention capacity than Caldwell composite flours. The correlations between cookie diameter and alkaline water retention capacity of composite flours were all positive with a minimum significance level of $p<0.06$.

Sugar-snap cookies made with Compton soft wheat composite flours had significantly larger Hunter Color Difference L-values than cookies made with Becker soft wheat composite flours. Cookies made with Becker soft wheat composite flours contained a significantly higher level of protein than cookies made with the other two soft wheat composite flours. The ash content of cookies containing Becker soft wheat composite flours was significantly higher compared to ash content of cookies prepared with Compton composite flours. The fat content of cookies made with Caldwell composite flours was significantly higher than fat content of Becker composite flour cookies. The correlations between protein content and Hunter Color L-value were both positive and statistically significant for cookies made with Becker and Caldwell soft wheat composite flours.

Shear compression was significantly higher for cookies containing Becker or Compton soft wheat composite flours compared to cookies containing Caldwell composite flours. Cookies made with

Caldwell composite flours had a significantly higher breaking strength than cookies made with Compton composite flours.

There were oat cultivar related differences in cookie diameter, alkaline water retention capacity of composite flours, protein content, shear compression and breaking strength of cookies. Sugar-snap cookies made with composite flours containing Porter hammer milled groat flour had a significantly larger mean diameter than cookies made with composites containing groats flours of the other two oat cultivars. The alkaline water retention capacity (AWRC) of Porter oat-wheat composite flours was significantly higher compared to the AWRC of Ogle oat-wheat composite flours. The correlations between cookie diameter and AWRC of composite flours of the three different oat cultivars were all positive and statistically significant.

Protein content was significantly higher in cookies made with Mariner and Porter hammer milled groat composite flours than in cookies made with Ogle composite flours. The correlations between Hunter Color Difference L-value and protein content for Mariner, Ogle and Porter composite cookies were all negative and statistically significant. The mean shear compression score of cookies made with Ogle hammer milled groat composite flours was significantly higher compared to shear compression for cookies made with Mariner and Porter composite flours.

There were level of oat flour substitution related differences in cookie diameter, alkaline water retention capacity of composite flours, Hunter Color Difference L-values, protein content, ash content, fat content and shear compression of cookies. The diameter of cookies containing 30 percent hammer milled groat flours was significantly larger than cookies containing 15 percent hammer milled groat flours. Composite flours containing 30 percent hammer milled groat flours had significantly higher alkaline water retention capacities (AWRC) compared to composite flours containing 15 percent hammer milled groat flours. Alkaline water retention capacity of composite flours was effected by wheat cultivar and the level of oat flour substitution. The correlation between cookie diameter and AWRC of 15 percent composite flours was positive and highly significant.

Hunter Color Difference L-values (lightness) for cookies containing 15 percent hammer milled groat flours were significantly higher than L-values for cookies containing 30 percent hammer milled groat flours. Cookies containing 15 percent hammer milled groat flours had significantly higher b-values (yellowness) compared to cookies containing 30 percent hammer milled groat flours.

Protein, ash and fat content of cookies all significantly increased as an additional 15 percent of hammer milled groat flour was incorporated into the composite flours. Protein content and ash content of cookies was effected by wheat cultivar and the level of oat flour substitution. Protein content of cookies was also effected by oat cultivar and the level of oat flour substitution.

The Pearson correlation coefficients between protein content and L- and b-values for cookies made with 15 percent and 30 percent oat wheat composite flours were all negative and statistically significant. The coefficients were larger and the level of significance higher for cookies made with 15 percent oat-wheat composite flours. Cookies made with 15 percent hammer milled groat flours had significantly higher mean shear compression than cookies made with 30 percent hammer milled groat flours.

The significance of the study is that whole grain oat flour is one of the few non-wheat flours that can be incorporated into sugar-snap cookies without lowering cookie quality. Other flours containing higher levels of protein and dietary fiber than soft wheat flours have required the use of surfactants to improve cookie spread. Whole grain oat flours from specific oat cultivars could be used to improve the baking quality of marginal quality soft wheat flours.

Proposal for Future Research:

The role of oat flour in composite flours used for chemically leavened baked goods should be further investigated. Oat cultivars that contain relatively high levels of protein, lipid and dietary fiber should be selected for study.

This current research effort left many questions unanswered. More sophisticated equipment for flour particle sizing should be used such as a Coulter Counter or Microtrac Particle Size Analyzer. The purpose would be to determine there is a flour particle size range associated with oat cultivars that contributes to flour functionality.

Whole grain oat flour should be fractionated to determine the functionality of oat globulins, lipids and specific classes of lipids in cookie spread and development of baked cookie color. The role of β-glucan in composite flours could be clarified. This soluble fiber absorbs large amounts of water which contributes to cookie dough viscosity during baking also exhibits a loss of viscosity at elevated temperatures.

Time lapse photography could be used to study the rheological properties of oat-wheat composite doughs during baking. Analysis of the kinetics of the three dimensional expansion that occurs in cookie dough during baking could determine the point at which maximum diameter is reached and if oat-wheat composite doughs exhibit controlled elastic shrinkage or structural collapse.

APPENDIX

Commercial Processing of Oats

The following procedures were used to process oats into groats and flakes by the Quaker Oats Company. The raw oats are first dehulled and then heated to inactivate oat lipase enzymes. If groats or dehulled oat kernels are to be flaked, the second stage is to adjust the moisture content and to use heated rollers to make oat flakes.

Part I.

Dehulling:

A 17 lbs portion of raw oats was passed through an impact huller twice to break groats from hulls. The huller speed was monitored via rpm measurements of a top motor spindle adjacent to the huller itself. A rpm reading of 1632 on the spindle-which corresponds to 1800 rpm was used to dehull the groats. The first pass of the 17 lb portion of the groats was done with the funnel shaped feed tube opened 1/2 turn CCW from the closed (fully CW) point. This material was then gathered in a cloth sack and is passed through the huller once again with the feed tube in the 1 1/2 turn CCW position. A cloth sack was then used to collect the material which was a mixture of hulls, oats and groats.

Pneumatic Separator:

A Sortex model pneumatic separator was next used on the oat mixture to remove the hull material. The Sortex has a cycling, surging air pattern that is created by a fan system and air pressure. The control should be set at 18. The hopper was filled with the oat mixture after checking that the flow path led to the left side. The motor was then turned on and the vibration intensity dial was set to 5. The vibrating feeder was activated to move the mixture past the separator tube. The separator tube removed the lighter weight hulls and allowed the heavier groats and whole oats to pass through for collection. The separation process was monitored by spot checking the collected portion for presence of oat hulls.

Oven Drying and Quick Cooling:

A Proctor and Schwartz batch oven, a gas fired forced air oven, was used to dry and toast the groats. The oven temperature had been equilibrated at 265°C for 1 hour prior to use with the reducer plate inside the oven. The groats were spread 1-1½ inches on metal screens and were placed inside the heated oven for 7.5 minutes. After the heating period, the screens containing the groats were immediately removed from the oven and placed on a blower apparatus which pulled room temperature air through the warm groats at a very high volume. Air was continually blown through the groats until they reached room temperature. The groats were placed in a plastic bag, labeled, moisture samples collected and then stored in plastic bins.

Part II

Moisture Adjustment

Groats that are to be flaked should contain a 10% H_2O level. A calculated amount of water was added to the groats while they are tumbling in a small ribbon mixer. The additional water was allowed to equilibrate in the groats during a minimum 48 hour holding period.

Flaking:

The oats were flaked using a Ross rolling machine. The rollers are heated with gas and required a warm-up period of three to four hours to equilibrate the rollers' temperatures. A 20 pound portion of groats were weighed into the steamer portion of the rolling machine. The groats were exposed to atmospheric pressure steam for 15 minutes. A small sample of groats was rolled into flakes and measured to determine if the standard for thickness for oat flakes was met. Oat flakes should be from 0.021 to 0.025 inches. The roller gap was adjusted to meet this standard. A setting of $11\frac{1}{2}$ - $12\frac{1}{2}$ is required. The remainder of the oats were then rolled by pulling the closure plate out to allow the groats to slowly be fed onto the rollers. The flaked oats were collected on clean sanitized trays.

Flake Drying

The target value for the oat flake moisture is between 9.5 to 10%. The flakes could be dried by using the Proctor and Schwartz batch oven at 110^{o}F or by the high volume air blower. The dried oat flakes were placed in double plastic bags, moisture, microbial and enzyme activity samples taken and the bags were sealed.

Enzyme Activity

The heat treatment in part one was designed to inactivate lipase found in oats. Commercial processors test heat treated oats for tyrosinase activity as an indicator of residual lipase activity. Tyrosinase enzyme is more heat stable than lipase and provides a rapid analytical test for oat processors.

EFFECT OF OAT FLOUR FRACTION
ON SUGAR-SNAP COOKIE QUALITY

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ABSTRACT

The functionality of unfractionated (total) fine (< 249 microns), or coarse (> 368 microns) oat flour fractions used at 15 and 30% substitutions levels in soft wheat flour composite of Becker, Compton or Caldwell cultivars was determined in sugar-snap cookies. A balanced complete block design was used in preparing the cookies. Dough handling properties were similar to the 100% wheat control when water was adjusted on the basis of wheat and total oat flour protein. Composite flour cookie quality was evaluated on the basis of diameter and top grain score.

INTRODUCTION

Whole grain oat flour is produced by grinding oat flakes or dehulled oat kernels into flour. Oat flour is high in protein and has a higher fat content than other cereal grains[1]. An increased market for oat bran, which is the outer layers of the oat kernel, has developed since reports of the ability of soluble fiber found in oat bran to lower serum cholesterol[2].

Relatively few research studies have been published on functionality of oat flour in baked products. Dodok[3] concluded that up to 15 percent of oat flour can be substituted for wheat flour in a biscuit formula. McKechnie[4] reported that oat flour can be substituted for up to 30 percent wheat flour in breads. The primary effect was increased moisture retention and freshness. Oomah[5] substituted roller milled oat flour and commercial hammer milled oat flour at the 5, 10, 15, 20 and 25 percent level in cookies. There was no significant difference in cookie spread except at the 5 percent substitution level. Cookie spread increased as an increasing amount of oat flour was substituted in the formula.

The objective of this study was to measure the functionality of oat flour fractions when substituted for wheat flour at two levels in sugar snap cookies. The second purpose was to measure the interaction of oat flour fractions with three soft wheat cultivars in sugar snap cookies.

METHODS

Three soft wheat cultivars (Becker, Caldwell and Compton) were combined with commercial oat flour and oat flour fractions to make composite flours. The soft wheat flours were grown in 1989 and donated by the U.S.D.A. Soft Wheat Quality Lab in Wooster, Ohio. A commercial oat flour, Quaker Oat flour No. 1, was donated by Quaker Oats Company, Barrington, Illinois. Oat flour fractions were prepared by sieving using a Sampl-Sifter (Great Western Mfg. Co., Leavenworth, Kansas) equipped with No. 40, 54, 74 and 94 screens. The contents of the No 40. (470 micron) and 54 (368 micron) screens were combined to make the coarse fraction. This coarse fraction might well be described as oat bran since commercial oat bran is the overs of a No. 60 screen. The oat flour that came through the No. 74 screen (<249 micron) was used as the fine oat flour fraction. The oat flour fractions were combined with the three soft wheat flours on the basis of dry weight to make composite flours of 15 and 30 percent oat flour. Sugar-snap cookies were prepared without composite or 100% wheat flours using AACC method 10-52[6]. Water addition to the formula was based on the protein content of wheat flour and total oat flour along with desirable dough consistency.

Protein content of flours and cookies was determined using AOAC Method 47.021, 24.038[7]. Moisture content of flours was determined by using AACC Method 44-40: Modified Vacuum Oven Method[6]. Fat content of flours was measured by the method of Price and Parsons[8] using chloroform and methanol extraction. Total dietary fiber was measured using the method of Prosky et al[9]. Alkaline water retention capacity was determined using AACC method 56-10[6].

RESULTS AND DISCUSSION

The effect of composite flour on cookie quality was evaluated on the basis of diameter and top grain score. Diameter is considered an important characteristic due to the level of automation involved in commercial cookie production and packaging. The top grain of a sugar snap cookie should be comprised of a numerous amount of surface cracks or islands. Top grain is a visual representation of the rheological properties of the cookie dough.

Control cookies were prepared with 100% wheat flour from each soft wheat variety. The average diameter of the two control cookies made from either 100 percent Caldwell or Compton soft wheat flours was 17 cm. Cookies made from 100 percent Becker soft wheat flour had an average diameter of 18.26 cm. The control cookies made from 100 percent soft wheat flour irregardless of the wheat variety had an average top grain score of 3 on a scale of 9.

Effect of Course Oat Flour Fraction

Substitution of course oat flour fractions at the 15 and 30 percent level lead to increased cookie diameters for all wheat varieties used in the composite flours (Table 1). However the increase was not statistically significant. Composite oat-wheat flours containing coarse oat flour fraction also improved the top grain scores of cookies made with all three types of soft wheat flours.

TABLE 1
Cookie diameters, top grain scores and alkaline water retention capacity (AWRC) for cookies prepared with composite of coarse oat flour fraction

Soft Wheat	Oat Fraction (%)	Cookie Diameter (cm)	Top Grain Score	AWRC (%)
Becker	0 (control)	18.26	3.0	56.7
	15	18.38	4.0	86.1
	30	18.23	5.5	114.3
Caldwell	0	17.94	3.0	55.0
	15	17.97	4.5	81.2
	30	18.17	5.5	109.2
Compton	0	17.91	3.0	57.0
	15	18.05	4.0	83.1
	30	18.11	6.5	116.7

Effect of Fine Flour Fraction

Cookie diameter decreased significantly ($p < 0.01$) when prepared from composites of 15 and 30 percent fine oat flour fraction combined with Becker soft wheat flour (Table 2). Fine oat flour fraction in combinations with Caldwell and Compton soft wheat flours did not cause a significant ($p < 0.01$) decrease in cookie diameter until substituted at the 30 percent level. Incorporation of the fine oat fraction in composite flours did not result in a clear trend on cookie top grain scores.

TABLE 2
Cookie diameters, top grain scores and alkaline water retention capacity (AWRC) for cookies prepared with composites of fine oat flour fraction

Soft Wheat	Oat Fraction (%)	Cookie Diameter (cm)	Top Grain Score	AWRC (%)
Becker	0 (control)	18.26	3.0	56.7
	15	17.90	2.5	65.9
	30	17.75	3.0	75.5
Caldwell	0	17.94	3.0	55.0
	15	17.75	4.0	62.6
	30	17.38	4.5	70.9
Compton	0	17.91	3.0	57.0
	15	17.76	4.0	63.9
	30	17.33	3.5	76.4

Effect of Total Oat Flour

Composite oat-wheat flours made from 15 and 30 percent total, i.e., unfractionated oat flour combined with Becker or Compton soft wheat flours produced sugar snap cookies with decreased cookie diameters (Table 3). In addition, cookies prepared from 30 percent composite flour for any of the three wheat varieties had smaller diameters than the cookies prepared from 15 percent composite flour. Cookies made from composites of 15 percent total oat flour and Caldwell soft wheat flour had larger diameters than the control made from 100 percent Caldwell soft wheat, however the difference was not significant. At the 30 percent level of substitution, cookie diameter for cookies prepared with this wheat variety was slightly smaller than the control. As had been true for cookies prepared with composites containing fine oat bran, composites of total oat flour did not produce cookies which exhibited a clear trend for influencing top grain scores.

TABLE 3
Cookie diameters, top grain scores and alkaline water retention capacity AWRC for cookies prepared with composites of total oat flour fraction

Soft Wheat	Oat Fraction (%)	Cookie Diameter (cm)	Top Grain Score	AWRC (%)
Becker	0	18.26	3.0	56.7
	15	17.96	3.0	71.9
	30	17.69	4.0	82.5
Caldwell	0	17.94	3.0	55.0
	15	18.03	3.5	67.7
	30	17.84	4.5	80.7
Compton	0	17.91	3.0	57.0
	15	17.64	3.5	70.1
	30	17.51	3.5	84.7

Alkaline Water Retention and Cookie Quality

The alkaline water retention capacity (AWRC) of the composite flours increased significantly ($p < 0.01$) with increasing levels of oats (Tables 1, 2, 3), but the degrees of magnitude of AWRC increase was greatest for composites with coarse oat fractions. The alkaline water retention capacity of soft wheat flours is highly negatively correlated with sugar snap cookie diameter without needing to adjust for protein or ash content[10]. Becker and Compton had similar AWRC which could contribute to the similarity of their interactions with total oat flour (Tables 1 and 4). The AWRC of fine oat flour fraction in combination with all three soft wheat flours was negatively correlated with cookie diameter. There was a positive correlation between cookie diameter and AWRC for coarse oat flour fraction combined with Caldwell and Compton but not Becker.

TABLE 4
Correlations between cookie diameter and alkaline water retention capacity

Soft Wheat	Oat Flour Fraction		
	Coarse	Fine	Total
Becker	-0.11	-0.93	-0.96
Caldwell	0.77	-0.97	-0.34
Compton	0.78	-0.97	-0.91

Proximate Analyses of Oat Flour Fraction

Chemical analysis of the oat flour fractions showed that coarse oat flour fraction contained significantly higher levels of protein, and total dietary fiber than total oat flour and fine oat flour fraction (Table 5).

TABLE 5
Chemical analysis of oat flour fractions

Oat Flour Fraction	Protein (%)	Lipid (%)	Total Dietary Fiber (%)
Coarse	24.3	8.6	20.10
Fine	15.37	7.2	6.23
Total	17.42	8.5	10.84

Oat flour lipids in the composite flours may have contributed to the increase in top scores and cookie diameter. Sahasrabudhe[11] found that phosphatidyl-choline was the major phospholipid in groat lipids in all groat fractions. Cole et al[12], Kissel et al[13], and Yamazaki and Donelson[14] concluded that the restoration of three to four times the lipid level of defatted wheat flour resulted in a larger cookie diameter with improved top grain scores. Soy lecithin has been used[13,15,16], to improve baking performance of protein fortified cookies. However, a particle size effect along with decreased solubility of oat protein may have also influenced sugar snap cookie quality.

CONCLUSIONS

The results have commercial, nutritional and economic significance. The coarse oat flour fraction could be used by commercial automated bakeries because the effect on cookie diameter was not significant. Composite oat wheat flours increased the nutrient value of a cookie because the coarse oat flour fraction contained at least twice the percentage of protein and dietary fiber as the soft wheat flour it replaced. The interaction with soft wheat cultivars to improve the rheological characteristic of cookie dough may lead to some wheat cultivars being considered more valuable because they can be successfully combined with oat flour or oat flour fractions to produce high protein, high fiber cookies.

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Table 81. Analysis of variance for protein content of oat forms[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	7.28	3.643	16.22	0.0004
F	1	0.83	0.827	3.69	0.0790
CxF	2	0.91	0.457	2.04	0.1730
Error	12	2.69	0.225		

[1] C= Oat Cultivar , F = Oat form

Table 82. Analysis of variance for ash content of oat forms[1]

Source of variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	0.50	0.251	19.20	0.0002
F	1	0.13	0.127	9.68	0.0090
CxF	2	0.04	0.019	1.48	0.2658
Error	12	0.16	0.013		

[1] C= Oat Cultivar , F = Oat form

Table 83. Analysis of variance for moisture content of oat forms[1]

Source of variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	0.88	0.444	15.93	0.0004
F	1	13.40	13.398	60.97	0.0001
CxF	2	0.44	0.221	11.68	0.0064
Error	12	0.33	0.028		

[1] C= Oat Cultivar , F = Oat form

Table 84. Analysis of variance for protein content of oat flours[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	22.58	11.29	128.62	0.0001
F	1	5.35	5.35	60.97	0.0001
M	1	0.41	0.41	4.72	0.0392
CxF	2	2.05	1.30	11.68	0.0002
CxM	2	1.14	0.57	6.51	0.0051
FxM	1	1.00	1.00	11.39	0.0023
Error	26	2.28	0.09		

[1] C= Oat Cultivar , F = Oat form , M= Mill type

Table 85. Analysis of variance for ash content of oat flours[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	0.55	0.28	32.83	0.0001
F	1	0.00	0.00	0.24	0.6280
M	1	0.02	0.02	2.50	0.1262
CxF	2	0.07	0.00	3.95	0.0319
CxM	2	0.01	0.01	0.80	0.4621
FxM	1	0.07	0.07	8.76	0.0065
Error	26	0.95	0.01		

[1] C= Oat Cultivar , F = Oat form , M= Mill type

Table 86. Analysis of variance for fat content of oat flours[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	18.59	9.30	950.75	0.0001
F	1	0.25	0.25	25.91	0.0001
M	1	0.43	0.43	43.65	0.0001
CxF	2	0.03	0.01	1.48	0.2468
CxM	2	0.03	0.01	1.51	0.2386
FxM	1	0.19	0.19	19.20	0.0002
Error	26	0.25	0.01		

[1] C= Oat Cultivar , F = Oat form , M= Mill type

Table 87. Analysis of variance for moisture content of oat flours[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	1.87	0.93	9.19	0.0010
F	1	17.24	17.24	169.62	0.0001
M	1	1.05	1.05	10.34	0.0035
CxF	2	0.49	0.25	2.42	0.1087
CxM	2	0.20	0.01	0.99	0.3844
FxM	1	0.53	0.52	5.17	0.0314
Error	26	2.64	0.10		

[1] C= Oat Cultivar , F = Oat form , M= Mill type

Table 88. Analysis of variance for total dietary fiber content of oat flours[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	38.79	19.39	21.54	0.0001
F	1	28.39	28.39	31.53	0.0001
M	1	11.14	11.14	12.38	0.0016
C x F	2	2.48	1.24	1.38	0.2705
C x M	2	3.12	1.56	1.73	0.1966
F x M	1	26.16	26.16	29.05	0.0001
Error	26	23.41	0.90		

[1] C= Oat Cultivar , F = Oat form , M= Mill type

Table 89. Analysis of variance for L-value of oat flours[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	12.71	6.36	94.71	0.0001
F	1	7.11	7.11	105.95	0.0001
M	1	7.84	7.84	116.80	0.0001
C x F	2	0.16	0.08	1.18	0.3231
C x M	2	0.26	0.13	1.98	0.1587
F x M	1	6.33	3.17	94.36	0.0001
Error	26	1.74	0.07		

[1] C= Oat Cultivar , F = Oat form , M= Mill type

Table 90. Analysis of variance for a-value of oat flours[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	0.06	0.03	1.13	0.3382
F	1	0.23	0.23	8.62	0.0069
M	1	0.12	0.12	4.52	0.0431
C x F	2	0.34	0.17	6.36	0.0057
C x M	2	0.05	0.02	0.85	0.4374
F x M	1	0.02	3.17	0.66	0.4252
Error	26	0.70	0.03		

[1] C= Oat Cultivar , F = Oat form , M= Mill type

Table 91. Analysis of variance for b-value of oat flours[1]

Source of variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	8.13	4.06	196.59	0.0001
F	1	0.42	0.42	20.43	0.0001
M	1	2.15	2.15	104.03	0.0001
CxF	2	0.09	0.05	2.39	0.1117
CxM	2	0.04	0.02	0.93	0.4072
FxM	1	0.67	0.67	32.25	0.0001
Error	26	0.54	0.02		

[1] C= Oat Cultivar , F = Oat form , M= Mill type

Table 92. Analysis of variance for alkaline water retention capacity of oat flours[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	12174.92	6087.46	115.28	0.0001
F	1	15053.24	15053.24	285.07	0.0001
M	1	17420.92	17420.92	329.91	0.0001
CxF	2	141.65	53.14	1.34	0.2790
CxM	2	383.58	191.79	3.63	0.0406
FxM	1	107.64	107.64	2.04	0.1653
Error	26	1372.93	52.80		

[1] C= Oat Cultivar , F = Oat form , M= Mill type

Table 93. Analysis of variance for particle size index of oat flours[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	12.49	6.36	0.54	0.5946
F	1	5.41	7.11	0.47	0.5051
M	1	231.88	7.84	20.03	0.0005
CxF	2	8.48	0.08	0.37	0.6998
CxM	2	31.96	0.13	1.38	0.2836
FxM	1	123.31	3.17	10.65	0.0057
Error	14	162.04	11.57		

[1] C= Oat Cultivar , F = Oat form , M= Mill type

Table 94. Analysis of variance for initial paste temperature of oat flours[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	144.89	72.44	17.59	0.0002
F	1	245.76	245.76	59.67	0.0001
M	1	812.01	812.01	197.15	0.0001
C x F	2	0.83	0.41	0.10	0.9051
C x M	2	51.49	25.74	6.25	0.0115
F x M	1	126.04	126.04	30.60	0.0001
Error	14	57.66	4.12		

[1] C= Oat Cultivar , F = Oat form , M= Mill type

Table 95. Analysis of variance for peak hot viscosity of oat flours[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	131002.58	65501.29	10.79	0.0015
F	1	24130.04	24130.04	3.97	0.0661
M	1	47615.04	47615.04	7.84	0.0142
C x F	2	14893.58	7446.79	1.23	0.3230
C x M	2	10902.08	5451.04	0.90	0.4297
F x M	1	18648.37	18648.37	3.07	0.1016
Error	14	85012.25	6072.30		

[1] C= Oat Cultivar , F = Oat form , M= Mill type

Table 96. Analysis of variance for 15 minute viscosity of oat flours[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	142684.75	71342.37	74.43	0.0001
F	1	181.50	181.50	0.19	0.6701
M	1	1232.67	1232.67	1.29	0.2758
C x F	2	10920.25	5460.12	5.70	0.0155
C x M	2	346.08	173.04	0.18	0.8367
F x M	1	7210.67	7210.67	7.52	0.0159
Error	14	13418.58	958.47		

[1] C= Oat Cultivar , F = Oat form , M= Mill type

Table 97. Analysis of variance for peak cold viscosity of oat flours[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	190596.58	95298.29	36.09	0.0001
F	1	42.67	42.67	0.02	0.9007
M	1	322.67	322.67	0.12	0.7319
CxF	2	4111.58	2055.79	0.78	0.4780
CxM	2	336.58	168.29	0.06	0.9385
FxM	1	11792.67	11792.67	4.47	0.0530
Error	14	36968.58	2640.61		

[1] C= Oat Cultivar , F = Oat form , M= Mill type

Table 98. Analysis of variance for initial paste temperature of oat starches[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	45.61	22.81	34.17	0.0001
F	1	3.08	3.08	4.62	0.0496
M	1	0.43	0.43	0.64	0.4374
CxF	2	0.76	0.38	0.57	0.5762
CxM	2	0.92	0.92	0.69	0.5198
FxM	1	2.28	2.28	3.42	0.0857
Error	14	9.34	0.67		

[1] C= Oat Cultivar , F = Oat form , M= Mill type

Table 99. Analysis of variance for peak hot viscosity of oat starches[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	4713.58	2356.79	3.85	0.0001
F	1	1066.67	1066.67	1.74	0.9007
M	1	620.17	620.17	1.01	0.7319
CxF	2	6315.08	3157.54	5.15	0.4780
CxM	2	669.08	169.54	0.55	0.9385
FxM	1	384.00	384.00	0.63	0.0530
Error	14	8581.25	612.95		

[1] C= Oat Cultivar , F = Oat form , M= Mill type

Table 100. Analysis of variance for 30 minute viscosity of oat starches[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	24054.33	12027.16	111.74	0.0001
F	1	590.04	590.04	5.48	0.9007
M	1	1218.37	1218.37	11.32	0.7319
CxF	2	741.33	370.67	3.44	0.4780
CxM	2	271.00	135.50	1.26	0.9385
FxM	1	70.04	70.04	0.65	0.0530
Error	14	1506.83	107.63		

[1] C= Oat Cultivar , F = Oat form , M= Mill type

Table 101. Analysis of variance for peak cold viscosity of oat starches[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	137187.25	68593.62	36.03	0.0001
F	1	3978.37	3978.37	2.09	0.1703
M	1	22878.37	22878.37	12.02	0.0038
CxF	2	992.25	496.12	0.26	0.7743
CxM	2	1617.25	808.62	0.42	0.6621
FxM	1	4788.37	4788.37	2.52	0.1351
Error	14	26654.75	1903.91		

[1] C= Oat Cultivar , F = Oat form , M= Mill type

Table 102. Analysis of variance for protein content of alkaline extracted oat starches [1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
M	1	0.00	0.00	0.24	0.6308
C	2	0.00	0.00	0.14	0.8715
F	1	0.62	0.62	42.55	0.0001
MXC	2	0.01	0.00	0.30	0.7473
MXF	1	0.00	0.00	0.00	0.9867
CXF	2	0.00	0.00	0.06	0.9423
Error	14	0.20	0.01		

[1] M = Mill, C = Oat cultivar ,F = Oat form

Table 103. Analysis of variance for cookie diameter: Effect of mill [1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	0.31	0.15	10.17	0.0019
M	1	0.33	0.33	21.58	0.0004
L	1	0.04	0.04	2.54	0.1335
CXM	2	0.25	0.12	8.24	0.0043
CXL	2	0.06	0.03	2.17	0.1515
MXL	1	0.49	0.49	32.58	0.0001
Error	14	0.21	0.015		

[1] C = Oat cultivar , M = Mill, L = Level of oat flour substitution

Table 104 Analysis of variance for alkaline water retention capacity of composite flours: Effect of mill[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	61.61	30.80	6.71	0.0091
M	1	224.05	224.05	48.77	0.0001
L	1	823.80	823.80	179.30	0.0001
MXC	2	40.09	20.04	4.36	0.0337
CXL	2	23.26	11.63	2.53	0.1152
MXL	1	3.19	3.19	0.69	0.4187
Error	14	64.32	4.59		

[1] C = Oat cultivar , M = Mill, L = Level of oat flour substitution

Table 105. Analysis of variance for cookie L-value: Effect of mill[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	5.50	2.75	5.20	0.0205
M	1	3.97	3.97	7.50	0.0160
L	1	15.14	15.14	28.61	0.0001
MXC	2	0.04	0.02	0.04	0.9635
CXL	2	4.07	2.03	3.85	0.0467
MXL	1	0.31	0.31	0.59	0.4547
Error	14	7.41	0.529		

[1] C = Oat cultivar , M = Mill, L = Level of oat flour substitution

Table 106. Analysis of variance for cookie a-value: Effect of mill[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	0.13	0.06	1.99	0.5222
M	1	3.53	3.53	5.33	0.0001
L	1	0.03	0.03	0.41	0.5930
MXC	2	0.05	0.02	0.04	0.7622
CXL	2	0.87	0.43	1.78	0.0278
MXL	1	0.19	0.19	0.08	0.1792
Error	14	1.31	0.094		

[1] C = Oat cultivar , M = Mill, L = Level of oat flour substitution

Table 107. Analysis of variance for cookie b-value: Effect of mill[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	0.21	0.10	1.44	0.2708
M	1	0.05	0.05	0.68	0.4229
L	1	3.63	3.63	49.93	0.0001
MXC	2	0.28	0.14	1.96	0.1777
CXL	2	0.66	0.33	4.52	0.0306
MXL	1	0.09	0.09	1.24	0.2843
Error	14	1.02	0.073		

[1] C = Oat cultivar , M = Mill, L = Level of oat flour substitution

Table 108. Analysis of variance for cookie protein content: Effect of mill[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	0.52	0.26	39.14	0.0001
M	1	0.33	0.33	49.05	0.0001
L	1	0.64	0.64	95.94	0.0001
MXC	2	0.01	0.00	0.47	0.6322
CXL	2	0.02	0.01	1.68	0.2214
MXL	1	0.00	0.00	0.03	0.8640
Error	14	0.09	0.01		

[1] C = Oat cultivar , M = Mill, L = Level of oat flour substitution

Table 109. Analysis of variance for cookie ash content: Effect of mill[1].

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	0.01	0.00	4.10	0.0398
M	1	0.00	0.00	4.53	0.0515
L	1	0.03	0.03	37.48	0.0001
MXC	2	0.00	0.00	0.56	0.5822
CXL	2	0.01	0.00	6.99	0.0078
MXL	1	0.00	0.00	0.16	0.6957
Error	14	0.01	0.00		

[1] C = Oat cultivar , M = Mill, L = Level of oat flour substitution

Table 110. Analysis of variance for cookie lipid content: Effect of mill[1].

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	0.84	0.42	1.07	0.3710
M	1	0.54	0.54	1.36	0.2628
L	1	0.52	0.52	1.33	0.2679
MXC	2	0.00	0.00	0.01	0.9930
CXL	2	0.09	0.04	0.12	0.8913
MXL	1	0.14	0.14	0.35	0.5658
Error	14	5.52	0.39		

[1] C = Oat cultivar , M = Mill, L = Level of oat flour substitution

Table 111. Analysis of variance for cookie moisture retention: Effect of mill [1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	3.17	1.58	0.07	0.9322
M	1	0.19	0.19	0.01	0.9275
L	1	136.28	136.28	6.07	0.0273
MXC	2	69.84	34.92	1.55	0.2456
CXL	2	39.46	19.73	0.88	0.4371
MXL	1	32.36	32.36	1.44	0.2499
Error	14	314.43	22.46		

[1] C = Oat cultivar , M = Mill, L = Level of oat flour substitution

Table 112. Analysis of variance for cookie shear compression: Effect of mill[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	24.31	12.15	10.07	0.0019
M	1	0.98	0.98	0.81	0.3828
L	1	66.83	66.83	55.37	0.0001
MXC	2	4.14	2.07	1.71	0.2159
CXL	2	11.68	5.84	4.84	0.0253
MXL	1	2.41	2.41	2.00	0.1792
Error	14	16.90	1.21		

[1] C = Oat cultivar , M = Mill, L = Level of oat flour substitution

Table 113. Analysis of variance for cookie breaking strength: Effect of mill[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	13.36	6.68	2.64	0.1063
M	1	15.86	15.86	6.27	0.0253
L	1	15.99	15.99	6.32	0.0248
MXC	2	2.07	1.03	0.41	0.6719
CXL	2	3.49	1.74	0.69	0.5175
MXL	1	0.01	0.01	0.00	0.9608
Error	14	35.41	2.53		

[1] C = Oat cultivar , M = Mill, L = Level of oat flour substitution

Table 114. Analysis of variance for cookie diameter: Effect of oat processing[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	0.37	0.18	6.17	0.0120
F	1	0.03	0.03	1.00	0.3351
L	1	1.37	1.37	45.29	0.0001
CXF	2	0.08	0.04	1.32	0.2988
CXL	2	0.26	0.13	4.33	0.0345
FXL	1	0.00	0.00	0.00	0.9724
Error	14	0.42	0.03		

[1] C = Oat cultivar , F = Form, L = Level of oat flour substitution

Table 115. Analysis of variance for alkaline water retention capacity of composite flours: Effect of oat processing[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	69.67	34.83	13.36	0.0006
F	1	533.17	533.17	204.55	0.0001
L	1	879.91	879.91	337.58	0.0001
CXF	2	56.65	28.33	10.87	0.0014
CXL	2	23.65	11.83	4.54	0.0303
FXL	1	7.55	7.55	2.90	0.1109
Error	14	36.49	2.61		

[1] C = Oat cultivar , F = Form, L = Level of oat flour substitution

Table 116. Analysis of variance for cookie L-value: Effect of oat processing[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	4.01	2.00	4.13	0.0389
F	1	0.14	0.14	0.29	0.5961
L	1	10.20	10.20	21.05	0.0004
CXF	2	10.51	5.25	10.84	0.0014
CXL	2	1.46	0.73	1.51	0.2545
FXL	1	1.57	1.57	3.25	0.0930
Error	14	6.79	0.48		

[1] C = Oat cultivar , F = Form, L = Level of oat flour substitution

Table 117. Analysis of variance for cookie a-value: Effect of oat processing[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	0.43	0.21	2.25	0.1418
F	1	0.50	0.50	5.29	0.0374
L	1	0.08	0.08	0.90	0.3595
CXF	2	0.14	0.07	0.72	0.5034
CXL	2	1.27	0.63	6.67	0.0092
FXL	1	0.00	0.00	0.01	0.9326
Error	14	1.33	0.09		

[1] C = Oat cultivar , F = Form, L = Level of oat flour substitution

Table 118. Analysis of variance for cookie b-value: Effect of oat processing[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	0.78	0.39	1.67	0.2231
F	1	0.11	0.11	0.49	0.4973
L	1	2.01	2.01	8.62	0.0109
CXF	2	2.01	1.00	4.30	0.0351
CXL	2	0.60	0.30	1.28	0.3074
FXL	1	0.62	0.62	2.64	0.1262
Error	14	3.27	0.23		

[1] C = Oat cultivar , F = Form, L = Level of oat flour substitution

Table 119. Analysis of variance for cookie protein content: Effect of oat processing[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	2.00	1.00	6.98	0.0079
F	1	0.03	0.03	0.21	0.6538
L	1	1.83	1.83	12.77	0.0031
CXF	2	0.43	0.21	1.49	0.2584
CXL	2	0.11	0.05	0.38	0.6922
FXL	1	0.54	0.54	3.79	0.0720
Error	14	2.01	0.14		

[1] C = Oat cultivar , F = Form, L = Level of oat flour substitution

Table 120 . Analysis of variance for cookie ash content: Effect of oat processing[1].

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	0.00	0.00	0.09	0.9138
F	1	0.00	0.00	1.11	0.3109
L	1	0.05	0.02	52.25	0.0001
CXF	2	0.00	0.00	0.94	0.4150
CXL	2	0.01	0.00	5.50	0.0173
FXL	1	0.00	0.00	0.43	0.5217
Error	14	0.01	0.00		

[1] C = Oat cultivar , F = Form, L = Level of oat flour substitution

Table 121. Analysis of variance for cookie lipid content: Effect of oat processing[1].

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	0.72	0.36	1.23	0.3228
F	1	1.12	1.12	3.79	0.0719
L	1	3.18	3.18	10.79	0.0054
CXF	2	2.87	1.43	4.86	0.0249
CXL	2	0.29	0.14	0.50	0.6196
FXL	1	0.48	0.48	1.61	0.2246
Error	14	4.13	0.29		

[1] C = Oat cultivar , F = Form, L = Level of oat flour substitution

Table 122. Analysis of variance for cookie moisture retention: Effect of oat processing[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	0.20	0.10	0.01	0.9936
F	1	6.09	6.09	0.38	0.5461
L	1	0.72	0.72	0.05	0.8349
CXF	2	60.34	30.17	1.90	0.1868
CXL	2	80.59	40.30	2.53	0.1152
FXL	1	26.40	26.40	1.66	0.2186
Error	14	222.12	15.91		

[1] C = Oat cultivar , F = Form, L = Level of oat flour substitution

Table 123. Analysis of variance for cookie shear compression: Effect of oat processing[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	4.28	2.14	0.92	0.4203
F	1	3.04	3.04	1.31	0.2708
L	1	53.61	53.61	23.14	0.0003
CXF	2	1.19	0.60	0.26	0.7764
CXL	2	1.34	0.67	0.29	0.7533
FXL	1	0.49	0.49	0.21	0.6526
Error	14	32.44	2.32		

[1] C = Oat cultivar , F = Form, L = Level of oat flour substitution

Table 124. Analysis of variance for cookie breaking strength: Effect of oat processing[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
C	2	0.87	0.44	0.15	0.8613
F	1	3.32	3.32	1.15	0.3022
L	1	5.16	5.16	1.78	0.2032
CXF	2	6.78	3.39	1.17	0.3386
CXL	2	7.44	3.72	1.28	0.3074
FXL	1	2.71	2.71	0.94	0.3495
Error	14	40.54	2.89		

[1] C = Oat cultivar , F = Form, L = Level of oat flour substitution

Table 125. Analysis of variance for cookie diameter: Effect of wheat cultivar[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
W	2	0.49	0.25	4.65	0.0207
C	2	0.64	0.32	6.06	0.0080
L	1	1.13	1.13	21.27	0.0001
WXC	4	0.20	0.05	0.93	0.4634
WXL	2	0.02	0.01	0.20	0.8215
CXL	2	0.03	0.01	0.29	0.7508
Error	22	1.17	0.05		

[1] W = Wheat cultivar, C = Oat cultivar , L = Level of oat flour substitution

Table 126. Analysis of variance for alkaline water retention capacity of composite flours: Effect of wheat cultivar[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
W	2	18.84	9.42	4.71	0.0198
C	2	72.16	36.08	18.04	0.0001
L	1	865.63	865.63	432.90	0.0001
WXC	4	76.13	19.03	9.52	0.0001
WXL	2	15.83	7.91	3.96	0.0340
CXL	2	4.85	2.42	1.21	0.3167
Error	22	43.99	2.00		

[1] W = Wheat cultivar, C = Oat cultivar , L = Level of oat flour substitution

Table 127. Analysis of variance for cookie L-value: Effect of wheat cultivar[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
W	2	19.16	9.58	10.37	0.0007
C	2	2.20	1.10	1.19	0.3229
L	1	36.18	36.18	39.17	0.0001
WXC	4	1.19	0.30	0.32	0.8607
WXL	2	0.59	0.29	0.32	0.7282
CXL	2	4.19	2.09	2.27	0.1268
Error	22	20.32	0.92		

[1] W = Wheat cultivar, C = Oat cultivar , L = Level of oat flour substitution

Table 128. Analysis of variance for cookie a-value: Effect of wheat cultivar[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
W	2	0.50	0.25	2.18	0.1373
C	2	0.18	0.09	0.80	0.4640
L	1	0.05	0.05	0.47	0.5022
WXC	4	0.05	0.01	0.10	0.9807
WXL	2	0.09	0.04	0.39	0.6793
CXL	2	0.72	0.36	3.13	0.0638
Error	22	2.54	0.11		

[1] W = Wheat cultivar, C = Oat cultivar , L = Level of oat flour substitution

Table 129. Analysis of variance for cookie b-value: Effect of wheat cultivar[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
W	2	4.55	2.27	8.14	0.0033
C	2	0.02	0.01	14.11	0.9680
L	1	6.94	6.94	34.10	0.0001
WXC	4	0.65	0.16	1.01	0.7122
WXL	2	0.01	0.00	0.92	0.9803
CXL	2	0.33	0.16	0.00	0.5845
Error	22	6.69	0.30		

[1] W = Wheat cultivar, C = Oat cultivar , L = Level of oat flour substitution

Table 130. Analysis of variance for protein content: Effect of wheat cultivar[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
W	2	4.15	2.07	123.70	0.0001
C	2	0.69	0.34	20.50	0.0001
L	1	1.77	1.77	105.40	0.0001
WXC	4	0.02	0.00	0.37	0.8301
WXL	2	0.14	0.07	4.26	0.0273
CXL	2	0.13	0.06	3.95	0.0342
Error	22	0.37	0.02		

[1] W = Wheat cultivar, C = Oat cultivar , L = Level of oat flour substitution

Table 131. Analysis of variance for cookie ash content: Effect of wheat cultivar[1].

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
W	2	0.01	0.00	5.04	0.0158
C	2	0.00	0.00	2.44	0.1105
L	1	0.12	0.12	121.46	0.0001
WXC	4	0.00	0.00	0.88	0.4903
WXL	2	0.01	0.00	3.48	0.0486
CXL	2	0.00	0.00	1.54	0.2371
Error	22	0.02	0.00		

[1] W = Wheat cultivar, C = Oat cultivar , L = Level of oat flour substitution

Table 132. Analysis of variance for cookie lipid content: Effect of wheat cultivar[1].

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
W	2	5.83	2.91	6.14	0.0076
C	2	0.25	0.12	0.26	0.7727
L	1	2.40	2.40	5.06	0.0349
WXC	4	2.12	0.53	1.12	0.3732
WXL	2	0.97	0.48	1.02	0.3781
CXL	2	2.98	1.49	3.13	0.0635
Error	22	10.45	0.47		

[1] W = Wheat cultivar, C = Oat cultivar , L = Level of oat flour substitution

Table 133. Analysis of variance for moisture retention: Effect of wheat cultivar[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
W	2	2.68	1.34	0.06	0.9383
C	2	20.65	10.32	0.49	0.6174
L	1	8.34	8.34	0.40	0.5345
WXC	4	90.20	22.55	1.08	0.3920
WXL	2	56.99	28.49	1.36	0.2774
CXL	2	105.42	52.71	2.52	0.1037
Error	22	460.86	20.95		

[1] W = Wheat cultivar, C = Oat cultivar , L = Level of oat flour substitution

Table 134. Analysis of variance for cookie shear compression: Effect of wheat cultivar[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
W	2	48.11	24.05	21.81	0.0001
C	2	15.22	7.61	6.90	0.0047
L	1	50.74	50.74	46.01	0.0001
WXC	4	2.82	0.70	0.64	0.6401
WXL	2	0.97	0.48	0.44	0.6485
CXL	2	3.26	1.63	1.48	0.2493
Error	22	24.26	0.57		1.0000

[1] W = Wheat cultivar, C = Oat cultivar , L = Level of oat flour substitution

Table 135. Analysis of variance for breaking strength of cookies: Effect of wheat cultivar[1]

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Probability
W	2	15.68	7.84	4.97	0.0166
C	2	2.39	1.19	0.76	0.4803
L	1	0.14	0.14	0.09	0.7712
WXC	4	4.34	1.08	0.69	0.6086
WXL	2	10.22	5.11	3.24	0.0585
CXL	2	8.97	4.48	2.84	0.0799
Error	22	34.73	1.58		

[1] W = Wheat cultivar, C = Oat cultivar , L = Level of oat flour substitution

Table 136. Pearson correlation coefficients and probabilities for cookies made with hammer milled groat composite flours.[1]

	Diameter	L-value	a-value	b-value	AWRC	Protein	Ash	Lipid	Moisture	Texture	Crispness
Diameter	1.00	-0.35	0.02	-0.24	0.77	0.77	0.25	0.41	0.19	-0.59	-0.68
	0.000	0.259	0.943	0.455	0.004	0.003	0.440	0.189	0.555	0.039	0.014
L-value		1.00	-0.62	0.85	-0.67	-0.55	-0.74	-0.29	-0.55	0.32	0.42
		0.000	0.032	0.000	0.017	0.066	0.005	0.354	0.061	0.302	0.169
a-value			1.00	-0.42	0.12	-0.04	0.03	0.22	0.48	0.12	-0.15
			0.000	0.177	0.697	0.909	0.916	0.486	0.109	0.714	0.634
b-value				1.00	-0.69	-0.37	-0.77	-0.35	-0.30	0.41	0.30
				0.000	0.013	0.232	0.003	0.259	0.337	0.180	0.340
AWRC					1.00	0.79	0.69	0.44	0.21	-0.64	-0.62
					0.000	0.002	0.014	0.156	0.515	0.023	0.032
Protein						1.00	0.53	0.19	0.31	-0.65	-0.62
						0.000	0.073	0.536	0.329	0.021	0.031
Ash							1.00	0.19	0.20	-0.25	-0.35
							0.000	0.545	0.532	0.425	0.263
Lipid								1.00	0.25	-0.12	-0.75
								0.000	0.440	0.701	0.005
Moisture									1.00	-0.26	-0.36
									0.000	0.414	0.252
Texture										1.00	0.40
										0.000	0.194
Crispness											1.00
											0.000

[1] n= 12

Table 137. Pearson correlation coefficients and probabilities for cookies made with roller milled groat composite flours.[1]

	Diameter	L-value	a-value	b-value	AWRC	Protein	Ash	Lipid	Moisture	Texture	Crispness
Diameter	1.00	0.10	0.43	0.35	-0.27	0.05	-0.19	-0.25	-0.46	0.07	0.05
	0.000	0.748	0.159	0.261	0.393	0.883	0.554	0.434	0.128	0.810	0.877
L-value		1.00	-0.14	0.77	-0.73	-0.79	-0.69	0.00	-0.22	0.57	0.23
		0.000	0.659	0.003	0.007	0.002	0.013	0.999	0.488	0.054	0.465
a-value			1.00	0.04	-0.38	-0.12	-0.05	-0.33	-0.46	0.35	0.32
			0.000	0.893	0.224	0.713	0.881	0.289	0.133	0.257	0.309
b-value				1.00	-0.73	-0.79	-0.71	0.13	-0.46	0.62	0.29
				0.000	0.007	0.002	0.009	0.686	0.130	0.032	0.349
AWRC					1.00	0.84	0.70	0.33	0.24	-0.75	-0.42
					0.000	0.001	0.010	0.298	0.448	0.005	0.178
Protein						1.00	0.73	-0.07	0.19	-0.79	-0.29
						0.000	0.007	0.833	0.549	0.002	0.355
Ash							1.00	0.07	0.29	-0.74	0.14
							0.000	0.832	0.352	0.006	0.671
Lipid								1.00	0.05	-0.17	-0.16
								0.000	0.867	0.596	0.580
Moisture									1.00	-0.51	-0.33
									0.000	0.092	0.294
Texture										1.00	0.18
										0.000	0.578
Crispness											1.00
											0.000

[1] n= 12

Table 138. Pearson correlation coefficients and probabilities for cookies made with hammer milled flake composite flours.[1]

	Diameter	L-value	a-value	b-value	AWRC	Protein	Ash	Lipid	Moisture	Texture	Crispness
Diameter	1.00	-0.13	0.58	-0.54	0.27	0.10	-0.05	-0.22	-0.24	0.01	0.27
	0.000	0.681	0.047	0.067	0.396	0.749	0.871	0.497	0.0443	0.969	0.391
L-value		1.00	-0.09	0.30	-0.09	-0.00	-0.41	0.22	-0.14	0.11	-0.09
		0.000	0.787	0.334	0.776	0.992	0.189	0.480	0.652	0.722	0.774
a-value			1.00	-0.36	0.29	0.29	0.02	-0.18	-0.12	-0.35	0.59
			0.000	0.245	0.354	0.352	0.951	0.581	0.719	0.260	0.040
b-value				1.00	-0.29	-0.06	-0.17	0.23	0.53	0.05	-0.35
				0.000	0.359	0.848	0.590	0.475	0.075	0.866	0.265
AWRC					1.00	0.75	0.80	0.54	-0.31	-0.76	-0.09
					0.000	0.004	0.002	0.067	0.324	0.004	0.778
Protein						1.00	0.72	0.55	-0.43	-0.68	-0.26
						0.000	0.009	0.065	0.166	0.014	0.417
Ash							1.00	0.58	-0.35	-0.78	-0.26
							0.000	0.048	0.262	0.003	0.399
Lipid								1.00	-0.45	-0.44	-0.16
								0.000	0.140	0.149	0.613
Moisture									1.00	0.19	-0.15
									0.000	0.562	0.632
Texture										1.00	0.11
										0.000	0.728
Crispness											1.00
											0.000

[1] n= 12

Table 139. Pearson correlation coefficients and probabilities for cookies made with Mariner hammer milled groat composite flours.[1]

	Diameter	L-value	a-value	b-value	AWRC	Protein	Ash	Lipid	Moisture	Texture	Crispness
Diameter	1.00	-0.20	-0.33	-0.20	0.69	0.38	0.45	0.09	-0.08	-0.18	-0.27
	0.000	0.526	0.295	0.525	0.013	0.220	0.137	0.783	0.791	0.577	0.399
L-value		1.00	0.10	0.43	-0.41	-0.73	-0.71	-0.08	0.22	0.01	-0.39
		0.000	0.766	0.162	0.179	0.007	0.010	0.800	0.486	0.967	0.209
a-value			1.00	0.05	-0.37	-0.22	-0.14	-0.16	0.34	0.57	-0.32
			0.000	0.867	0.241	0.481	0.673	0.615	0.277	0.050	0.312
b-value				1.00	-0.29	-0.69	-0.66	-0.01	-0.03	0.33	-0.21
				0.000	0.354	0.013	0.019	0.975	0.929	0.296	0.509
AWRC					1.00	0.63	0.74	0.35	-0.52	-0.38	-0.00
					0.000	0.027	0.006	0.259	0.086	0.219	0.987
Protein						1.00	0.78	-0.08	-0.36	-0.25	0.17
						0.000	0.003	0.796	0.249	0.420	0.587
Ash							1.00	0.46	-0.44	-0.33	0.40
							0.000	0.132	0.154	0.298	0.196
Lipid								1.00	-0.28	-0.52	0.57
								0.000	0.383	0.081	0.052
Moisture									1.00	-0.00	-0.37
									0.000	0.99	0.229
Texture										1.00	-0.30
										0.000	0.348
Crispness											1.00
											0.000

[1] n= 12

Table 140. Pearson correlation coefficients and probabilities for cookies made with Ogle hammer milled groat composite flours.[1]

	Diameter	L-value	a-value	b-value	AWRC	Protein	Ash	Lipid	Moisture	Texture	Crispness
Diameter	1.00	-0.67	0.39	-0.44	0.74	0.390	0.57	0.08	0.17	-0.43	-0.26
	0.000	0.017	0.199	0.155	0.006	0.210	0.051	0.813	0.596	0.157	0.403
L-value		1.00	-0.66	0.77	-0.61	-0.71	-0.78	0.08	-0.45	0.29	0.21
		0.000	0.019	0.003	0.034	0.010	0.003	0.802	0.142	0.367	0.507
a-value			1.00	-0.45	0.54	0.25	0.24	0.09	0.56	-0.26	-0.29
			0.000	0.143	0.069	0.432	0.453	0.781	0.058	0.403	0.356
b-value				1.00	-0.40	-0.63	-0.62	0.13	-0.21	0.32	0.18
				0.000	0.190	0.027	0.031	0.676	0.511	0.308	0.557
AWRC					1.00	0.10	0.59	0.41	0.47	-0.76	-0.43
					0.000	0.749	0.042	0.183	0.120	0.004	0.153
Protein						1.00	0.64	-0.29	-0.00	0.09	0.27
						0.000	0.025	0.360	0.987	0.786	0.392
Ash							1.00	0.02	0.33	-0.23	-0.28
							0.000	0.957	0.295	0.467	0.380
Lipid								1.00	-0.02	-0.42	-0.40
								0.000	0.952	0.176	0.202
Moisture									1.00	-0.04	-0.55
									0.000	0.888	0.064
Texture										1.00	0.00
										0.000	0.993
Crispness											1.00
											0.000

[1] n= 12

Table 141. Pearson correlation coefficients and probabilities for cookies made with Porter hammer milled groat composite flours.[1]

	Diameter	L-value	a-value	b-value	AWRC	Protein	Ash	Lipid	Moisture	Texture	Crispness
Diameter	1.00	-0.59	0.02	-0.63	0.80	0.74	0.69	-0.13	0.13	-0.17	-0.06
	0.000	0.043	0.949	0.026	0.002	0.006	0.011	0.689	0.692	0.590	0.855
L-value		1.00	-0.31	0.78	-0.73	-0.725	-0.71	0.41	-0.46	0.26	0.02
		0.000	0.323	0.003	0.007	0.008	0.009	0.186	0.126	0.410	0.958
a-value			1.00	-0.41	0.22	-0.71	0.22	-0.27	-0.03	0.09	-0.23
			0.000	0.189	0.485	0.825	0.496	0.385	0.919	0.759	0.471
b-value				1.00	-0.68	-0.73	-0.68	0.32	-0.28	0.25	-0.06
				0.000	0.014	0.007	0.015	0.313	0.371	0.422	0.848
AWRC					1.00	0.95	0.95	-0.03	0.22	-0.48	-0.09
					0.000	0.000	0.000	0.919	0.493	0.110	0.758
Protein						1.00	0.62	-0.15	0.26	-0.13	-0.03
						0.000	0.031	0.639	0.422	0.694	0.924
Ash							1.00	0.04	0.22	-0.62	0.01
							0.000	0.899	0.499	0.031	0.981
Lipid								1.00	-0.12	-0.34	0.61
								0.000	0.703	0.282	0.034
Moisture									1.00	-0.14	0.24
									0.000	0.672	0.457
Texture										1.00	-0.34
										0.000	0.272
Crispness											1.00
											0.000

[1] n= 12

Table 142. Pearson correlation coefficients and probabilities for cookies made with Becker composite flours.[1]

	Diameter	L-value	a-value	b-value	AWRC	Protein	Ash	Lipid	Moisture	Texture	Crispness
Diameter	1.00	-0.45	0.26	-0.40	0.86	0.75	0.58	0.21	0.35	-0.84	-0.00
	0.000	0.144	0.418	0.190	0.000	0.004	0.045	0.503	0.259	0.000	0.994
L-value		1.00	-0.10	0.24	-0.67	-0.76	-0.64	0.04	-0.20	0.46	-0.18
		0.000	0.748	0.450	0.015	0.004	0.023	0.887	0.521	0.135	0.565
a-value			1.00	-0.39	0.27	0.37	0.27	0.00	0.15	-0.09	-0.50
			0.000	0.208	0.387	0.242	0.395	0.99	0.631	0.778	0.096
b-value				1.00	-0.27	-0.40	-0.45	0.20	-0.37	0.53	0.19
				0.000	0.397	0.19	0.194	0.530	0.237	0.073	0.534
AWRC					1.00	0.85	0.61	0.09	0.19	-0.85	-0.06
					0.000	0.000	0.034	0.769	0.554	0.000	0.840
Protein						1.00	0.73	-0.09	0.17	-0.67	-0.06
						0.000	0.006	0.789	0.599	0.015	0.857
Ash							1.00	0.15	0.09	-0.58	0.27
							0.000	0.626	0.772	0.049	0.391
Lipid								1.00	-0.19	-0.09	0.64
								0.000	0.561	0.759	0.023
Moisture									1.00	-0.22	-0.24
									0.000	0.486	0.452
Texture										1.00	0.04
										0.00	0.896
Crispness											1.00
											0.00

[1] n= 12

Table 143. Pearson correlation coefficients and probabilities for cookies made with Caldwell composite flours.[1]

	Diameter	L-value	a-value	b-value	AWRC	Protein	Ash	Lipid	Moisture	Texture	Crispness
Diameter	1.00	-0.35	0.02	-0.24	0.77	0.44	0.22	0.41	0.19	-0.60	-0.68
	0.000	0.259	0.943	0.455	0.004	0.153	0.491	0.189	0.547	0.039	0.014
L-value		1.00	-0.62	0.85	-0.67	-0.74	-0.75	-0.29	-0.55	0.32	0.42
		0.000	0.032	0.000	0.017	0.006	0.004	0.354	0.061	0.302	0.169
a-value			1.00	-0.42	0.12	0.10	0.06	0.22	0.48	0.12	-0.15
			0.000	0.177	0.697	0.75	0.851	0.486	0.109	0.714	0.635
b-value				1.00	-0.69	-0.61	-0.77	-0.35	-0.30	0.41	0.30
				0.000	0.013	0.034	0.003	0.259	0.337	0.180	0.340
AWRC					1.00	0.62	0.66	0.44	0.21	-0.64	-0.62
					0.000	0.029	0.018	0.156	0.515	0.023	0.032
Protein						1.00	0.66	0.03	0.44	-0.63	-0.33
						0.000	0.019	0.932	0.148	0.028	0.294
Ash							1.00	0.18	0.22	-0.24	-0.35
							0.000	0.566	0.480	0.445	0.269
Lipid								1.00	0.25	-0.12	-0.75
								0.000	0.436	0.701	0.005
Moisture									1.00	-0.26	-0.36
									0.000	0.414	0.252
Texture										1.00	0.40
										0.000	0.194
Crispness											1.00
											0.000

[1] n= 12

Table 144. Pearson correlation coefficients and probabilities for cookies made with Compton composite flours.[1]

	Diameter	L-value	a-value	b-value	AWRC	Protein	Ash	Lipid	Moisture	Texture	Crispness
Diameter	1.00	-0.34	-0.39	-0.24	0.57	0.27	0.44	0.45	0.28	-0.51	0.06
	0.000	0.271	0.212	0.441	0.052	0.378	0.155	0.145	0.375	0.086	0.840
L-value		1.00	-0.41	0.91	-0.71	-0.47	-0.70	-0.34	-0.08	0.73	-0.44
		0.000	0.183	0.000	0.009	0.125	0.011	0.283	0.808	0.007	0.149
a-value			1.00	-0.39	-0.06	-0.04	-0.00	-0.50	0.32	-0.12	0.12
			0.000	0.211	0.855	0.909	0.985	0.098	0.312	0.705	0.699
b-value				1.00	-0.76	-0.64	-0.78	-0.46	0.07	0.75	-0.55
				0.000	0.004	0.026	0.003	0.133	0.831	0.005	0.072
AWRC					1.00	0.82	0.97	0.75	-0.23	-0.86	0.36
					0.000	0.001	0.000	0.004	0.465	0.000	0.248
Protein						1.00	0.85	0.78	-0.59	-0.78	0.64
						0.000	0.000	0.003	0.041	0.003	0.024
Ash							1.00	0.76	-0.23	-0.81	0.36
							0.000	0.004	0.474	0.001	0.252
Lipid								1.00	-0.50	-0.64	0.48
								0.000	0.095	0.023	0.112
Moisture									1.00	0.37	-0.49
									0.000	0.238	0.102
Texture										1.00	-0.54
										0.000	0.069
Crispness											1.00
											0.000

[1] n= 12

Figure 42 Sugar-snap cookies made with composites of Mariner, Ogle and Porter whole grain hammer milled groat flour and Caldwell soft wheat flour

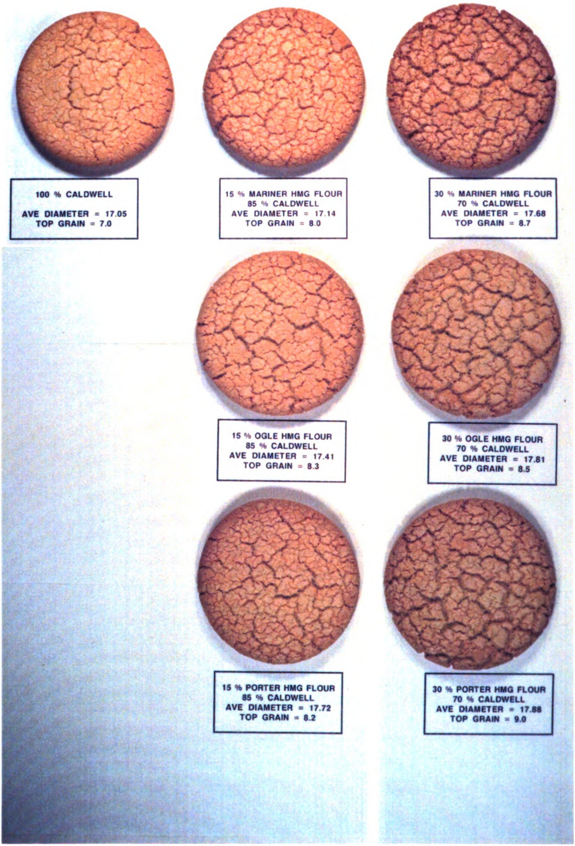

100 % CALDWELL
AVE DIAMETER = 17.05
TOP GRAIN = 7.0
15 % MARINER HMG FLOUR
85 % CALDWELL
AVE DIAMETER = 17.14
TOP GRAIN = 8.0
30 % MARINER HMG FLOUR
70 % CALDWELL
AVE DIAMETER = 17.68
TOP GRAIN = 8.7
15 % OGLE HMG FLOUR
85 % CALDWELL
AVE DIAMETER = 17.41
TOP GRAIN = 8.3
30 % OGLE HMG FLOUR
70 % CALDWELL
AVE DIAMETER = 17.81
TOP GRAIN = 8.5
15 % PORTER HMG FLOUR
85 % CALDWELL
AVE DIAMETER = 17.72
TOP GRAIN = 8.2
30 % PORTER HMG FLOUR
70 % CALDWELL
AVE DIAMETER = 17.88
TOP GRAIN = 9.0

Figure 43. Sugar-snap cookies made with composites of Mariner, Ogle and Porter whole grain roller milled groat flour and Caldwell soft wheat flour

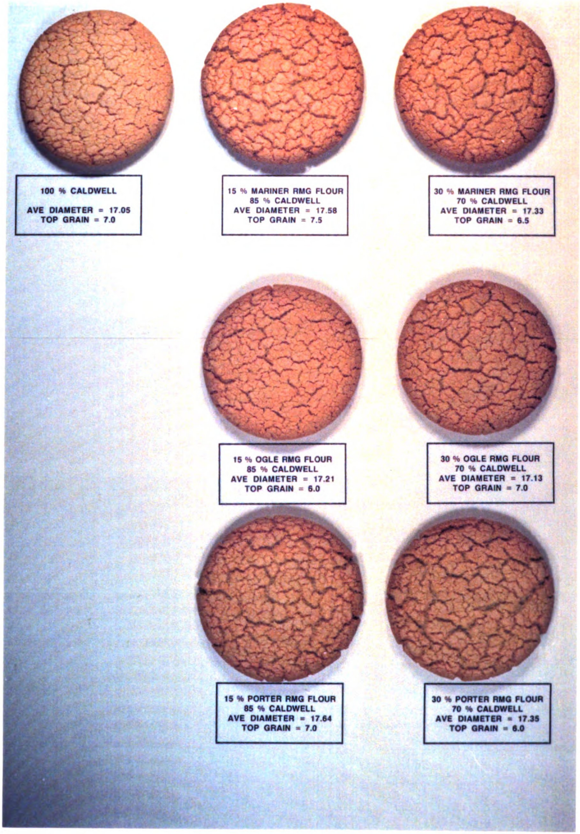

100 % CALDWELL
AVE DIAMETER = 17.05
TOP GRAIN = 7.0
15 % MARINER RMG FLOUR
85 % CALDWELL
AVE DIAMETER = 17.58
TOP GRAIN = 7.5
30 % MARINER RMG FLOUR
70 % CALDWELL
AVE DIAMETER = 17.33
TOP GRAIN = 6.5
15 % OGLE RMG FLOUR
85 % CALDWELL
AVE DIAMETER = 17.21
TOP GRAIN = 6.0
30 % OGLE RMG FLOUR
70 % CALDWELL
AVE DIAMETER = 17.13
TOP GRAIN = 7.0
15 % PORTER RMG FLOUR
85 % CALDWELL
AVE DIAMETER = 17.64
TOP GRAIN = 7.0
30 % PORTER RMG FLOUR
70 % CALDWELL
AVE DIAMETER = 17.35
TOP GRAIN = 6.0

Figure 44. Sugar-snap cookies made with composites of Mariner, Ogle and Porter whole grain hammer milled flake flour and Caldwell soft wheat flour


100 % CALDWELL
AVE DIAMETER = 17.05
TOP GRAIN = 7.0
15 % MARINER HMF FLOUR
85 % CALDWELL
AVE DIAMETER = 17.23
TOP GRAIN = 6.8
30 % MARINER HMF FLOUR
70 % CALDWELL
AVE DIAMETER = 17.13
TOP GRAIN = 8.5
15 % OGLE HMF FLOUR
85 % CALDWELL
AVE DIAMETER = 17.07
TOP GRAIN = 7.3
30 % OGLE HMF FLOUR
70 % CALDWELL
AVE DIAMETER = 17.26
TOP GRAIN = 8.0
15 % PORTER HMF FLOUR
85 % CALDWELL
AVE DIAMETER = 17.48
TOP GRAIN = 8.0
30 % PORTER HMF FLOUR
70 % CALDWELL
AVE DIAMETER = 17.47
TOP GRAIN = 8.8

Figure 45. Sugar-snap cookies made with composites of Mariner, Ogle and Porter whole grain hammer milled groat flour and Becker soft wheat flour

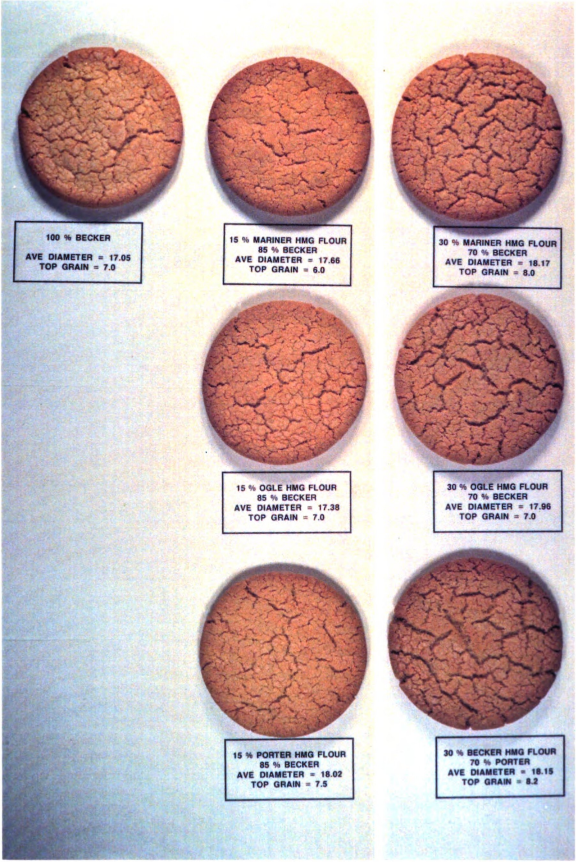

100 % BECKER
AVE DIAMETER = 17.05
TOP GRAIN = 7.0
15 % MARINER HMG FLOUR
85 % BECKER
AVE DIAMETER = 17.66
TOP GRAIN = 6.0
30 % MARINER HMG FLOUR
70 % BECKER
AVE DIAMETER = 18.17
TOP GRAIN = 8.0
15 % OGLE HMG FLOUR
85 % BECKER
AVE DIAMETER = 17.38
TOP GRAIN = 7.0
30 % OGLE HMG FLOUR
70 % BECKER
AVE DIAMETER = 17.96
TOP GRAIN = 7.0
15 % PORTER HMG FLOUR
85 % BECKER
AVE DIAMETER = 18.02
TOP GRAIN = 7.5
30 % BECKER HMG FLOUR
70 % PORTER
AVE DIAMETER = 18.15
TOP GRAIN = 8.2

Figure 46. Sugar-snap cookies made with composites of Mariner, Ogle and Porter whole grain hammer milled groat flour and Compton soft wheat flour

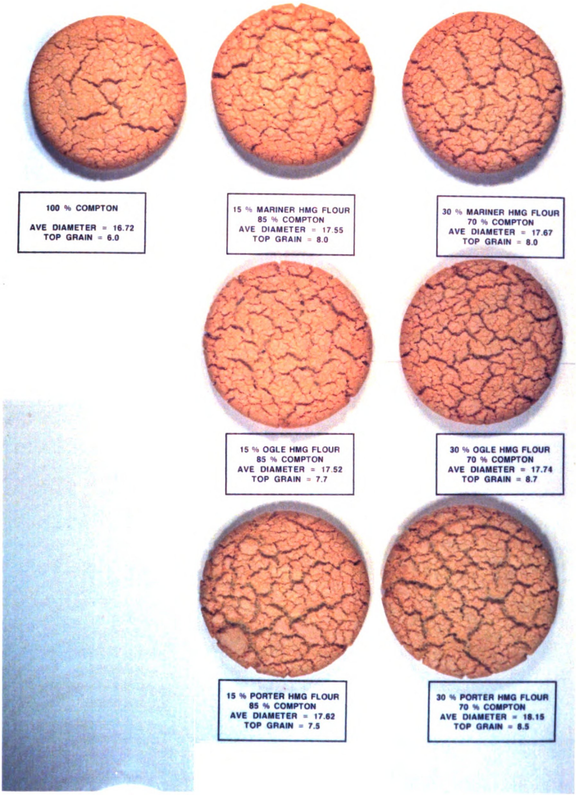
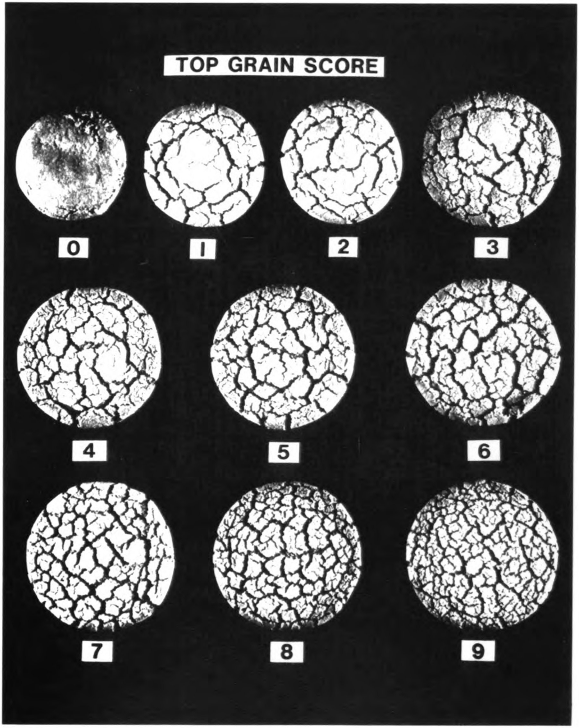

100 % COMPTON
AVE DIAMETER = 16.72
TOP GRAIN = 6.0
15 % MARINER HMG FLOUR
85 % COMPTON
AVE DIAMETER = 17.55
TOP GRAIN = 8.0
30 % MARINER HMG FLOUR
70 % COMPTON
AVE DIAMETER = 17.67
TOP GRAIN = 8.0
15 % OGLE HMG FLOUR
85 % COMPTON
AVE DIAMETER = 17.52
TOP GRAIN = 7.7
30 % OGLE HMG FLOUR
70 % COMPTON
AVE DIAMETER = 17.74
TOP GRAIN = 8.7
15 % PORTER HMG FLOUR
85 % COMPTON
AVE DIAMETER = 17.62
TOP GRAIN = 7.5
30 % PORTER HMG FLOUR
70 % COMPTON
AVE DIAMETER = 18.15
TOP GRAIN = 8.5

Figure 47. Sugar-snap cookie top grain score standards from U.S.D.A. Soft Wheat Quality Laboratory at Wooster, Ohio


TOP GRAIN SCORE
0
1
2
3
4
5
6
7
8
9

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REFERENCES

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