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

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

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ABSTRACT

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

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The functionality of oat-wheat composite flours in sugar-snap cookies was studied. The effect of processing was determined by production of whole grain oat flour from groats and rolled oat flakes. The effect of milling was determined by comparing hammer milled flours to roller milled flours. Three oat cultivars were milled into separate oat flours. Straight grade flours of three different soft wheat cultivars were combined with oat flours to make composite flours containing 15 and 30 percent oat flour.

Chemical analyses of the oat flours indicated the method of milling and processing groats into flakes influenced protein content. Roller milling produced oat flour with a finer particle size than hammer milling. Flour particle size influenced lipid analysis, viscoamylograph properties and alkaline water retention capacity. Oat cultivars differed in resistance to particle reduction forces during milling and processing. Oat cultivars differed in protein, ash,

lipid, total dietary fiber and b-glucan content. Scanning electron microscopy of aleurone cell walls did not find a relationship between aleurone and subaleurone cell wall width and dietary fiber content.

The functional properties of oat-wheat composite flours in sugar-snap cookies were affected by the method of milling oats, processing groats into flakes, level of substitution and wheat cultivar used to produce the composite flour. Cookies made with hammer milled groat flour composites had larger diameters and better top grain scores than cookies made with roller milled groat flours. Cookies made with hammer milled flake flours had restricted cookie spread and poorer top grain scores than cookies made with hammer milled groat flours. Wheat cultivars related effects included diameter, protein content, and textural properties. Incorporation of hammer milled groat flours into sugar snap cookies increased cookie spread and improved top grain scores. Cookies made with 30 percent oat flour had larger diameters, better top grain scores and lower Hunter Color Difference L-values (lightness) than cookies containing 15 percent oat flour. Alkaline water retention capacity was positively correlated to cookie diameter when hammer milled groat flours were used in sugar-snap cookies.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Oats have been identified as a good source of protein, polyunsaturated fatty acids and soluble dietary fiber. Yet, the use of whole grain oat flour in the United States is mostly limited to baby cereals and ready to eat breakfast cereals. Oat bran usage in the United States has increased significantly since scientific studies linked the intake of dietary fiber with prevention of atherosclerosis, diverticulosis, colonic cancer, appendicitis and reduction of serum cholesterol. Consumers have become more interested in purchasing fiber enhanced foods. Foods targeted by industry for incorporation of fiber are baked goods, breakfast cereals and snack foods.

Whole grain oat flour lacks the structural proteins required for most baked products. Sugar-snap cookies are a chemically leavened baked product that is of optimum quality when a minimum of gluten is formed during the mixing and handling of the cookie dough.

Soft wheat flours are preferentially used by commercial bakeries for cookies. The sugar-snap cookie formulation is used by the baking industry to evaluate cookie flour quality or to determine if the end product will have desirable characteristics. Cookie doughs made with soft wheat flours must expand and flow during the baking process to enable heat coagulation of flour proteins and loss of moisture. Sugar-snap cookie diameters and top grain scores are indicators of the rheological properties of cookie doughs during baking.

Non-wheat flours substituted into wheat flour to be used for cookie manufacture should not detrimentally affect flavor, appearance or texture of the end product. The flavor of whole grain oat flour has already been made familiar to consumers in the form of breakfast cereals and oatmeal cookies. Cookies made from substituted or composite flours should be of comparable quality to cookies made from 100 percent soft wheat flour.

The study had four objectives. The first objective was to determine the effect of two different types of mill on the chemical and functional properties of whole grain oat flour. The second objective was to compare the functionality of oat flour from three different oat cultivars. The third objective was to determine the effect of processing groats into oat flakes prior to milling into oat flour. The fourth objective was to determine the interaction of flours from three different soft wheat cultivars with whole grain oat flours.

REVIEW OF LITERATURE

Whole grain oat flour has not been reported as being used extensively in chemically leavened baked products. Baby cereals and ready to eat breakfast cereals are the major oat flour products (Weaver et al, 1981). Whole grain oat flour lacks the proteins required to form gluten in baked products. Replacement of wheat flour with a percentage of non-wheat flour reduces the structural organization of gluten within a baked product. However, since sugar snap cookies are not greatly dependent on a gluten structure for the finished product to have the desired quality characteristics, use of a composite flour made of whole oat flour and soft wheat flour could be feasible.

Composite Flours

Composite flours are flour mixtures in which wheat flour has been replaced by flours from other cereal grains, starches or protein concentrates. Traditionally, many European countries have produced breads prepared from mixtures of wheat and rye flours. Bean flour, potato flour and barley flour were used to prepare breads during World War I and II (de Ruiter, 1978). Composite flours have been developed for economic and nutritional reasons.

Economic, Nutritional and Consumer Considerations

Economic and nutritional reasons are the basis for use of composite flours In developing countries. Composite flours are used to decrease the amount of wheat imports which contribute to foreign debt (Fellers and Bean, 1988). The Food and Agriculture Organization of the United Nations (FAO) initiated a "Composite

Flour Program" in 1964 with the objective of using raw materials other than wheat in the production of bread, biscuits, pastas and other similar flour based foods. Nutritionally, composite flours can be formulated to provide extra nutrients such as vitamins, amino acids and trace elements (de Ruiter, 1978).

Composite flours in developed countries meet consumer demand for variety and specific nutritional factors in the diet. In the United States, composite flours find their greatest use in providing variety to the diet in such products as multigrain breads, rye and triticale breads, potato bread, oatmeal cookies, corn bread and buckwheat pancakes. Soy breads and breads with increased levels of dietary fiber are examples of nutritionally enhanced breads produced in the United States (Fellers and Bean, 1988). Sievert et al (1990) concluded that a major problem associated with addition of high levels of dietary fiber sources into traditional foods is the detrimental effect these ingredients have on the physical and sensory properties of the foods. Changes in flavor, palatability, appearance and texture are unacceptable to most marketers and consumers.

One approach used by research programs has been to establish the percentage of wheat flour that can be replaced by other flours without major changes in quality of the final product and without requiring considerable adjustment in the commercial manufacturing process. An acceptable composite flour should produce baked products and pastas that are of comparable quality to an 100% wheat product. Several researchers have prepared biscuit, cookies and baked goods other than bread from composite flours. Composite flours may be in some ways be more suitable for producing baked goods such as cookies rather than bread. Cookie doughs require less gluten formation than bread doughs. Commercial production requirements for wire cut cookies include dough plasticity, minimum elasticity and a low degree of gluten development (Matz and Matz, 1978).

Composite Flour Research in Cookie Systems

Fogg and Tinklin (1972) replaced all purpose wheat flour at levels of 6 and 15 percent by weight in sugar snap cookies with glandless cotton seed flour. Two different particle sized cotton seed flours (CSF) were used in the sugar snap cookies. Fine CSF passed through 100 mesh (150 millimicron) and coarse CSF passed through 80 mesh (100 millimicron) Cookies containing cotton seed flour had significant ($p < 0.05$) reductions in mean tenderness, height, volume and specific volume (volume/wt). Cookie weight increased as the amount of CSF in the formula increased. Cookies containing coarsely ground CSF were less tender, had less width, volume and specific volume than cookies containing equal amounts of finely ground cotton seed flour. Fogg and Tinklin concluded "coarse CSF absorbed moisture more readily or bound moisture more securely than fine CSF". Cookie spread (width/height) increased with increasing amount of CSF in the formula. Spread of cookies containing CSF appeared to be dependent upon interaction of grind and level of cotton seed flour.

Vecchionacce and Setser (1980) substituted liquid cyclone processed cotton seed flour at levels of 12, 24, 36 and 48% by weight for all purpose commercial wheat flour. The cotton seed flour (CSF) on a dry weight basis was composed of 66% protein so that substitution of 48% CSF produced a cookie which contained 15.6% protein. Sodium stearoyl 2 lactylate (SSL) or xanthan gum (XG) were added at the 1% level of combined flour weight to the formula to function as stabilizers. Increasing the level of CSF produced darker cookies with an increasing reddish hue as measured by the Gardener automatic color meter. Sugar-snap cookies containing 24 and 36% CSF had higher spread ratios than the control cookie. Spread ratio was less than the control cookie at the 12% and 40% level of substitution. Addition of SSL produced more tender cookies at the 0, 12 and 24% level of substitution. Xanthan gum significantly increased the shortness value of cookies containing 36 and 48% CSF. Taste panelists rated cookies with increasing amounts of CSF higher in the categories of color, texture and tenderness. Flavor scores were significantly higher when cookies contained cookies with SSL and 24, 36 and 48% CSF compared to cookies with xanthan gum and the same levels of CSF.

Tsen et al (1973) prepared sugar-snap cookies using soft wheat flours fortified with three different soy products: full fat soy flour, defatted soy flour or two soy protein isolates. The fortification levels for each soy product in combination with the wheat flour were 8, 12, 16, 20, 24, 30, 40 and 50 percent. The soy products significantly reduced cookie spread and increased cookie thickness as progressively more soy product was blended with the wheat flour. Full fat soy flour (22.2% crude lipid) had less effect on cookie spread than defatted flours at all fortified levels. Tsen attributed this effect to a lower protein level in full fat (40%) soy flour than in defatted (52.6%) soy flour. Sodium-stearoyl 2 lactylate (0.5%) increased the spread ratio of cookies made of any of the types of wheat flours. A sub-study examined the effects of surfactants on cookies fortified with 12% defatted soy flour. The addition of 0.5% sodium-stearoyl 2 lactylate increased the spread ratio of cookies made from wheat flours blended with 12% defatted soy flour. The effect of the surfactants, sodium-stearoyl 2 lactylate and sodium-stearoyl fumarate on cookie spread were compared at five levels of surfactant and two levels of shortening The conclusion was that the individual surfactants increased cookie spread and decreased the levels of shortening required in the cookie doughs prepared with any of the types of soy-wheat composite flours.

McWatters (1978) evaluated the cookie baking properties of defatted soybean, peanut, and field pea flours. These flours were substituted at the 10, 20 and 30% level for wheat flour. Soybean flour exhibited high water absorptive properties and cookie doughs required a higher level of water addition. Water absorptive properties at the 20 and 30% replacement levels restricted cookie spread and development of typical top grain. Cookie doughs made with peanut and field pea flours had handling properties similar to the 100% wheat controls. Cookies with all three levels of field pea flour did not differ significantly from the 100% wheat controls in dough and baking characteristics. However, a beany flavor was detected at the 30% level. As the amount of peanut flour increased., cookies had significantly ($p < 0.01$) decreasing scores for appearance and color.

Badi and Hoseney (1976) prepared cookies from grain sorghum and millet flours. The products showed poor spread even with the addition of small quantities of wheat lipids, soy lecithins or soy oils. Sorghum and millet flour cookies lacked the required cohesive properties of a cookie dough. A pretreatment process which consisted of wetting, hydration for 6 hours and air drying to 12% moisture was required to produce sorghum and millet flours that could be combined with wheat flour. Composite flours of wheat flour and treated sorghum or millet flour did produce acceptable cookies.

Badi and Hoseney (1978) used corn flour as a partial and total replacement for soft wheat flour in sugar-snap cookies. Cookies made with untreated corn flour had a markedly reduced cookie spread and a poor top grain. A pretreatment process of hydration for 6 hours, air drying at room temperature and addition of 0.6% soybean lecithin was required to increase cookie diameter and improve top grain. Centrifugation and reconstitution of corn flour fractions indicated that enzymatic activity occuring during the hydration process could increase cookie diameters. Corn flour particle size and starch damage were found to be unrelated to cookie spread.

Gorczyca and Zabik (1979) substituted 10, 20 and 30% cellulose and coated cellulose particles in sugar snap cookies. The non-coated celluloses differed in particle size, ranging from average particle size 30-35 to 150-225 microns. Soy lecithin was added to the micro III method formula at the 2% level total weight of flour and cellulose. Top grain scores and cookie spread decreased as the amount of cellulose added increased. Increasing levels of cellulose substitution increased the moisture content producing cookies with lower levels of breaking strength and shear values. Cookies with 20 to 30% cellulose were softer and thicker while being lighter in color. Cookies containing all five types of cellulose at the 10% level of substitution were judged by taste panelists to be acceptable. Pectin-coated cellulose had been reported to have the greatest hypocholesterolemic effect but produced cookies with the poorest top grain.

Oomah (1983) measured baking properties of wheat-oat composite flours. Two types of oat flour were substituted for wheat flour at levels of 5, 10, 15, 20, 25 percent by weight. One of the oat flours was a commercial hammer milled product made from conditioned groats or rolled oats. The second flour was roller milled from groats. Cookies baked with roller milled oat flour had a progressive increase in cookie spread (width/thickness) as oat flour was substituted at higher percentages. There was no significant difference in cookie spread between the 100 percent wheat flour control and the cookies made with commercial hammer milled flour except at the 5 percent substitution level.

Hoojjat and Zabik (1984) investigated the effect of navy bean and sesame flours on the baking properties of sugar-snap cookies. Combinations of navy bean - sesame seed flours were substituted for soft wheat flour at the 20 and 30% levels. Navy bean-sesame seed combinations were 20:0, 15:5, 10:10, 5:15, 0:20 for the 20% composite flours. Thirty percent composites consisted of combinations of 30:0, 20:10, 15:15, 10:20, 0:30. navy bean sesame seed flour. Cookies made with navy bean flour had dough handling properties like the 100% wheat flour controls. As the amount of sesame seed flour increased the doughs became more sticky. Cookie diameter decreased and thickness increased with increasing amounts of navy bean and sesame seed flour. Composite flours of 20 and 30% sesame flour produced cookies that were tougher than the controls. Increasing the amount of navy bean flour produced cookies that required less force than the controls to break them.

Sievert et al (1990) investigated the functional properties of soy polysaccharides and wheat bran in soft wheat products. The soy polysaccharides tested were derived from processing dehulled and defatted soybean flakes. The raw material was primarily cell wall material of the soybean cotelydon. The polysaccharides included mainly cellulose, arabinogalactan, arabinan and an acidic polysaccharide complex. The soft wheat cookie flour was a blend of Pacific Northwest varieties. Cookies were baked by AACC method 10-52. As the percentage of fiber added increased, cookie diameter decreased. Influence on cookie spread varied with the source of fiber. Coarse and fine wheat bran had a significant effect in cookie diameter at the 5% level. Coarse wheat bran had the least effect, soy polysaccharides and fine bran had the greatest effect. At levels greater than 10%, fine bran was worse than coarse bran. Addition of soy polysaccharides produced lighter colored cookies and had a more pronounced effect on top grain characteristics than adding wheat bran. As the amount of soy polysaccharides increased, a desirable top grain was replaced by fine hairline cracks. A similar less pronounced effect was seen for fine wheat bran. Coarse bran affected top grain appearance the least. Adding 15% coarse wheat bran affected top grain characteristics rather than cookie spread.

Oat Cultivar Related Properties

The origin of oats can be traced back to about 2000 B.C., being grown in the areas surrounding the Mediterranean Sea. (Schrickel, 1986) The two species most frequently cultivated in the world are *Avena sativa* and *A. byzantina*. *A. sativa* has a white or yellow seed coat. *A. byzantina* has red seed coat. *A. sativa* is the most popular species grown in the United States and the world.

Oat cultivars are grown in agricultural areas based upon environmental conditions and disease situations in the growing area. Webster's New World Dictionary (1986) defined a cultivar as a variety of a plant species originating and continuing in cultivation and given a name in a modern language. Spring oats grown in the Northern Hemisphere are planted in April or May and harvested in July or August (Schrickel,1986). The planting schedule for oats make the crop more susceptible to disease than other small grains because the regions are warm and humid (Simon and Murphy, 1961).

Schrickel (1986) ranked the primary oat diseases in the United States in order of economic importance as being yellow dwarf virus, leaf or crown rust (*Puccinia coronata*), septoria (*Septoria avenae*), stem rust (*Puccinia graminis*), halo blight (*Pseudomonas coronafaciens*), loose smut (*Ustilago avenae*) and covered smut (*Ustilago kolleri*). Cultivars planted in the United States must be resistant to barley yellow dwarf (Red Leaf) virus disease (Freed et al 1986). Barley Yellow Dwarf Virus (BYDV) seriously depresses oat yields. Crown rust has been the most widespread and destructive disease of oats, causing reduced crop yield and grain quality in major oat producing areas of the United States (Simon and Murphy, 1961). The best method for avoiding losses due to BYDV and crown rust is to grow disease resistant cultivars or varieties. Oat breeders over the last 50 years have developed several varieties of oats with reasonably good genetic resistance to these diseases.

Oat cultivars not only differ in resistance to disease but also in yield, protein content, lipid, fiber and mineral content. There are co-relationships between yield and protein content. A depression in yield due to low levels of rainfall may result in higher levels of protein (Welch et al, 1991). This negative relationship between yield and protein concentration exists for the majority of oat cultivars. One recent exception to the relationship was the Wisconsin grown cultivar, Dal (Burrows, 1986). Miller et al (1980) reported that the environment influenced changes in oat groat phytic acid levels and these influences are similar for different oat cultivars.

Oat Protein:

Robbins et al (1971) analyzed protein content in 286 different oat cultivars and reported a range of 12.4 - 24.4% protein (db) in oat groats. High protein oats are those that contain more than 17 percent protein on a dry basis (Paton, 1977). According to Kim et al (1979), oat protein is composed of glutelins (66%), albumins (7.5%), globulins (12.9%) and prolamines (13.9%). Saigo et al (1983) reported that the predominate storage protein in oats is globulins. Pomeranz (1973), Cluskey et al (1979) and Zarkadas et al (1982) concluded that oat groats contain good quality protein and that lysine is the limiting amino acid. A unique characteristic of oats is that the nutritional quality of the protein as measured by amino acid profile is only slightly changed as the protein level is increased due to breeding practices (Burrows, 1986).

Youngs and Gilchrist (1976) studied protein distribution within oat kernels of a single cultivar. Growing conditions and level of fertilizer application influenced the groat protein concentration. As protein content increased, protein concentration increased in the bran, germ and starchy endosperm fractions of the groat. This deposition pattern was different from that previously found in two wheat cultivars. The bran fraction showed a greater increase in protein (2.5 - 2.8% vs 0.6 - 2.3%) than other oat fractions.

Wu and Stringfellow (1973) air classified ground oat flour from one high protein (17.2% db) and one normal protein (12.8% db) variety. The coarse residue or particles > 30µ had a higher protein percentage (24.2 and 29.2), fat percentage (3.2 and 2.8) and crude fiber (5.0 and 6.4) than the total groat in both cultivars. For particles less than 30µ, protein content decreased with increasing particle size. The crude fiber content increased with increasing particle size.

MacArthur and D'Appolonia (1979) studied sugars in oat cultivars with three different protein levels, high (21.1%) intermediate (19.9%) and low (16.5%) protein levels. The oat flour with the highest protein content also contained the higher percentage (1.3%) of total sugar. The oat brans contained less total sugar (2.6-3.4%) than the wheat bran (4.9%). The intermediate protein containing oat cultivar contained the most total sugar (3.4%) in its oat bran. Sucrose was the predominate free sugar in oat and wheat flour. The amount of sucrose varied according to the protein level in the oat flour, high protein oats containing the most sucrose and low protein oats containing the least sucrose.

Oat Fiber:

The major component of soluble fiber found in the kernels of oats (*Avena sativa*) is (1-3)(1-4)-b-D-glucopyranose or β-glucan (Welch et al, 1991). β-glucan is located throughout the cell walls of the endosperm but is present in higher amounts in the thicker cell walls of the subaleurone layer (Wood, 1989 and Fulcher, 1986). β-glucan is the active serum cholesterol lowering component in oat bran (Anderson and Chen, 1986).

The level of β-glucan found in oats can be dependent on cultivar type and levels of nitrogen fertility. Welch and Lloyd (1989) reported that when oat cultivars were grown under similar conditions, kernel levels of β-glucan ranged from 3.2 to 6.3%. The results indicated that plant breeding could influence oat β-glucan levels. Welch et al (1991) reported that increased application of nitrogen based fertilizers led to significantly higher ($p < 0.05$) levels of kernel β-glucan. Cultivar differences in β-glucan levels were more predominate when relatively low levels of nitrogen fertilizer was available. This study indicated a positive relationship between β-glucan levels and protein within a cultivar.

Oat Lipid:

Oat groats contain a higher concentration of lipids than other cereal grains. Weber (1973) measured the lipid content of seven cereal grains and reported values of 7.6% for oat groats as compared to 4.4% for corn, 2.1% for wheat, 2.2% for rice, 1.8% for rye, 3.4% for sorghum and 2.1% for barley. Youngs et al (1977) and Sahasrabudhe (1979) found that digalactosyldiglycerides (DGDG) were the major glycolipid component in the groat lipid (6.9-7.6%). Phosphatidylcholine was the major phospholipid in groat lipids and in all groat fractions, ranging from 2.8 - 6.1%.. Most of the triglycerides had a high level (ratio of 1 to 2.2) of unsaturation.

Lipid concentration and fatty acid concentration in oats is highly heritable (Youngs,1986). Multiple genes are involved in the inheritance of oil content (Frey et al. 1975). Breeding procedures are continually being evaluated to determine if oats can be developed as an oilseed crop (Branson and Frey, 1989).

Youngs et al (1977) analyzed two oat cultivars for lipids and fatty acids. The cultivar Dal had high lipid concentration, (8.0%) and Froker, a medium lipid concentration (5.5%). Bran contained more free and bound lipids than the starchy endosperm. Bran contains less palmitic and more stearic acid than the other fractions. Saastamoinen et al (1989) compared the oil content and fatty acid composition of seven of the most commonly cultivated Finnish oat varieties. Average oil content ranged from 6.1 to 7.8%. The environment had an effect on oil content of oats. Low growth temperatures increased the percentage of oil in oats and the synthesis of oleic and linoleic acids while decreasing the concentrations of stearic and palmitic acid.

Youngs and Forsberg (1979) and Gullord (1980) concluded that there was no significant correlation between oil and protein content in oats. The environment had a greater effect on protein content so variation among oil concentrations was usually less than that among protein concentration.

Oat Starch:

Starch is the major carbohydrate in oats. The amount varies with cultivars and with the method of extraction. Paton (1977) used an alkaline extraction procedure combined with centrifugation on nine oat cultivars and found starch levels which ranged from 43.7-61.0%. MacArthur and D'Appolonia (1979) used a centrifugation extraction method for starch from three cultivars containing high, intermediate and low protein levels. The results were starch levels ranging from 67 - 73.5%.

The nine oat cultivars analyzed by Paton (1977) were grown at various locations in Canada and the United States. Fertilizer application was at two levels; no fertilizer application or 500 kilograms per hectare (kg/ha). Fertilizer application increased protein content. There was an inverse relationship between protein content and starch content. The cultivars in this study contained higher (57-61%) yields of starch in varieties that had lower (14.3-15.9%) protein content.

MacArthur and D'Appolonia (1979) also reported that in oat groats, starch concentration varied inversely with protein content, the high protein cultivar contained the least starch. The starch granule of the higher level protein oat flour had the highest granule density which indicated a more compact granule structure which might explain differences in pasting properties. The high protein oat flour starch also had a slightly lower water binding capacity.

Amylose content and lipid content was slightly higher in high protein oats than in intermediate or low protein oats (27.9 vs 25.5 and 25.9%) with lipid values at 1.11 vs 0.67 and 0.81%.

Oat Structure and Processing

Oats are a member of the gramineae or grass family and contain similar structures as those found in wheat, barley, corn and rice (Fulcher, 1986). However, the oat kernel has specific structural and chemical components that are different than other cereal grains. These greatly influence processing characteristics of oats. The oat kernel is divided into four distinct parts: pericarp, seed coat, germ and endosperm (Kent, 1983). Oats are covered by an additional layer outside the pericarp. This layer is the husk and unlike the husk in wheat and rye, it remains attached after threshing (Frolich and Nyman, 1988). The husk must be removed to process oats for human consumption.

Oat structures and related chemical components

Commercial oat bran is composed of the pericarp, seed coat, aleurone and subaleurone layer (Kent, 1983). The aleurone layer has cuboidal cells with relatively thick cell walls (50-150 µm). The subaleurone layer has more irregular shaped cells and is not present at all points in the kernel. These two outer layers contain a high proportion of aleurone grains and protein bodies. Aleurone grains are protein bodies located exclusively in the aleurone layer and have been shown by selective staining (Fulcher and Wong, 1980; Gates and Oparka, 1982) to differ chemically from protein bodies located in the starchy endosperm. The subaleurone layer of high protein oats

(> 17% protein) has been shown to contain a large concentration of protein bodies and a lower percentage of starch granules (Fulcher, 1986). Phytin and phenolic compounds are associated with the primary cell wall of the aleurone layer of oats (Yiu, 1986). Beta glucan occurs in the inner cell walls of the aleurone layer and in the cell walls of the adjacent starchy endosperm (Fulcher, 1986).

The starchy endosperm of oats contains oat protein bodies and starch granules (Yiu, 1986). Starch in oats is found as simple and compound grains. The oat starch compound grain is composed of two to several polygonal granules. Lipids in oats range from 5 to 9% depending on the variety. Most of the groat lipid is stored in the endosperm in the form of oil droplets.

Commercial processing

All oats used as human food are commercially processed (Kent, 1983). The enzyme lipase is located almost entirely in the pericarp or outer layers of the groat. The enzyme comes in contact with oat lipids during the milling process. The enzyme lipase hydrolyzes oat lipids which contain high percentages of oleic, linoleic and palmitic fatty acids into glycerol and free fatty acids. The presence of free fatty acids lead to a bitter flavor in oatmeal. Free fatty acids react with bicarbonate of soda to form sodium salts of fatty acids which have a soapy flavor. The heat treatment known as the Miag process quickly raises the temperature of cleaned oats to 96^{o}-$100^{o}C$ for 2-3 minutes to inactivate lipase and other unwanted enzymes.

Lookhart et al (1986) reported on the effect of commercial processing on chemical and physical properties of oat groats. The stages of commercial processing monitored were; dehulling-to give "original groats", drying to yield "dried groats" and steaming and rolling to produce "oat flakes." Scanning electron micrographs of the de-hulled groat showed rounded compound starch granules with diameters of 3 - 15µm. No fractured granules were seen. The protein bodies were small (diameter 0.5-2.0µm) and randomly distributed. The cell walls were intact. Drying resulted in a split groat that had some starch granules fractured into individual granules. The oat flake contained fragmented cell walls that were separated from other cell components. There was an increase in starch fragments into more individual granula than in dried groat; less protein bodies were visible. Browning of the oat flakes was speculated to be caused by the Maillard reaction and from heating.

Chang and Solulski (1985) examined the functional properties of oat flour roller milled from wild and domestic oat groats. The groats were steamed to inactivate oat lipase and kiln dried prior to processing. The steam treatment denatured oat proteins and decreased nitrogen solubility. The proteins were insoluble in the pH range 3 - 6, the range of pH commonly used in foods.

Yiu (1986) used fluorescence microscopy to study the effects of processing and cooking on the structural and microchemical composition of oats. The bran, starchy endosperm and germ differed in milling properties, cell structure and chemical contents. The aleurone and subaleurone cell walls were relatively resistant to processing. Microscopic examination indicated that most endospermic cell walls were altered by processing. Many of the cell walls of the subaleurone and aleurone layer remained relatively intact after processing. Mechanical forces did not disrupt the structural association between beta-glucan and the cell walls.

Proteins and lipids in the endosperm tissue were most susceptible to processing (Yiu, 1986). Both proteins and lipids changed from distinct structural units to aggregated masses as a result of processing. Rolled oats contained many intact as well as broken starch granules. The broken starch granules were not gelatinized by the processing methods used to prepare rolled groats. Rolled oats had most of the lipid content still within cells that had intact cell walls. Individual lipid bodies could not be detected. Yiu concluded that the loss of lipids in rolled oats due to processing and cooking was insignificant.

Oomah (1987) studied the effect of the commercial processing steps of conditioning, drying, cutting and grinding on oat protein solubility and pasting characteristics. Roller milled flour from groats was compared to hammer milled flour from rolled oats. Oat flour prepared from hammer milled rolled oats did not differ significantly in protein content from steel cut oats. Roller milled oat flour contained twice as much protein soluble in distilled water than hammer milled oat flour. The conclusion was that heat treatment, the Miag process, used in preparing commercial oat flour may effect protein solubility. Steam treatment was suggested to cause stable protein aggregates to be formed through non-covalent bonds.

Pasting characteristics of oat flours roller milled from oats in different stages of commercial processing showed few differences (Oomah, 1987). Flours milled from conditioned groats had initial swelling at a lower temperature than flour milled from dehulled groats. Oat flours roller milled from groats dried after conditioning had a lower peak torque than flour milled from steel cut oats. The hold torque of flour milled from steel cut oats was also higher than that of flour from dried groats.

Differential scanning calorimetry results were that heat treatment of oats raised the starch transition temperature by up to $2^{o}C$ (Oomah, 1987). The transition peak was narrower by $2\text{-}3^{o}C$ and there was a 20% reduction in enthalpy associated with starch gelatinization. The conditioning and drying processes caused a partial denaturation of oat proteins as indicated by an decrease in the transition enthalpy for the protein endotherm. A decrease in denaturation enthalpy has been explained as the increase in the ability of the protein to bind water (Wright, 1984).

Effect of Milling on Cereal Grains:

Milling subjects particles to a combination of two or more of the following forces: compression, impact and/or shear forces (Haque, 1991). A compression or nipping force reduces particle size in a roller mill while impact or blow forces reduce particle size in a hammer mill.

Hammer milling:

Hammer milling produces a large amount of heat during impact which results in a loss of moisture from grain as evaporation (Haque, 1991). Nishita and Bean (1982) measured a $75^{o}C$ temperature in hammer milled rice flour.

The size of particles produced by hammer mills is dependent on the clearance between the hammer tip and the screen and the diameter of the perforations of the screen (Haque, 1991). Size reduction in hammer milling is caused by the explosion due to the impact of the hammers, cutting by the edge of the hammers and rubbing action or attrition through the perforations of the screen. A disadvantage of hammer milling is that it produces less uniform product size. The particle size of hammer milled rice flour was finer than that of roller milled rice flour as measured by Ro-Tap sieving for 30 minutes (Nishita and Bean, 1982).

Higher levels of damaged starch (20%) as measured by percent glucose were produced by hammer milling rice flour, than roller milling (1.2%) (Nishita and Bean, 1982). The level of damaged starch and finer particle size was thought to contribute to a higher alkaline water retention capacity in hammer milled rice flour than in roller milled rice flour.

Roller milling:

Roller milling subjects particles mainly to shear and compressive forces due to the corrugations on the roller surface and pressure exerted by rolls while pulling particles toward the nip (Haque, 1991). Milling performance in a roller mill is affected by roll diameters, speed and the ratio of the fast roll and slow roller (differential). The greater the roller diameter, the longer the time a particle will be in contact with it and the result is a finer grind. The faster the roll, the larger the amount of particles that pass through the rollers. If there is a great deal of difference between roller speeds more shearing action will occur.

The compression action of roller mills yields finer particles for harder grains because they are more brittle. A cereal with a softer grain will tend to flake in a roller mill system. Yamazaki (1959b) reported that the granularity of roller milled flours from soft and hard wheat can be influenced by adjusting the moisture levels of the kernels.

The advantage of roller mills is that a more uniform product size is produced than with hammer milling (Haque, 1991). The rolling process does not generate as much heat as hammer milling so less moisture is lost from the particles being milled. Roller milled rice flour had a temperature of 30°C (Nishita and Bean, 1982). One disadvantage to roller milling is that elongated or fibrous materials such as oat hulls may be inefficient to grind (Haque, 1991).

Particle Size Related Properties

Shellenberger (1977) stated an effect of grinding that can be measured and related to kernel hardness is flour granularity. Particle size index is considered the most practical and reproducible method of measuring granularity. Wheat starch granules embedded in the protein matrix of the endosperm are susceptible to damage during grinding and this damaged starch can affect the baking performance of flour. Starch damage increased water absorption in dough, increased gassing power, reduced tolerance to mixing and could be deleterious to bread quality. Starch damage is related to kernel hardness, protein content, tempering conditions and roll pressure.

Sullivan et al (1960) examined the relation of particle size to certain flour characteristics. A hard winter wheat was roller milled with an experimental Allis mill 5 times to reduce flour to finer than average granulation by using roll pressure. Extensive air classification (19 times) was used to separate the flour completely into fractions of different particle sizes. The smallest flour fraction, less than 8 microns, had an ash content twice that of the parent flour. The level of ash was said to be determined by the presence of endosperm cell wall material and peripheral cells in the flour fractions. Protein content was highest in the smallest size range of 1 to 16 microns due to protein fragments

The influence of milling was stated to be, that finer flour had more broken endosperm cells (Sullivan et al, 1960). An increase in the percent of particles below 55 to 70 microns could cause an increase in the specific surface (specific surface=cm^2/cm^3) of a flour. Visco-amylogram results were that increased protein content was linked to decreased starch content. If all other factors were equal, a higher protein content resulted in a lower amylograph viscosity. Starch damage was dependent on the type of grinding and was not correlated to the fineness of grind.

Weaver et al (1981) investigated the effect of milling on trace elements (iron, zinc, manganese, copper, chromium, nickel) and protein content of oats. Quick cooking oat flakes were prepared from Grade B groats by drying, cutting, steaming and rolling. Oat flour was rolled and ground from the cut, steamed grade B groats. Oat flour and quick cooking oat flakes contained similar levels of protein and mineral concentrations except for iron. Oat flour contained greater (P=0.04) amounts of iron than in oat flakes.

Nishita and Bean (1982) used sieve size analysis, scanning electron microscopic examination and the Hunter Color Difference meter to measure particle size in rice flour ground with seven different mills (burr, blade, roller, hammer, pin, turbo or high speed impact). The Hunter Color Difference meter indicated the relative particle size produced by the different mills. Finer flours gave the largest "L" values for whiteness and smallest "b" values for yellowness. Turbo milled rice flour had the largest "L" value (+93.9) and smallest "b" value (+3.4) in agreement with scanning electron microscope examination. Pin and hammer milled flour had, respectively, the second and third highest "L" values.

Visco-amylograph properties were influenced by particle size (Nishita and Bean, 1982). Coarsely ground rice flours produced amylograph pasting curves with initial viscosity increases at 10.5°C higher than rice flours with finer particles. Coarser flours had lower peak viscosities and lower viscosities upon cooling than flours containing finer particles. Coarsely ground rice flour did not have the thickening ability of more finely ground flours.

The highest alkaline water retention capacity was in flour with the finest particle size and highest percentage of damaged starch, ex. turbo and hammer milled flour (Nishita and Bean, 1982). With the exception of roller milled rice flour, as the percentage of damaged starch increased, alkaline water retention capacity increased. Roller milled rice flour with 1.2% damaged starch retained as much water as pin milled (2x) with 16% damaged starch.

Burr milled flours, with the coarsest particle size and intermediate level of starch damage, retained the least alkaline water.

The Endosperm Separation Index (ESI), is a measure of the milling quality or how easily endosperm is separated from bran flakes (Yamazaki and Andrews, 1982a). Soft and hard wheat cultivars are known to produce patent flours and straight grade flours that differ in particle size distribution (Chadhary et al, 1981, Donelson and Yamazaki, 1972). Chadhary et al (1981) concluded that a flour characteristic related to flour granulation was more influential on cake volume than flour particle size.

Gaines (1985) evaluated 219 soft red winter and soft white winter wheat cultivars for associations between particle size, protein content, kernel hardness and other functional properties. Softer wheat kernels were lower in protein content and when milled produced flour with smaller particle size. A smaller straight-grade flour particle size was generally associated with a higher rating for Endosperm Separation Index. Cakes baked with the finer flours had larger volumes and sugar snap cookies had larger cookie spread or diameters. If a soft wheat flour that inherently milled into finer flour particles was subjected to an over milling treatment to increase particle size reduction, the cookies baked with the over milled flour had a smaller diameter.

Scalon et al (1988) measured the particle size related properties of flour roller milled from hard red spring wheat farina. The number, type and properties of flour particles were dependent on the manner of fracture and where it occured. The coarse fraction had the highest protein content. The starch granules in the coarse fraction still had wedge protein adhering to the starch granules as in the intact granule. The lower protein content in the fine fraction was thought to be due to a higher percentage of individual starch granules. The fine fraction exhibited greater water absorption.

Kurimoto and Shelton (1988) measured the effect of flour particle size on baking quality in yeast bread and on other flour attributes. Flour particle size indicated the degree of fineness and total flour surface area. A hard red spring wheat was roller milled to different particle sizes by adjusting the moisture level of the farina.. Protein content slightly decreased as flour particle size decreased. In wheat flour, protein content and particle size were highly correlated ($r=0.96$, $p< 0.01$). There was a significant difference in Hunter Color Difference meter readings only for the 55.9 and 42 µm particle size range. Smaller particles resulted in a smoother surface with an increased amount of light reflected off the surface. Medium sized flour particles (62.6 and 55.9 µm) produced yeast bread loaves of slightly higher volume and weight. The level of damaged starch (27 and 28 Farrand Units) in the medium flour particle size range may have contributed to the differences in loaf volume and weight.

Cookie Flour Quality

Mailhot and Patton (1988) defined flour quality as the ability of the flour to produce a uniformly good end product agreed to by the supplier and the customer. Soft winter wheats are the wheat class preferentially used for cookie flour. Flour specifications have been developed which primarily assist in milling operations. These specifications include ash (0.42-50%), presence of bleaching or maturing agents (none or light Cl_2), particle size range (0-125µm), starch damage (low as possible) and protein (7.0-9.5%).

Sugar snap cookies are one baking test used by industry to evaluate soft wheat flour suitability for specific baked products because flours meeting these physiochemical requirements may not bake a satisfactory product (Yamazaki, 1969). Sugar snap cookies are evaluated on the basis of cookie spread or diameter with the desired width to thickness (W/T) ratio being 8.0-9.5 (Mailhot and Patton, 1988). Top grain score or the degree of surface break-up is considered optimum if there are "fairly wide cracks somewhat evenly spaced to give uniformly sized islands" (Sollars, 1959). Top grain score is a function of cookie spread.

The flour components of protein, starch, lipid and non-starchy polysaccharides all contribute to the baking performance of soft wheat flours. The functionality of flour components can only be determined when the isolation and reconstitution methods do not influence flour properties (Pomeranz, 1988).

Physiochemical requirements of Cookie Flour

Ash or mineral content is sometimes related to the efficiency of the milling process to remove the bran from the endosperm (Mailhot and Patton, 1988). Minerals in the wheat kernel are concentrated in areas adjacent to the bran and bran coat. Flours with higher levels of ash are darker in color because of the fine bran particles. The level of ash must be controlled in cookie flours to accurately perform the MacMichael viscosity test on unbleached cookie flours (Brennis, 1965).

Bleaching Agents: Cookie flours are not usually bleached because flour color is not critical in the baked product. Chlorine bleach treatment of soft wheat flour also increases cookie thickness and decreases cookie spread in a direct proportion to the amount of bleach utilized (Brennis, 1965). Commercial bakeries may use chlorinated cookie flours to achieve uniform spread. Donelson (1990) reported that chlorination in the pH 3.90-3.66 range resulted in reduced cookie spread and increased alkaline water retention capacity (AWRC) of the parent soft wheat flour. The loss in cookie spread was due to an increase in the hydration of the starch fraction of the soft wheat flour.

Particle size: A standardized milling procedure is required if soft wheat particle size is to be an indicator of cookie flour quality (Gaines, 1985). The study of 219 soft red winter and soft white winter straight grade flours found a significantly negative correlation (P=0.001) between flour particle size (mean volume diameter) and cookie diameter. Cookie flours with smaller average particles baked larger cookies. Yamazaki (1959b) had previously concluded that baking characteristics of wheat varieties may be due to granulation differences along with the presence of purified starch tailings and mechanically injured starch. Donelson and Yamazaki (1972) concluded that soft wheat flour particle size is an inherited trait of a wheat variety which is not influenced to a larger extent by crop year.

Starch and Starch damage: Starch comprises about 54-72% of the wheat kernel dry weight depending on variety and growing conditions (Pomeranz, 1988). Particle size distribution or range can be related to starch damage levels in soft wheat flours (Brennis, 1965). The study found flours with a higher percentage of particles over 60 microns in size had a lower percentage of starch damage. The grinding action of mill rolls produces a degree of damage to wheat starch during milling of the wheat kernels into flour. Wheat starch granules are firmly embedded in the protein matrix and this results in physical damage of starch granules. Damaged starch granules swell extensively in cold water and are largely responsible for differences in flour water absorption (Tipples, 1969). In soft wheat, the starch granules are not as strongly held in the protein matrix and this lessens the level of damage. Under uniform milling conditions, soft wheat has finer granulation and a lower absorption properties than that of hard wheat containing the same level of protein (Yamazaki, 1969). Brennis (1965) reported the percentage of starch damage in resulting cookie baking tests was inversely related to cookie W/T ratio.

Greenwood (1976) used optical and scanning electron microscopy to show the state of organization of starch granules in cookies and other baked goods. Depending on the type of cookie, the starch granules ranged from being in a swollen state to being in the disrupted state. Lineback and Wongsrikasem (1980) used light and scanning electron microscopy to observe the degree of gelatinization of wheat starch granules in commercially baked sugar cookies. Wheat starch granules had a low degree of deformation and folding in sugar cookies. Only 9% of the total starch granules exhibited a loss of birefringence. Enzymatic determination measured 4% gelatinization in starch that had been extracted from the cookies. Abboud and Hoseney (1984) used differential scanning calorimetry on baked sugar-snap cookies and reported the starch to be ungelatinized.

Protein: The specification of 7.0 to 9.5% protein in cookie flour is based on functionality. High protein flours tend to cause puffed peaked crown cookies (Brennis, 1965). Additional amounts of sugar and shortening must be incorporated in the formula to produce cookies of acceptable quality. Wheat endosperm proteins have the unique property of forming gluten when hydrated and mixed with water (Pomeranz, 1988). Gluten is a complex of gliaden and glutenin proteins. Gliaden contributes extensibility to a flour dough system while glutenin contributes elasticity. Gluten is the primary structural component of wheat flour dough and enables dough to retain leavening gases.

The formula for sugar-snap cookies contains a high concentration of sugar and fat and a low amount of water. Tsen (1976) had identified the need for sugar-snap cookie dough to have tensile strength and extensibility for sheeting. The gluten network in sugar-snap cookies is not extensive, however, the gliaden and glutenin is not functionally inert (Gaines, 1990). Gaines (1990) used dithioerythritol, a chemical which cleaves disulfide bonds and interacts with resulting thiol groups, to influence the rheological properties of sugar-snap cookie dough. The result was a definitive change in the dough consistency and cookie spread. He concluded that the protein precursors to gluten associate in sugar-snap cookies to form a few intra- and intermolecular bonds. The previous evidence for this conclusion was the fact that the level of mixing action and handling of cookie doughs such as rolling can reduce cookie spread (Gaines et al, 1988).

Role of other flour components in cookie quality

Lipids: Wheat flour lipids comprise an average of 2% by weight of the flour (MacRitchie, 1981). The major components of the non-polar fraction are steryl esters, monoglycerides, diglycerides, triglycerides and free fatty acids. The polar fraction is mostly galactolipids and phospholipids. The non-polar fraction is approximately 50.9% and the polar fraction is approximately 49.1% of the wheat flour lipids (MacMurray and Morrison, 1970).

An early study of lipid functionality in flours (Cole et al, 1960) used water saturated n-butyl alcohol to extract essentially all flour lipids. Later research (Finney et al, 1976) reported on the effect of solvents on extracted flours. The study determined that butanol forms a complex with wheat starch and this interaction influences the functional properties of extracted flours. Cookies prepared with water saturated butanol extracted unbleached soft wheat flours had decreased diameters (7.49cm vs 8.79cm) when compared to the parent flour. The defatted cookies were also browner in color leading to the conclusion that lipids interfered with the browning reaction that takes place during baking. In contrast, Kissel et al (1971) reported that cookies from petroleum ether extracted flours were lighter than normal color and the normal yellow color returned as the percentage of restored lipid increased.

Kissel et al (1971) defined "free lipids" as those that are extracted from wheat flour with petroleum ether. Other researchers (Kissel and Yamazaki, 1975; Yamazaki and Donelson, 1976; Clements and Donelson, 1981 and Clements, 1980) defined "free lipids" as those that are extracted from flour with non-polar solvents such as hexane.

Regardless of the solvent, restoring lipids to flours resulted in an increase in cookie diameter, and improvement of top grain scores (Cole et al, 1960; Kissel et al 1971; Yamazaki and Donelson, 1976). Kissel et al (1971) defatted flours of four wheat varieties; two soft red (Thorne and Blackhawk), one soft white (Avon) and one semihard red (Purkof). When three to four times the lipid level of the parent flour was added to defatted flours and there was an increase in top grain scores and cookie diameter in all four wheat varieties. For each wheat variety, restoration of an increasing amount of lipid resulted in a larger cookie diameter, a better top grain score and a more intense yellow hue. The conclusion was that addition of free flour lipid could significantly improve the baking performance of poor quality flour. Kissel and Yamazaki (1975) used free lipids from flour to increase the cookie spread and top grain scores of cookies fortified with gluten and soy protein. Yamazaki et al (1979) extracted lipids from soft white and red wheat bran with hexane. The bran lipids had the same cookie diameter increasing effect as flour lipids. A addition of 6% lipids (flour weight basis), increased the cookie spread and top grain scores of cookies baked from a semi-hard red winter wheat with poor cookie spread potential.

The phospholipid fraction of wheat flour appears to have the most influence on lipid functionality in sugar-snap cookies. Cole et al (1960) and Clements and Donelson (1981) restored the phospholipid fraction of defatted flours with the result of producing cookies with diameters and top grain scores very similar to cookies baked from the parent flours. The addition of phospholipids from non-wheat sources, soybeans and corn, to defatted flours had an improving effect on cookie spread, top grain and color (Cole et al, 1960). Clements and Donelson (1981) separated hexane extracted flour lipids into ten fractions using preparative thin layer chromatography (TLC). When the flour lipid fraction that corresponded to digalactosyldiglyceride (DGDG) and phosphatidylcholine (PC) was added to defatted flour, cookie spread and top grain scores were very similar to the controls. Restoration of a glycolipid which corresponded to monogalactosyldiglyceride (MGDG) resulted in partial recovery of flour properties.

Yamazaki and Donelson (1976) evaluated the external characteristics and the internal appearance of cookies baked from defatted flours. The optimum internal structure was light in color with a well layered crumb and received a score of 9. A rating of 0 was the bottom of the scale used for a cookie with only a top and bottom surface. The average internal score for cookies baked from defatted flours was a 3, indicating the presence of one large coalesced gas pocket and dark and greasy walls.

Clements (1980) demonstrated the effect of lipid removal on the internal structure of sugar-snap cookies by a resin embedding method. Four straight grade flours from two different wheat classes, hard and soft, were used in the study. The wheat varieties used were Arthur, a soft red winter, Chris, a hard red spring, Eagle, a hard red winter and Yorkstar, a soft white winter. Cookies baked from hexane extracted soft red winter wheat flour had a 2 cm decrease in diameter while cookies baked from hexane extracted hard red winter and spring wheat flours had a 1 cm decrease. Top grain, which is a consequence of spread, was less desirable than the control for all varieties. The interior of cookies baked from defatted soft wheat had no interior cell walls, possessing only a large pocket enclosed by a thin shell. The free flour lipids appear to stabilize gas cell walls during oven expansion. The weak gluten and high dough plasticity of soft white wheats without the flour lipids contributed to collapsed cell walls instead of retaining expanding gases until the structure solidified.

Non-starchy polysaccharides: The primary non-starchy polysaccharide of straight grade soft wheat flour are tailings. Straight grade soft wheat flour can be fractionated into five components - free lipids, gluten, tailings, starch and water solubles. Tailings are the wheat flour fraction that contains a high level of water soluble pentosans (Yamazaki, 1955). Wheat pentosans are polysaccharides with the pentoses, arabinose and xylose as the major structural component (Campbell, 1972). They are primarily found in and just inside the cell walls of the intact wheat kernel. The concentration of pentosans is higher in bran than in endosperm therefore white flour contains ~ 2-3% pentosans. However, wheat endosperm pentosans are hydrophillic and immobilize free water in doughs. Pentosans can absorb 15 times their own weight in water (Bushuk, 1966). An excessive amount of pentosans reduced the spread of sugar snap cookies (Sollars, 1959).

Yamazaki et al (1977) fractionated three pure variety straight grade wheat flours into five fractions: free lipids, starch, gluten, tailings and water solubles. The wheat varieties fractionated were Shawnee, a hard red winter, and Thorne and Blackhawk, soft red winter wheats. The tailings from the three flours had respective alkaline water retention capacities of 165.9%, 193.4% and 266.1%. The tailings, starch and gluten had an additive effect on depressing cookie diameter.

Flour moisture: The concept of an "optimized baking test", in which the performance of a wheat flour is not tested under fixed or arbitrary circumstances was supported by flour moisture studies done by Doescher and Hosney (1985) and Gaines and Kwolek (1982). Doescher and Hosney (1985) reported flour moisture effected cookie symmetry and top grain or surface cracking. Increasing flour moisture resulted in a decrease in the number of islands on the cookie surface and the size of the cracks between the islands became larger. Flour moisture was found to be more important than total moisture in the cookie formula. Cookies prepared with equal amounts of total water did not have similar cracking patterns.

The micro-method III formula requires that the amount of water added be adjusted to produce optimum dough consistency. AACC (1983). Gaines and Kwolek (1982) stated that flour moisture levels above 14% are detrimental to micro-method III cookie top grain. The study examined stickiness and consistency in flour with four levels of flour moisture; 11.5, 12.5, 13.0 and 14.5 percent moisture. In flours with low moisture content (11.5%), a relatively small change in dough water absorption levels caused relatively large changes in dough stickiness.

Cookie spread and top grain score are external characteristics of sugar-snap cookies. Cookie spread is determined by the spreading rate and the setting time (Abboud et al, 1985a). Good quality cookie doughs have a faster spreading rate during baking. Yamazaki (1959b) reported that cookie doughs that spread the least have an earlier increase in viscosity during the baking period. Brennis (1965) attributed the rate of viscosity increase to the relative ability of gluten and starch to attract water in the presence of sugar during the earlier stages of baking.

Commercial requirements for quality:

The level of automation involved in commercial baking of cookies dictates a specific level of uniformity in cookie qualities. Cookie doughs used in commercial bakeries must have an even consistency with the baked cookies being resistant to fracture and crumbling (Fuhr, 1962). The baked cookies must have uniform diameters and thicknesses to give the customer a neat full package. Automated packaging requires uniform cookie size to allow the bottom seam of continuous wrapping machines to have the proper overlap to seal.

MATERIALS AND METHODS

This research project was composed of three parts. The first part was the production of oat flour from three oat cultivars or varieties. The second part was the evaluation of chemical and physical properties of the flours. The third part was measuring the functionality of oat flour in sugar snap cookies when substituted at two levels for soft wheat flour.

Oat Flours :

Three oat cultivars were used in the study to prepare whole grain oat flour: Mariner, Ogle and Porter. Mariner was donated by Michigan Foundation Seed (East Lansing, Michigan). Ogle and Porter were purchased from Purdue Agricultural Alumni Seed Improvement Association, Inc (Romney, Indiana). The three oat cultivars were dehulled and commercially heat processed to inactivate oat lipase by the Quaker Oats Company (Barrington, Illinois). Raw oats were put through an impact dehuller two times to break groats from the hulls. The lighter weight hulls, were separated from oats and groats by a pneumatic separator. The groats were heated to 265^{o}C for 7.5 minutes to inactivate oat lipase, dry and toast the groats. Half of the groats from each oat cultivar were steamed and flaked into rolled oats. A description of the processing from raw oats to flakes is given in the Appendix. The batches of oat groats and oat flakes were tested for tyrosinase activity. Tyrosinase activity measurements are used to indicate if residual lipase activity is present in the heat treated oat product. The tyrosinase enzyme is more heat stable than lipase and a rapid analytical test for tyrosinase activity is available for oat processors (Webster, 1986). Equal amounts of the groats and rolled oat flakes from each cultivar were then milled into whole oat flour. See Figure 1.

Mills:

A Fitzmill model JT (Fitzpatrick Co., Chicago, Ill.) equipped with a screen containing round holes, 4 x 10^{-2} inches in diameter, was used to make hammer milled whole oat flour. A Brabender Quadrumat Jr. Mill (C.W. Brabender Instruments, Inc., So. Hackensack, NJ) was used with a No. 70 gritz gauze reel sifter to make roller milled whole oat flour. The roller milled flours were mixed in a Kitchen Aid Mixer, Model K5SS (Kitchen Aid Co., St. Joseph, Mi) at speed 4 for 15 minutes to evenly distribute the sifted bran, break and reduction flour fractions. The roller milled and hammer milled flours were bagged in moisture proof polyethylene bags and stored at 2°C.

Wheat flour:

Two red soft wheat flours (Becker and Compton) and one white soft wheat flour (Caldwell) were donated by the United States Agriculture Research Service (U.S.A.R.S.) Soft Wheat Quality Laboratory (Wooster, Ohio). The three wheat flours were milled as straight grade with no chlorine or bleaching treatment. The flours were bagged in moisture proof polyethylene bags for storage at 2°C.

Oat-wheat Flour Composites:

Oat-wheat flour composites were prepared by substituting hammer and roller milled oat flours at the 15 and 30 percent level (14% mb) for a soft wheat flour variety. Hammer milled and roller

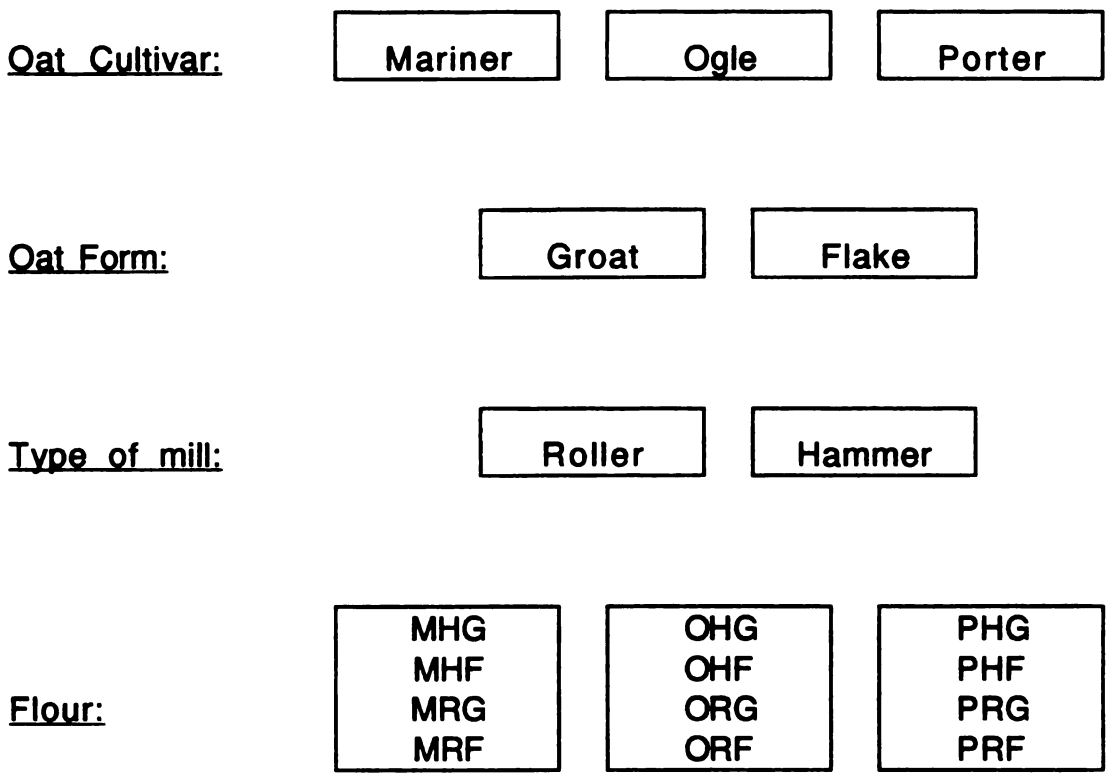


Figure 1. Experimental Design for Oat Flour Production.

milled oat flours were each separately blended with the three soft wheat cultivars to make composite flours. Flour for six batches of cookies was weighed into a glass jar at least 10 times the volume of the flour. Uniform mixing was achieved by rotating the jar in a tumbling motion eight times to the right and then eight times to the left, followed by an additional eight more times to the right (Personal communication, J. Donelson). Composite flour aliquots for each batch of cookies were weighed into pint jars, covered with a screw cap and sealed with Parafilm (American Can Corp Greenwich, Ct.) and stored at 20^{o}C until time of use.

Experimental design for sugar-snap cookie preparation:

The experimental design for measuring the functionality of oat flour in sugar-snap cookies was to separately examine the effects of processing, method of milling and oat cultivar-wheat variety interaction. The experimental design for measuring the effect of processing on cookie quality is given in Figure 2. Only hammer milled whole grain oat flours were used for this sub-study. The gravity feed system of a roller mill does not efficiently feed oat flakes into the rollers. The soft wheat variety was selected based on a preliminary study. The preliminary study used a commercial oat flour, Quaker Oat flour No.1., and the three different soft wheat varieties. A description of the study is given in the Appendix. The soft wheat variety selected for use had produced the best quality cookies on the basis of cookie diameter and top grain scores.

The same wheat variety was used to measure the effect of milling on cookie quality. See Figure 3. Only whole grain oat flours

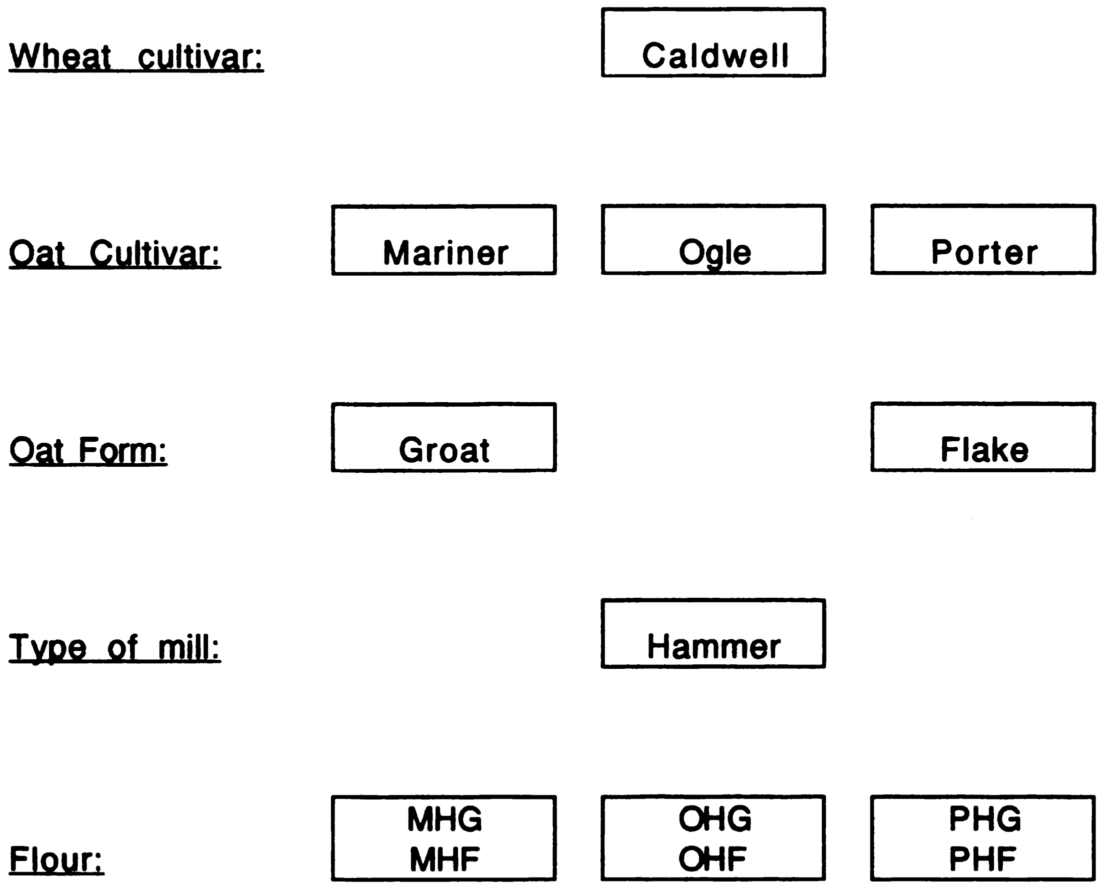


Figure 2. Experimental Design for Effect of Processing.

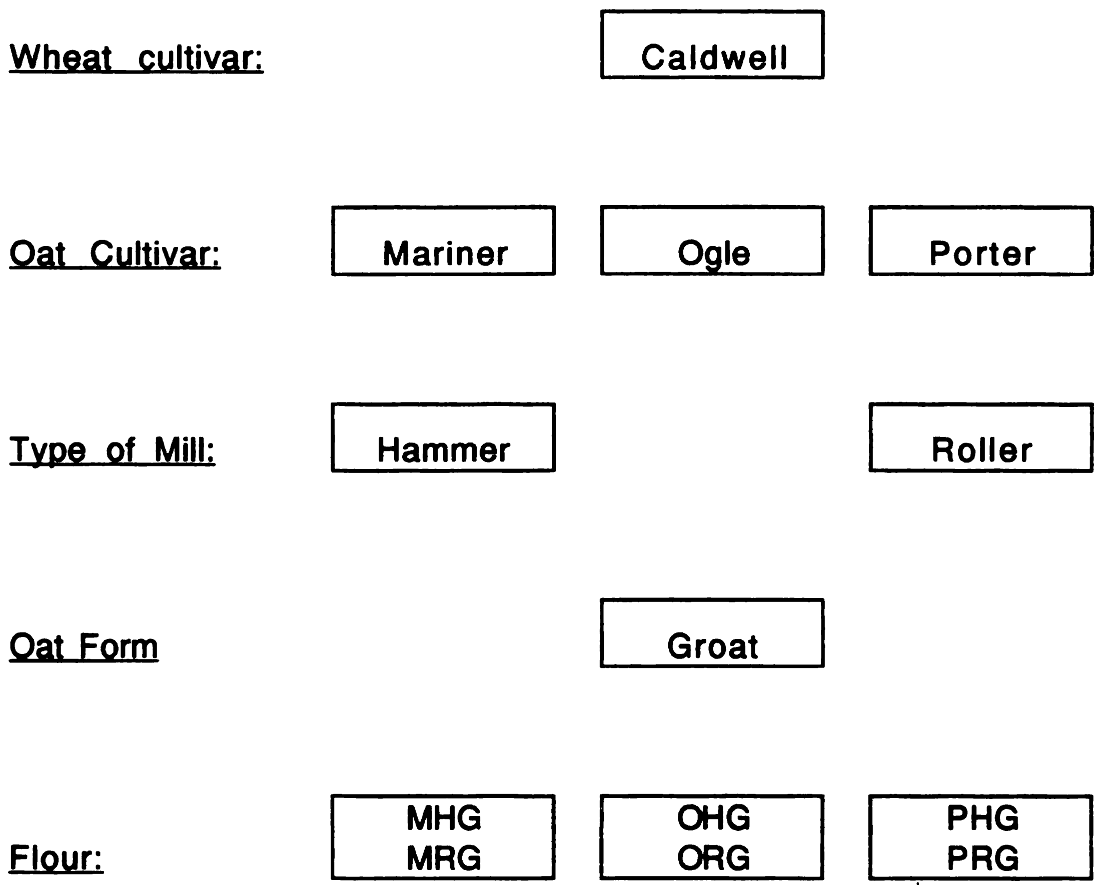


Figure 3. Experimental Design for Effect of Milling.

from groats were used in this sub-study to eliminate the influence of moist heating from the flaking process.

The experimental design for measuring the effect of the interaction of whole grain oat flour and soft wheat flour on cookie qualities is given in Figure 4. Only hammer milled whole grain oat flour from groats was used in this sub-study. The rationale was to increase the applicability to a commercial cookie production system which would more likely purchased hammer milled whole grain oat flour from groats.

Physical properties of oat groats and flours

The 1000 kernel weight of the oat groats was measured using the method of Glover (1985). The kernel moisture content of all three cultivars was between 6.82 to 7.08 percent. One hundred randomly chosen whole dehulled kernels were weighed. The selection process was replicated six times without replacement for each cultivar. The average weight was then multiplied by 10. The 1000 kernel weight was the average value of six trials.

Particle size index of whole grain oat flours was determined in duplicate using a modification of AACC Method 55-30 (AACC, 1989) A No. 100 U.S screen with 12 rubber sieve cleaners was used on a Ro-Tap Sieve Shaker (W.S. Tyler, Cleveland, Ohio). Flour color was measured in triplicate with a Hunter Color Difference meter Model D25-PC2 (Hunter Associates Laboratory, Inc. Reston, Va) using Hunter Lab Tile Standard No. C2-30954 (White, L = 92.3, a = -0.9, b = +0.1). The L value represented reflectance ranges from black to white (0 to 100), a value was reflectance ranges from green to red

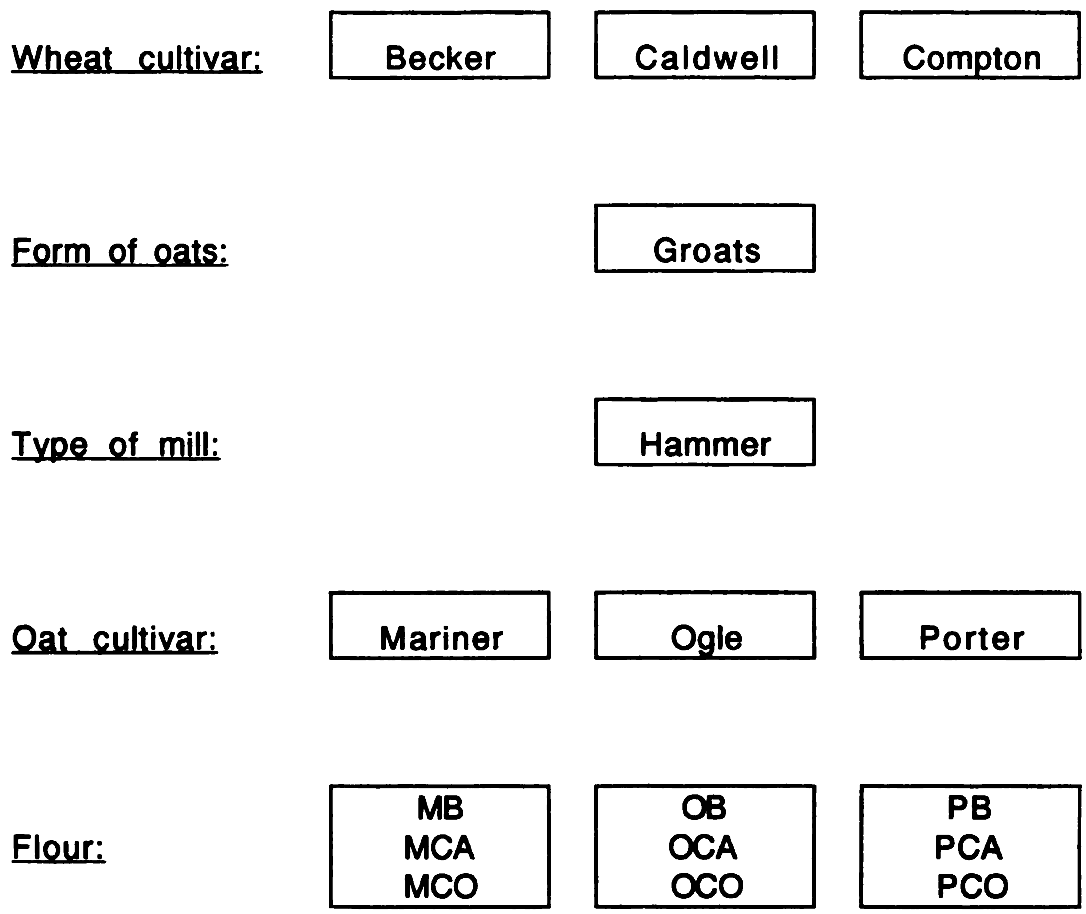


Figure 4. Experimental Design for Interaction with Wheat Cultivars

(-a to +a) and the b value was reflectance ranges from blue to yellow(-b to +b).

Chemical Analyses of Oat Flours:

Moisture content was determined in triplicate by AACC method 44-40: Modified Vacuum Oven method (AACC, 1989) Protein content and ash was measured in triplicate by AOAC methods 24.038 and 14.006 (AOAC, 1984) Carbohydrate content was calculated by the difference between the sum of protein, ash, and fat in three dried samples.

Lipid extraction procedure: Percentage fat was determined in triplicate by the method of Price and Parsons (1974). A 6.25 g sample (db) of oat flour and 290 ml of chloroform-methanol-water (1.0:1.0:0.9) was placed in a 500 ml separatory funnel. The mixture was swirled to solubilize the flour and initiate extraction. After 48 hours, the lower chloroform layer was filtered through a plug of glass wool into a 500 ml Erlenmeyer flask with a ground glass stopper. A 100 ml volume of chloroform was added to the separatory funnel to replace the original volume every 24 hours for two times. The three volumes of extract were quantitatively transferred to a desiccated, pre-weighed 500 ml evaporating (boiling) flask. The extracts were concentrated to less than 5 ml under vacuum in a 50°C water bath using a Bucchi Rotovapor R rotary evaporator (Bucchi Inc., Switzerland). The rest of the chloroform was evaporated under a hood overnight. The flask containing the extract was dried in a moisture oven at 90-100°C for 45 minutes and then placed in a desiccator containing anhydrous $CaSO_4$ for 45 minutes before weighing. The lipids were then redissolved in chloroform, placed in tightly capped glass vials and stored in the refrigerator at -4°C until separation into lipid classes.

A silicic acid column was used to separate the lipid into classes. The silicic acid was prepared by the method of Hirsch and Ahrens (1958). Fifty grams of 325 mesh silicic acid was washed with four 50 ml portions of anhydrous methanol. The silicic acid was dried and activated by a 24 hour holding period at 100°C. The glass column (30 cm x 2 cm) was prepared by first packing one inch of glass wool into the bottom. A 10 gram portion of the dried activated silicic acid was dispersed in chloroform and poured into the glass column. The silicic acid column was allowed to settle for 8 hours with intermittent rinsings of chloroform. Five grams of anhydrous sodium sulfate was placed on the column immediately before use.

From 0.4 to 0.6 grams of lipid was placed on the silicic acid column. Fifty ml of each solvent was used to elute the different classes of lipids. Chloroform was used to elute neutral lipids, acetone was used to elute glycolipids and anhydrous methanol was used to elute phospholipids. The elutant from each lipid class was collected in pre-weighed desiccated 50 ml boiling flasks. The solvents were removed by evaporation with a Buchi Rotovapor. The percentage of each lipid class was determined by weighing the desiccated 50 ml boiling flasks and the lipid residue.

Total dietary fiber assay: Total dietary fiber was determined in triplicate by the AOAC methods 43.A14 - 43.A20 (AOAC, 1984) with the modification for enzyme activity of the heat stable α-amylase. The enzymes were from Sigma (St. Louis, Mo), heat stable α amylase (A-5426), protease (P-3910) and amyloglucosidase (A-9913). A technical bulletin from Sigma described the appropriate modification for the specific lot of the enzymes The phosphate buffer (50 ml) was added to the dried oat flour samples for at least 30 minutes prior to addition of the heat stable α amylase enzyme to allow complete solubilization of the oat flour.

β-glucan Assay: Total β-glucan content was measured in triplicate using the method of Carr et al (1990). See Figure 5. The oat flour samples were dried in a vacuum oven at 90-100°C for 24 hours. A 200 mg sample of oat flour from each cultivar was extracted with refluxing 80% (v/v) ethanol (5 ml) for two 30 minute periods. After cooling, the extracted residues were recovered quantitatively and the supernatants were discarded. The ethanol treated residues were extracted with 1.0 N NaOH (10 ml) at 20°C for 16 hours. The extract was next neutralized by the addition of 1.0 N HCl and centrifuged at 2500 rpm to remove insoluble materials. The supernatent was collected. The pellet was washed with an additional 10 ml of water and centrifuged for a second time. The supernatent from the first and second centrifugation was combined and adjusted to equal volume before assaying for β-glucan.

A commercial cellulase, (Sigma C 0901) from *P. funiculosum* was heat treated to remove any contaminating amylolytic activity. The heat treatment consisted of suspending the crude enzyme (0.40 g) in 10 ml of a 0.05 M sodium acetate-HCl buffer (pH 4.0) for 10 minutes. The enzyme solution was then centrifuged at 2,500 rpm for

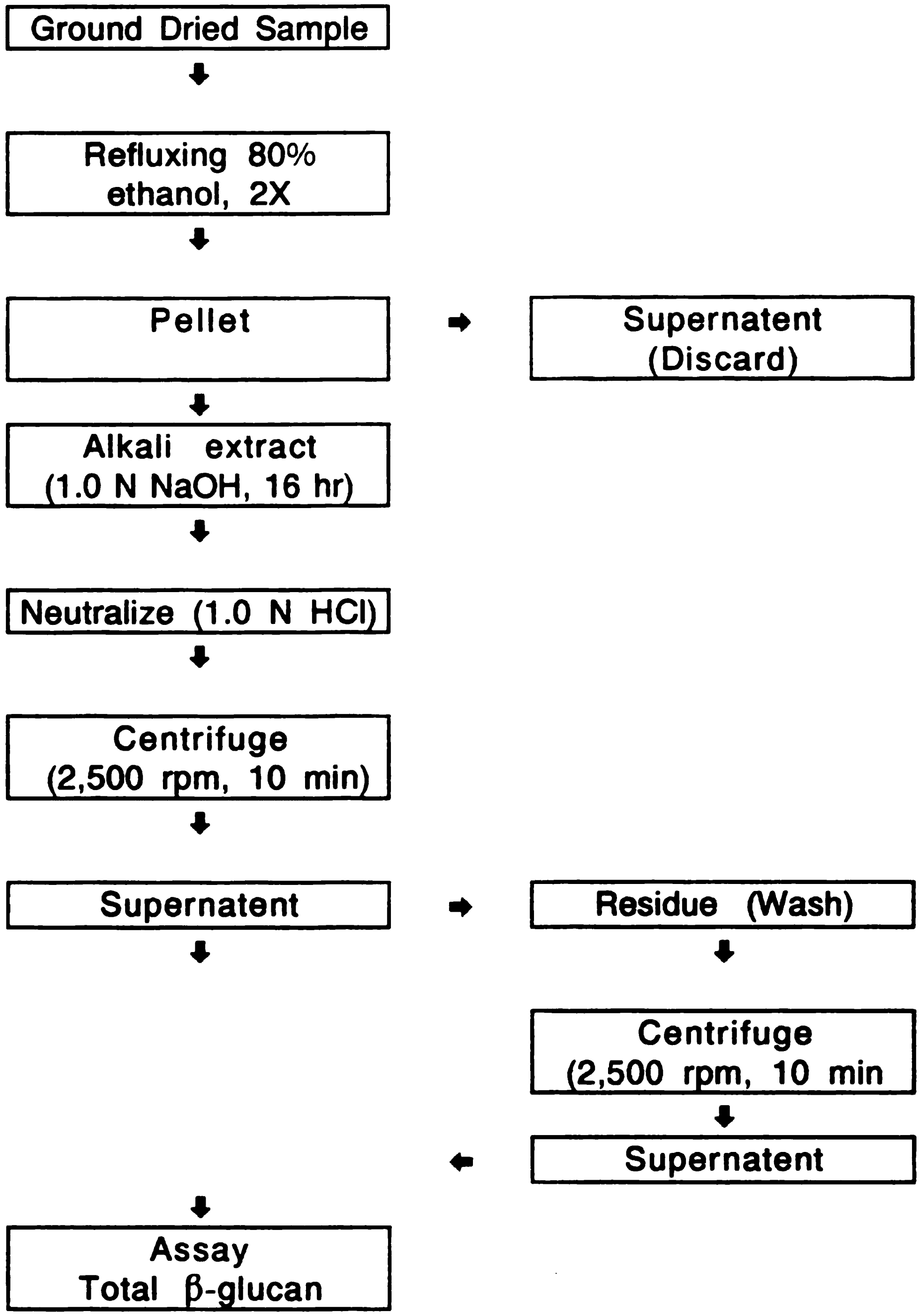


Figure 5. Quantiative extraction procedure for total β-glucan determination in oat flours. Adapted from Carr et al (1990).

10 minutes. The supernatent was transferred into 5 (1x10 cm) tubes and heated in a 70°C water bath for 1 hour. The tubes containing the supernatent were immediately cooled by placement in an ice bath for 2 minutes. The supernatent was next dialyzed for 16 hours against 2 L of 0.05 M sodium acetate-HCL buffer at 4°C. The enzyme solution was then centrifuged for 30 minutes at 2,500 rpm. The purified enzyme preparation was contained in the supernatent. The enzyme preparation could be stored at 4°C for one week before using in the assay.

The enzyme converted the (1-3)(1-4)-β-D-glucan of the oat flour samples into glucose. The percent glucose was measured using the glucose oxidase/peroxidase procedure AOAC Methods 31.240-243 (AOAC, 1984).

Oat starch isolation: Oat starch was isolated by alkaline extraction using the method of Paton (1977). See Figure 6. A 100 gram sample of oat flour and 1 L of deionized distilled water (DDW) was slurried for 2 minutes at high speed in a Waring Blender. The pH of the slurry was adjusted to 10.0 with [20% w/v] sodium carbonate. The slurry was heated to 45°C in a circulating water bath with intermittent stirring. The 45°C temperature was maintained for 30 minutes to extract oat proteins and non-starch carbohydrates. The slurry was centrifuged for 30 minutes in a refrigerated (10°C) centrifuge at 5,000 x g. The supernatent containing protein and non-starchy carbohydrates was discarded. The residue was resuspended in DDW. The alkaline extraction and centrifugation was repeated. The twice extracted residue was re-suspended in 500

100 g Flour

↓

Slurry in Waring Blendor
(1 L. Distilled Water, 1 min)

↓

pH Adjustment to 10
(20% w/v Sodium Carbonate)

↓

Heated Extraction, 45°C, 30 min

↓

Centrifuge
(5000 x g, 30 min)

↓

Re-suspend residue
(1 L. Distilled Water)

↓

Heated Extraction, 45°C, 30 min

↓

Re-suspend residue
(500 ml. Distilled Water)

↓

Remove Coarse Bran
(Pour through No 100 sieve)

↓

Centrifuge
(1500 x g, 30 min)

↓

Remove fine bran layer with spatula

↓

Suspend starch in Distilled Water

↓

Neutralize starch
(2 N HCl)

↓

Centrifuge
(1500 x g, 30 min)

↓

Rewash starch
(500 ml Distilled water)

↓

Pour through No 200 sieve

↓

Freeze dry

Figure 6. Oat starch Isolation adapted from Paton (1977).

ml of DDW. The coarse bran was removed by pouring through a No 100 sieve. The starch milk was centrifuged at 1500 x g for 30 minutes. The fine bran layer which settled above the starch was removed with a metal spatula. The starch was suspended in DDW and neutralized with 2 N HCl. The neutralized starch milk was centrifuged at 1500 x g for 30 minutes. The supernatent was discarded. The starch was re-washed with 500 ml of DDW and filtered through a No 200 sieve. The starch milk was lyophilized for 48 hours in a Virtis Unitrap II freeze dryer at a pressure of 4-6 x 10^{-2} Torr and tray temperature of 40-50°C. The dried starch was stored in a desiccator over anhydrous $CaSO_4$ until pasting properties were measured.

Functional characteristics:

Pasting characteristics of the oat flour and starch were determined in duplicate for each sample using a Brabender Viskograph-E (C.W. Brabender Instruments, Inc., So. Hackensack, NJ). The pasting procedure of Chang and Sosulski (1985) was used for a 11% slurry (db) of oat flour. The flour slurry was heated at a constant rate of 1.5°C increase per minute. The pasting procedure of Doublier et al (1977) was used for oat starch with a 9% slurry (db). The starch slurry was heated at a constant rate of 6.0°C increase per minute. The initial pasting temperature or temperature at which the viscosity curve of an amylogram first increased by 10 Brabender Units (BU) was recorded for oat flours and starches. The holding period was 15 minutes for oat flours and 30 minutes for oat starches. The peak hot viscosity was the maximum viscosity of the gel during the 96°C holding period. The peak cold viscosity was the maximum viscosity of the gel upon cooling to 50°C. The viscosity after 15 minutes at 96°C was measured for flours while the viscosity after 30 minutes was measured for starches.

Alkaline water retention of wheat flours, oat flours and oat-wheat composites was determined in triplicate by AACC method 56-10 (AACC, 1989).

Sugar-snap cookie preparation and evaluation:

A balanced complete block design with three replications of each treatment was used in the preparation of the sugar snap cookies. Room temperature, humidity and barometric pressure was monitored during the baking periods with a Weather Measure Metereograph, Model M701-E (Weather Measure Corp. Sacramento, Ca)

Sugar snap cookies were made using AACC Method 10-52 (AACC, 1989). A National nonrecording micromixer was used to mix the cookie dough. A pre-heated, humidified rotary hearth electric oven (National Manufacturing Co., Lincoln, NE) was used to bake the cookies at 204°C. for 13 minutes. The cookies were cut 6.0 mm in diameter and 0.6 mm thick. Average cookie diameter (cm) was determined using all four cookies from both bakes. The top grain score was assigned by comparing the degree of surface cracking to a set of photographs from the Soft Wheat Quality Lab at Wooster of sugar-snap cookie standards. The standards represented the scale for top grain score from 0 to 9. See Appendix. A 0 was poor compared to a 9 which was optimum. The color of two cookies from each treatment were measured with a Hunter Color Difference meter Model D25-PC2 (Hunter Associates Laboratory, Inc. Reston, VA) using

Hunter Lab Tile Standard No. C2-12403 (Yellow, L = 78.4, a = -3.0, b = +22.7). A second measurement of color difference was taken after a 60^{o} rotation to calculate an average value for each cookie.

Objective measurement of tenderness and crispness was accomplished using a Food Technology Corporation Model TR-5 Texture Recorder (Rockville, Md) equipped with a FTA-300 Force Transducer. Tenderness and crispness determinations were done in duplicate. The standard shear compression cell (CS-1) with a range of $\frac{1}{10}$ was used to measure tenderness as pounds of force per gram. The single blade shear cell (CA-1) with a range of $\frac{1}{100}$ was used to measure crispness as pounds of force per square millimeter.

Excess cookie dough was stored in sealed polyethylene bags at 5^{o}C for moisture analysis. Moisture retention was determined in duplicate by measuring the difference between moisture in cookie dough and baked cookies crumbs using AACC method 44-40: Modified Vacuum Oven method (AACC, 1989).

Scanning Electron Microscopy

Sample preparation:

Groats of each cultivar weighing 0.03 grams were vacuum dried (25 psi) for 5 hours at 90-100^{o}C and stored in a desiccator containing anhydrous $CaSO_4$. The groats were frozen in liquid nitrogen for five minutes before being cut in half latitudinally or longitudinally. The cut groats were sonicated in 100 % ethanol for 5 minutes to remove cell debris from the cut surface. The samples were stored in a vacuum desiccator for at least 24 hours prior to mounting, to allow the ethanol to completely evaporate. Groats were mounted on aluminum stubs with adhesive tabs. Graphite paint was used to minimize charging.

Oat flour fractions from the particle size index determination were also examined using Scanning Electron Microscopy (SEM). Flour fractions ('overs' and 'thrus' of a No.100 screen) and freeze dried starch samples were each lightly dusted onto separate adhesive tab coated aluminum stubs.

The groat, flour and starch samples were coated with a 56 nm layer of molecular gold using an Emscope Sputter coater. Samples were stored in a vacuum desiccator containing anhydrous $CaSO_4$.

SEM Procedure:

A JOEL JSM-35C Scanning Electron Microscope was used at an accelerating voltage of 15 kV to make electron micrographs of the groat, flour and starch samples. The working distance was 15 and the condenser lens setting was at 400. Polaroid positive/negative Type 665 Film (Polaroid, Cambridge, Ma) was used to record the images.

Aleurone cell wall study:

Micrographs of the aleurone and subaleurone cell layer were taken at three position on the kernel using the method of Ewers (1982). Five kernel of each cultivar were examined to determine the variance in cell wall thickness. The cell wall thickness was measured on each micrograph using a ruler.

Statistical Analysis of Data

Oat Flour Characteristics:

A three factor analysis of variance was performed using SAS (Cary, N.C) to determine if any significant differences existed in the main effects of oat variety, form of oats and type of mill for the mean values of flour moisture, protein, ash, total dietary fiber (TDF), lipid, alkaline water retention capacity (AWRC), particle size index and Hunter color difference values (L-value, a-value and b-value) . The same three main effects were used in analysis of variance of viscosity characteristics of oat flours and oat starches. The Bonferroni t tests for differences between the means was also done to calculate minimum significant differences (MSD) at specified probability levels.

Cookie Quality Characteristics:

The cookie quality studies were designed to test the three null hypotheses:

1. The method of milling does not influence oat-wheat composite flour functionality in sugar snap cookies.
2. The processing step of flaking does not influence oat-wheat composite flour functionality in sugar snap cookies.
3. There is no difference in oat-wheat composite flour functionality in sugar snap cookies when different oat cultivars and soft wheat cultivars are used to make the composite flours.

A three factor analysis of variance was calculated to see if significant differences existed between the main effects of oat cultivar, type of mill and level of oat flour substitution. The main effects for the three factor analysis of variance for the second hypothesis were oat cultivar, type of processing (groats vs flakes) and level of oat flour substitution. The three factor analysis of variance for the third hypothesis used the main effects of oat cultivar, wheat cultivar and level of oat flour substitution. The variables analyzed were cookie diameter, tenderness, crispness, Hunter color difference values (L,a,b) and moisture retention.

The Bonferroni t-tests for differences between the means was also done to calculate minimum significant differences (MSD) at specified probability levels. The correlation procedure was used to calculate Pearson correlation coefficients and associated probabilities between cookie diameter, protein content, lipid content, alkaline water retention and Hunter color difference values.

RESULTS AND DISCUSSION

Groat and Flake Analyses

The three varieties of oats had different 1000 kernel weights as illustrated in Figure 7. Porter had the smallest kernel weight while Ogle had the largest kernel weight. Kernel weight will influence proximate analysis results to some degree because a larger groat would contain a higher proportion of starchy endosperm and a lower proportion of aleurone cells than a smaller groat. The aleurone layer is a single layer of cells which surrounds the starchy endosperm.

Table 1 contains means values of moisture for the two oat forms, groats and flakes, that were milled into flour for this study. There was a significant difference in the percent moisture of oat flakes compared to oat groats. Ogle groats and flakes contained a significantly higher level of moisture than groats and flakes of the other two cultivars.

Table 1. Composition of oat forms: Means for moisture

Main Effect	Classes	n	Moisture (%)	Level of Significance
Oat Form	Groats	9	6.99^{b}	
	Flakes	9	8.71^{a}	0.01
Oat Cultivar	Mariner	6	7.77^{b}	
	Ogle	6	8.15^{a}	
	Porter	6	7.63^{b}	0.01

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

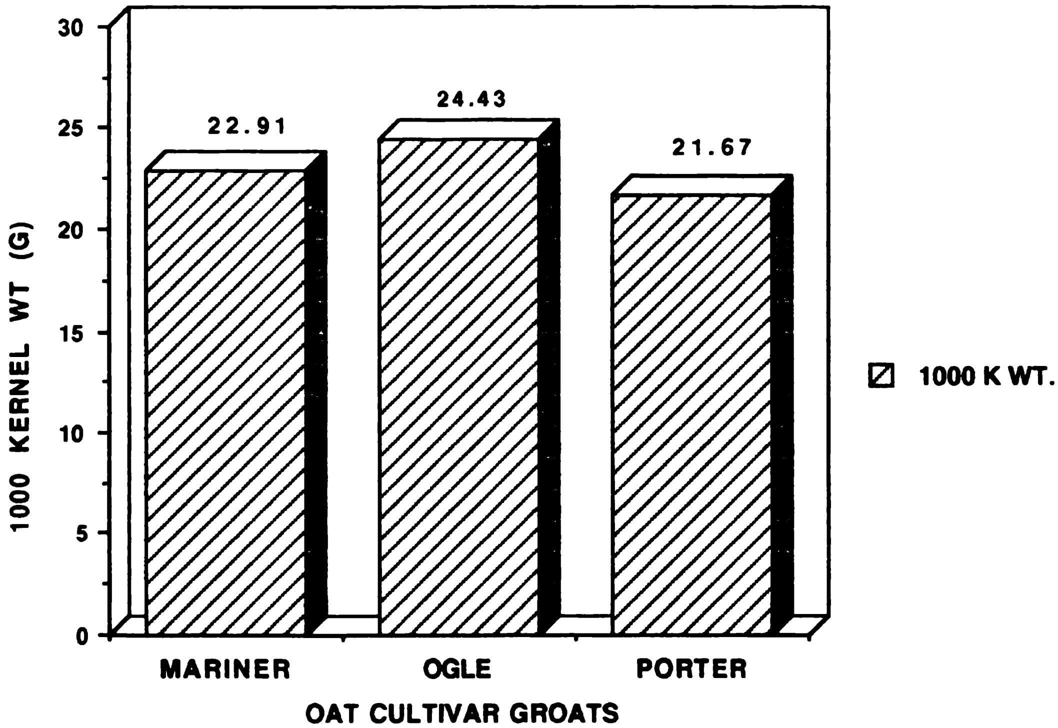


Figure 7. One Thousand Kernel Weights of Oat Cultivar Groats

Oat flakes contained a larger percentage of protein than oat groats but the difference was not significant at the $p<0.01$ level as seen in Table 2. Processing oat groats into oat flakes subjected the chemical constitutents 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.

Table 2. Composition of oat forms: Means for protein[1]

Main Effect	Classes	n	Protein[2] (%)	Level of Significance
Oat Form	Groats	9	16.94[a]	
	Flakes	9	17.37[a]	n.s.
Oat Cultivar	Mariner	6	17.97[a]	
	Ogle	6	16.41[b]	
	Porter	6	17.10[a b]	0.01

[1] Dry Weight Basis
[2] (N x 6.25)
Means in the same main effect having a different superscript are significantly different.

Table 2 also shows the Mariner groats and flakes contained a significantly higher percentage of protein than Ogle groats and flakes but was not significantly higher than the Porter groats and flakes. The Ogle groats and flakes contained the lowest percent protein.

The percentage of protein contained in Ogle groats could be related to its large kernel size. Youngs (1972) hand dissected groats from five cultivars and two experimental lines of common oats. The results showed that most of the groat weight is in the bran and endosperm which also contained the greatest amount of the groat protein. Groats with higher protein content generally contained a larger amount of bran protein rather than endosperm protein. The bran weight increased as the total protein of the groat increased. In a larger groat, the bran or aleurone and subaleurone layer comprise a smaller percentage of the groat.

Ash is the inorganic residue from the incineration of organic matter (Pomeranz and Meloan, 1987). Table 3 shows that oat flakes contained a significantly higher percentage of ash than oat groats. The ash content of the oat groats depended on the mineral contents of the oat cultivar. The ash content of oat flakes could have been affected by the flaking process which disrupted the outer layer of the groats as they passed through the heated rollers.

Table 3. Composition of oat forms: Means for ash[1]

Main Effect	Classes	n	Ash (%)	Level of Significance
Oat Form	Groats	9	1.95^b	
	Flakes	9	2.11^a	0.01
Oat Cultivar	Mariner	6	2.08^a	
	Ogle	6	1.81^b	
	Porter	6	2.21^a	0.01

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

Table 3 also shows Mariner and Porter groats and flakes had a significantly higher ash content than groats and flakes of the Ogle cultivar. The percentage of ash contained in the Ogle cultivar could have been related to its large kernel size. The percentage of ash was consistently higher in oat flakes than in oat groats of the same cultivar.

Table 4 contains the means and standard deviations of the moisture, protein and ash content of oat cultivar groats and flakes. Mariner and Porter flakes contained a higher percentage of protein than Mariner and Porter groats.

Table 4. Thousand kernel weight, means and standard deviations of moisture, protein and ash contents of oat cultivar groats and flakes[1]

Oat Cultivar	1000 Kernel Wt (g)	Moisture %	Dry Basis	
			Protein[2] %	Ash %
Groats				
Mariner	22.91	7.06 $\pm$ 0.31	17.81 $\pm$ 0.64	2.00 $\pm$ 0.02
Ogle	24.43	7.08 $\pm$ 0.23	16.44 $\pm$ 0.27	1.78 $\pm$ 0.01
Porter	21.67	6.82 $\pm$ 0.06	16.58 $\pm$ 0.45	2.06 $\pm$ 0.03
Flakes				
Mariner	-	8.48 $\pm$ 0.03	18.12 $\pm$ 0.72	2.16 $\pm$ 0.18
Ogle	-	9.23 $\pm$ 0.05	16.38 $\pm$ 0.23	1.84 $\pm$ 0.08
Porter	-	8.43 $\pm$ 0.08	17.61 $\pm$ 0.29	2.35 $\pm$ 0.19

[1] n = 3

[2] (N x 6.25)

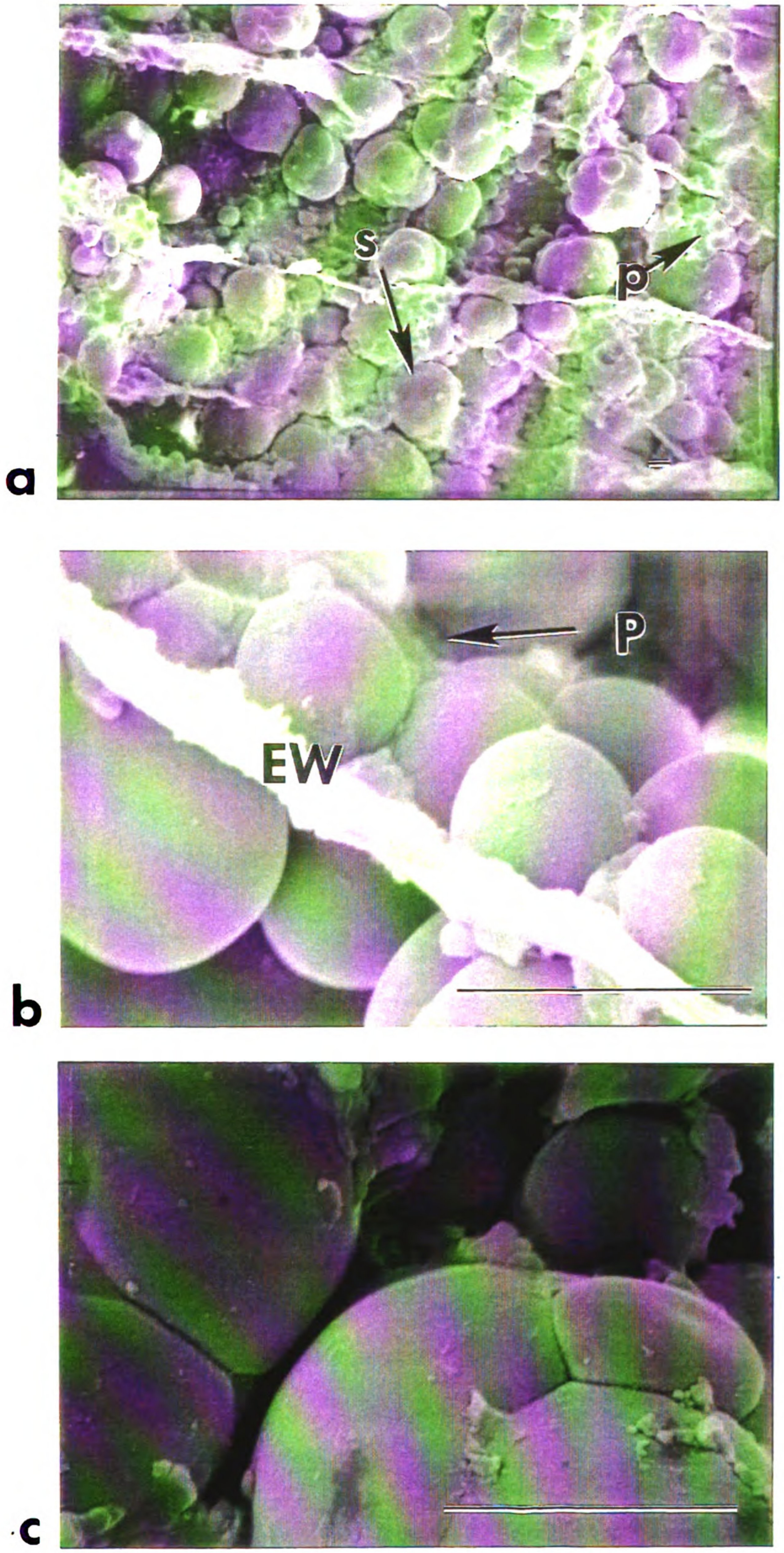
Figure 8 contains scanning electron micrographs of a longitudinal cross section of the endosperm of an Ogle groat which was representative of the three oat cultivars used in this study. Figure 8a illustrates the relative size of physical structures in the endosperm section. The cells are elongated and are packed tightly with starch granules and protein bodies. The intact compound starch granules are clearly larger than the protein bodies clustered along the relatively thin endosperm cell walls. The closeness of the association between protein body and endosperm cell wall can be seen in Figure 8b. Micrographs of oat flour frequently showed endosperm cell wall fragments with circular holes where protein bodies had been removed by the milling process. Figure 8c shows the native state of oat starch granules in the groat. The individual granules have a rounded surface with five sides that delineate a granule.

Oat Flour Analyses

Three factor analysis of variance determined if there were significant differences in the main effects of type of mill, form of oats and oat variety. The three possible two factor interactions; cultivar and form (c x f), cultivar and mill (c x m), mill and form (m x f), were also examined. The ANOVA tables are located in the Appendix.

Analysis of variance means were influenced by significant interactions between the main effects. The interaction of oat form x mill was significant at the $p<0.05$ level for oat flour moisture content and is illustrated in Figure 9. Hammer milling reduced

Figure 8. Scanning electron micrographs of structures and chemical components of the oat groat. Scale bar = 10 μ. a) Longitudinal cross section of Ogle groat endosperm containing starch granules (S) and protein bodies (P). b) Protein bodies (P) closely associated with endosperm cell wall (EW) in groat. c) Compound starch granules in endosperm cell of oat groat.


a
s
p
b
P
EW
c

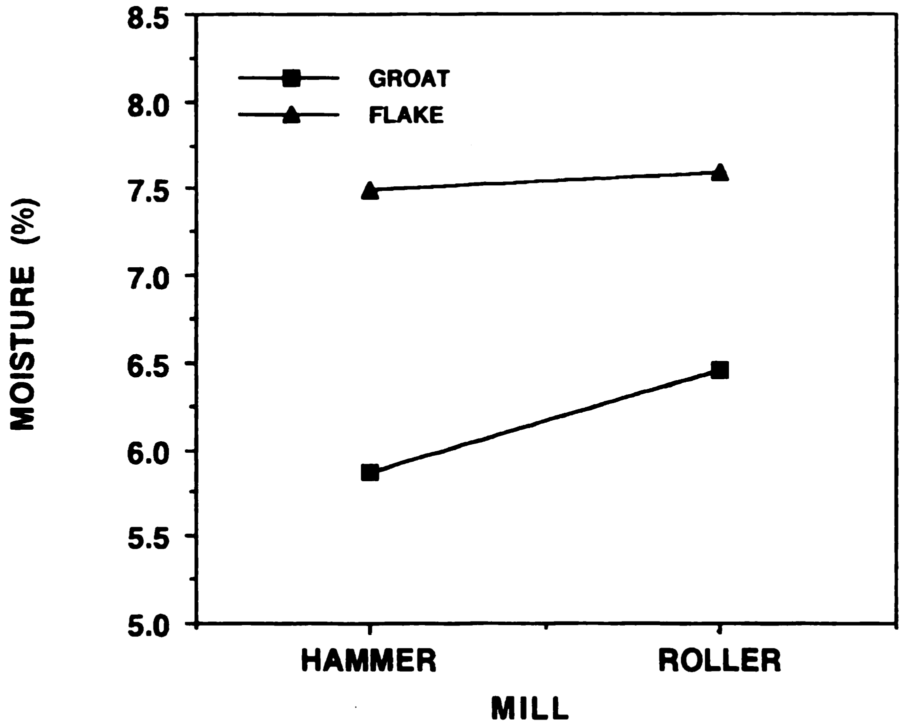


Figure 9. Interaction of Oat Form and Mill Type on Oat Flour Moisture Content.

moisture to a greater extent in flour milled from groats than in flour milled from flakes.

Hammer milled oat flours had significantly lower ($p<0.01$) moisture contents than roller milled oat flours as shown in Table 5. Oat flours require a moisture content of less than 11% to prevent growth of mold during storage. Oat flours in the current study had moisture contents ranging from 6 to 8%. Haque (1991) reported impact forces during hammer milling produced a large amount of heat which evaporated moisture from the grain.

Table 5. Proximate analysis of oat flours: Means for moisture content.

Main Effect	Classes	n	Moisture (%)	Level of Significance
Mill Type	Hammer	18	6.68^{b}	
	Roller	18	7.02^{a}	0.01
Oat Form	Groat	18	6.16^{b}	
	Flake	18	7.57^{a}	0.01
Oat Cultivar	Mariner	12	7.07^{a}	
	Ogle	12	6.94^{a}	
	Porter	12	6.54^{b}	0.01

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

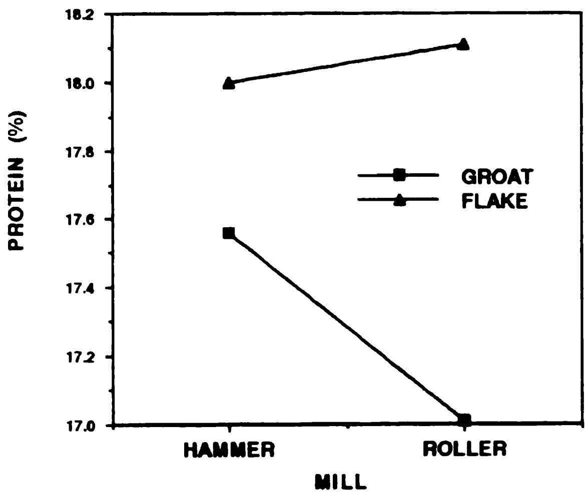
Table 5 shows oat flours milled from oat flakes were higher in moisture content than oat flours milled from groats. The flaking process required that the moisture content of oat groats be equilibrated to 10%. Oat flakes or rolled oats are commercially packed at a moisture content of about 10.5% (Kent, 1983). The moisture content of Mariner and Ogle flours was significantly higher ($p<0.01$) than that of Porter oat flours

All three interactions; mill x form, mill x cultivar, cultivar x form were significant at the $p<0.01$ level for protein content. The interactions are illustrated in Figure 10. Roller milling produced groat flours with lower protein contents than hammer milling as seen in Figure 10a. Figure 10b illustrates that the same reduction in protein content was shown for flours from the Mariner and Porter cultivars while the opposite effect was shown for Ogle flours. The difference in protein content of groat flours compared to protein content of flake flours from the Porter cultivar was much larger than for flours from the two other oat cultivars as seen in Figure 10c.

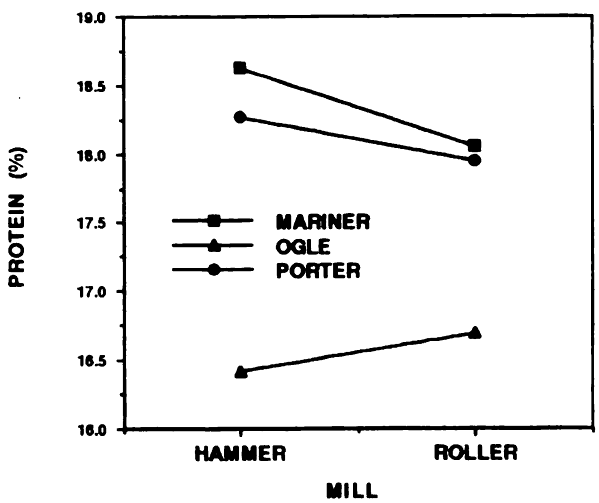
There was a significant difference in flour protein level due to the effect of the mill type at the $p<0.05$ level as shown in Table 6. The protein content of oat flours milled from oat flakes was significantly higher than oat flours milled from oat groats. Disruption of the outer bran layer during the flaking process did not appear to result in major losses of aleurone or protein bodies from this region. Yui (1986) had reported that oat groat aleurone and subaleurone cell walls were relatively resistant to processing.

Table 6 shows the protein contents of Mariner and Porter flours were higher than the protein content of Ogle flours. Mariner and Porter would be considered high protein oat cultivars according to the criteria given by Fulcher (1986) because they contained more than 17 percent protein. The relative protein content among the

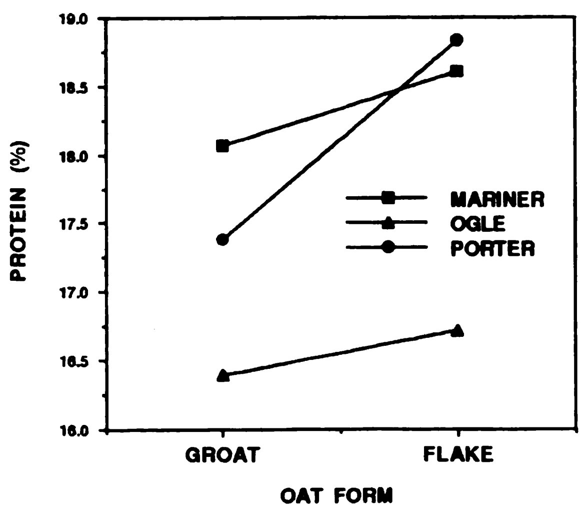
Figure 10. Interaction of Mill Type, Oat Form and Oat Cultivar on Oat Flour Protein Content.



Oat Form x Mill Interaction for Oat Flour Protein Content



Oat Cultivar x Mill Interaction for Oat Flour Protein Content



Oat Cultivar x Form Interaction for Oat Flour Protein Content three oat cultivars was maintained through the stages of processing and milling.

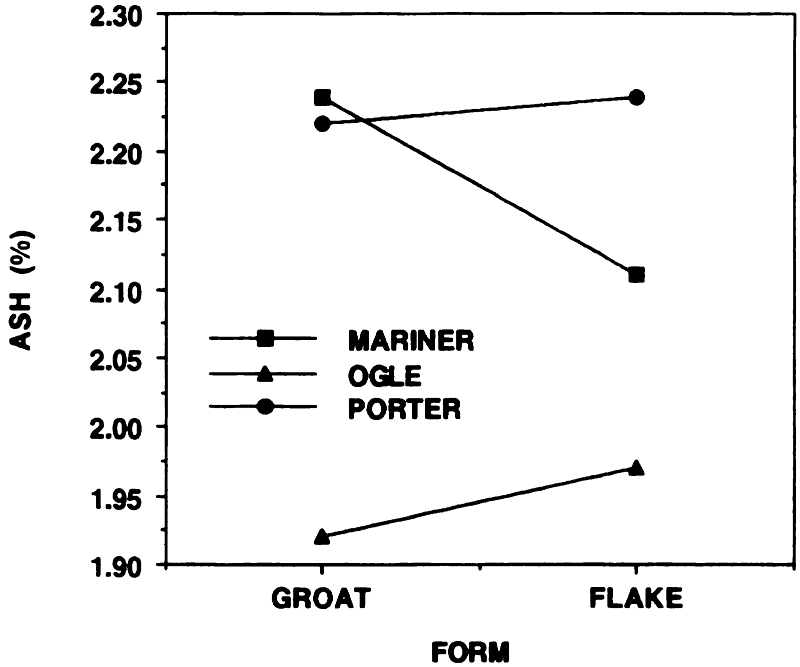
Table 6. Proximate analysis of oat flours: Means for protein content.[1]

Main Effect	Classes	n	Protein (%)	Level of Significance
Mill Type	Hammer	18	17.78[a]	
	Roller	18	17.56[b]	0.01
Oat Form	Groats	18	17.28[b]	
	Flakes	18	18.06[a]	0.01
Oat Cultivar	Mariner	12	18.34[a]	
	Ogle	12	18.56[b]	
	Porter	12	18.11[a]	0.01

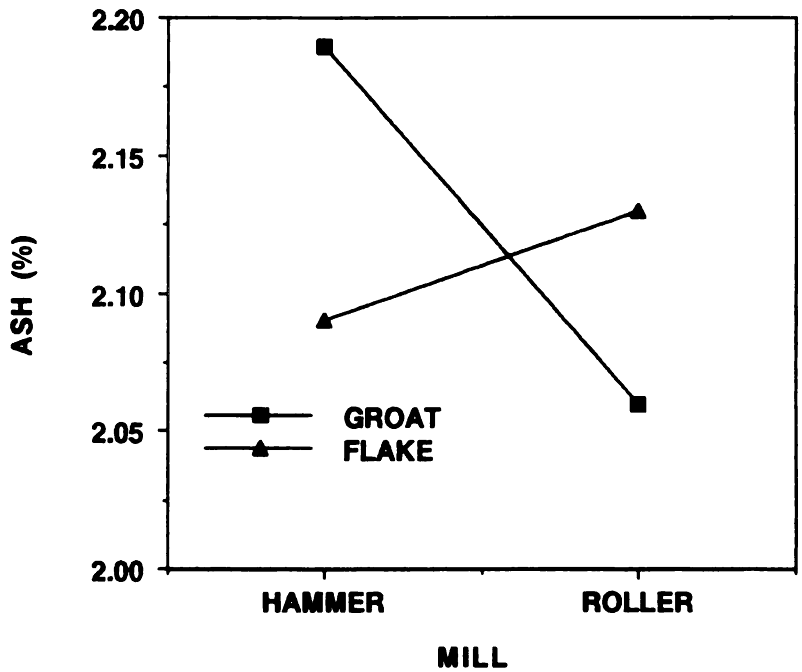
[1] (N x 6.25) , Dry Weight Basis
Means in the same main effect having a different superscript are significantly different.

Analysis of variance means were influenced by the interactions of cultivar x form and form x mill which were significant for oat flour ash content. These interactions are illustrated in Figure 11. The cultivar x form interaction was significant at the $p<0.05$ level while the form x mill interaction was significant at the $p<0.01$ level. The flaking process seemed to reduce ash levels in the Mariner cultivar while increasing ash levels in the two other cultivars. Roller milling may have contributed to reduced levels of ash in groats compared to an increase in the level of ash when flakes were similarly milled.

Figure 11. Interaction of Mill Type, Oat Form and Oat Cultivar on Oat Flour Ash Content.



Oat Cultivar x Form Interaction for Oat Flour Ash Content



Oat Form x Mill Interaction for Oat Flour Ash Content

These significant interactions contributed to lack of significance of the main effects of type of mill and form of oats on ash content as seen in Table 7. The means for ash content of oat flours by the type of mill used to grind the oat flours were not significantly different at the $p<0.05$ level. In wheat flours, ash content and protein content are closely associated because both increase from the inner to the outer part of the wheat kernel (McMasters et al, 1971). There was no significant difference in ash content of oat flours milled from groats or milled from flakes. The ash content of Mariner and Porter flours was significantly higher than the total ash content of Ogle flours.

Table 7. Proximate analysis of oat flours: Means for ash content.[1]

Main Effect	Classes	n	Ash (%)	Level of Significance
Mill Type	Hammer	18	2.14[a]	
	Roller	18	2.09[a]	n.s.
Oat Form	Groats	18	2.13[a]	
	Flakes	18	2.11[a]	n.s.
Oat Cultivar	Mariner	12	2.18[a]	
	Ogle	12	1.95[b]	
	Porter	12	2.23[a]	0.01

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

The interaction of form x mill was significant at the $p<0.01$ level for fat content. A lower percentage of fat was extracted from hammer milled groat flours than from roller milled groat flours as seen in Figure 12. The effect was the same for oat flours milled from flakes but the degree was not as pronounced.

A significantly higher percentage of fat was extracted from roller milled oat flours than hammer milled oat flours as seen in Table 8. Oat flours milled from flakes also contained a higher percentage of fat than oat flours milled from groats. Each of the oat flours from an individual oat cultivar contained a statistically different percentage of fat. Porter contained the highest amount of fat while Ogle contained the lowest amount of fat. The analysis results may have been affected by physical properties of the oat flours such as particle size. Yui (1986) reported oat lipid storage was mainly in the endosperm in the form of droplets and the endosperm cell walls of oat groats were disrupted by processing.

Table 8. Proximate analysis of oat flours: Means for fat content.

Main Effect	Classes	n	Fat (%)	Level of Significance
Mill Type	Hammer	18	7.54[b]	
	Roller	18	7.76[a]	0.01
Oat Form	Groats	18	7.56[b]	
	Flakes	18	7.73[a]	0.01
Oat Cultivar	Mariner	12	7.44[b]	
	Ogle	12	6.88[c]	
	Porter	12	8.61[a]	0.01

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

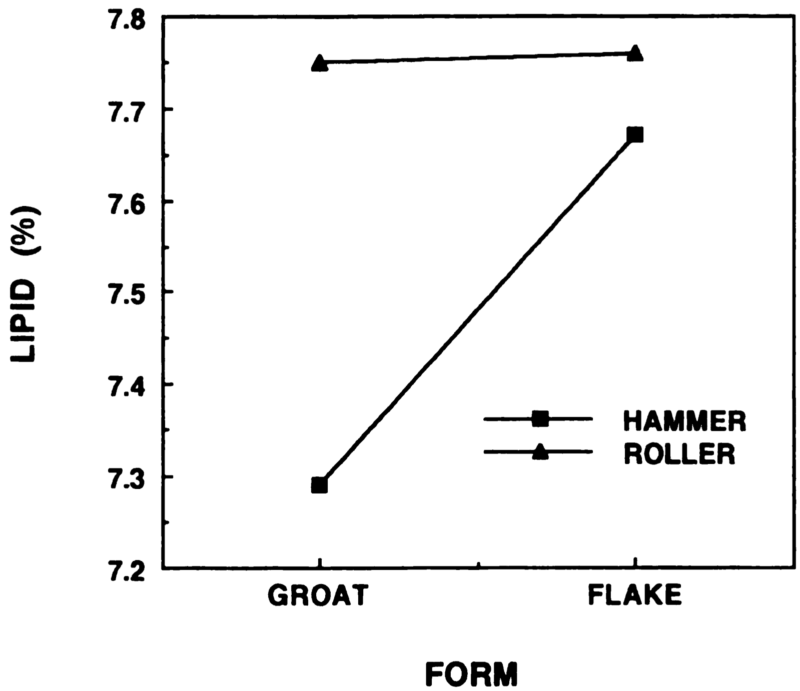


Figure 12. Interaction of Oat Form and Mill Type on Oat Flour Lipid Content

Table 9 shows a higher average percentage of total dietary fiber was measured for roller milled oat flours than for hammer milled oat flours. Oat flours milled from flakes were also determined to contained a higher percentage of total dietary fiber than oat flours milled from groats. Porter oat flours were determined to contain the highest amount of total dietary fiber at a significantly higher level than Ogle or Mariner oat flours.

Table 9. Proximate analysis of oat flours: Means for TDF content.

Main Effect	Classes	n	TDF (%)	Level of Significance
Mill Type	Hammer	18	11.69[b]	
	Roller	18	12.80[a]	0.01
Oat Form	Groats	18	11.36[b]	
	Flakes	18	13.13[a]	0.01
Oat Cultivar	Mariner	12	12.23[b]	
	Ogle	12	10.98[b]	
	Porter	12	13.53[a]	0.01

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

Table 10 contains the silicic acid column chromatography results for determining distribution of lipid classes in flours from the three oat cultivars. The recovery rates for the column chromatography were from 91-98 percent. Porter contained a higher percentage of neutral lipids than flours from the two other cultivars. Ogle flours contained a higher percentage of phospholipids than flours from the two other cultivars. There were no significant differences between oat cultivars at the $p<0.05$ level for any of the three classes of lipids. The distribution of lipid classes was similar to that reported for the Chief cultivar by Price and Parsons (1975). The lipid composition of the Chief cultivar was 72.9 percent neutral lipid, 17.0 percent glycolipid and 10.1 percent phospholipid. MacMurray and Morrison (1970) extracted lipids from wheat flours and determined that the non-polar or neutral fraction was approximately 50.9 percent of wheat flour lipids.

Table 10. Distribution of lipid classes in oat flours.[1]

Oat cultivar	Neutral lipids (%)	Glycolipids (%)	Phospholipids (%)
Mariner	62.5 ± 2.4	27.1 ± 6.6	10.3 ± 4.2
Ogle	62.3 ± 0.4	22.5 ± 0.4	15.1 ± 0.1
Porter	64.2 ± 0.7	24.7 ± 0.7	10.9 ± 1.4

[1] n= 3 Dry Weight Basis

Table 11 contains the results for β-glucan analysis of oat flours from the three cultivars. Flour from the oat cultivar Porter contained a significantly higher ($p<0.05$) percentage of β-glucan (5.32%) than the flours of the two other cultivars. Welch and Lloyd (1989) had reported kernel levels of β-glucan ranging from 3.2 - 6.3 percent. Carr et al (1990) reported "Quick" rolled oats contained 4.3 percent total β-glucan. Porter oat flours had been determined to contain the highest percentage of total dietary fiber of the three oat cultivar flours.

Table 11. Means and standard deviations of Total Dietary Fiber, β-Glucan Content and Alkaline Water Retention Capacity of Oat flours[1]

Oat cultivar	TDF[2] (%)	β-Glucan (%)	AWRC[3] (%)
Mariner	12.23 ± 1.71	4.73 ± 0.06	168.30 ± 31.31
Ogle	10.98 ± 1.57	4.72 ± 0.37	141.90 ± 27.74
Porter	13.52 ± 1.80	5.32 ± 0.12	186.71 ± 37.20

[1] n= 3
[2] Dry Weight Basis, Total dietary fiber in all four types of oat flour.
[3] 14% moisture basis

Table 12 contains the proximate analysis means and standard deviations for each of the twelve types of whole grain oat flours produced by this study. The flours hammer milled from groats consistently had lower moisture levels than their roller milled counterparts. Oat flours hammer milled from flakes had lower moisture contents with the exception of Porter oat flakes. Oat flours milled from flakes contained a higher percentage of protein than flours milled from groats with the exception of Ogle flour hammer milled from flakes.

Physical properties of oat flours

Determination of particle size index of whole grain oat flours was most likely effected by the level of fat in oat flours. The oat flours tended to clog the openings of the No 100 U.S. screen despite

Table 12 Proximate analysis of oat flours[1]:Means and standard deviations

Oat Flours	Moisture %	Protein[2] % (Dry Matter Basis)	Ash % (Dry Matter Basis)	Fat % (Dry Matter Basis)	TDF % (Dry Matter Basis)	CHO[3] % (Dry Matter Basis)
Mariner						
HM-Groat	6.35 ± 0.64	18.36 ± 0.21	2.33 ± 0.05	7.23 ± 0.03	10.52 ± 0.16	72.08
HM-Flake	7.52 ± 0.02	18.91 ± 0.10	2.09 ± 0.11	7.58 ± 0.12	12.07 ± 0.87	71.42
RM-Groat	6.74 ± 0.14	17.77 ± 0.08	2.16 ± 0.03	7.47 ± 0.05	11.59 ± 0.49	72.60
RM-Flake	7.67 ± 0.05	18.32 ± 0.06	2.14 ± 0.06	7.57 ± 0.03	14.73 ± 0.78	71.97
Ogle						
HM-Groat	6.10 ± 0.11	16.47 ± 0.15	1.97 ± 0.12	6.61 ± 0.04	11.34 ± 0.12	74.95
HM-Flake	7.58 ± 0.32	16.38 ± 0.16	1.92 ± 0.05	6.81 ± 0.12	10.20 ± 0.56	74.89
RM-Groat	6.23 ± 0.03	16.32 ± 0.14	1.87 ± 0.03	7.00 ± 0.04	9.55 ± 1.21	74.81
RM-Flake	7.86 ± 0.10	17.07 ± 0.49	2.01 ± 0.15	6.98 ± 0.09	12.84 ± 1.55	73.94
Porter						
HM-Groat	5.15 ± 0.18	17.85 ± 0.02	2.29 ± 0.19	8.02 ± 0.23	13.10 ± 0.42	71.84
HM-Flake	7.38 ± 0.20	18.70 ± 0.18	2.26 ± 0.06	8.62 ± 0.09	12.90 ± 1.32	70.42
RM-Groat	6.38 ± 0.30	16.94 ± 0.06	2.15 ± 0.02	8.78 ± 0.07	12.04 ± 1.28	72.13
RM-Flake	7.24 ± 0.21	18.96 ± 0.66	2.23 ± 0.06	8.74 ± 0.12	16.06 ± 0.64	70.04

1 n = 3

2 (N x 6.25)

3 Obtained by difference

the use of the 12 rubber sieve cleaners. Relative particle size of the oat flours was indicated by particle size index and flour color using a Hunter Color Difference meter.

The only significant interaction for particle size index was between form and mill type and is shown in Figure 13. There was a greater difference in flour particle size index between flours milled from groats compared to flours milled from flakes. The flaking process appeared to facilitate particle size reduction during milling.

The Hunter Color Difference meter measured the amount of light reflected from the sample surface. The sample with smaller flour particles would have a smoother surface than the sample with larger flour particles. The smoother surface would reflect more light and generate higher L-values (brightness) than the surface of a sample comprised of larger flour particles. Kurimoto and Shelton (1988) reported the correlation of the L-value with mean flour particle size determined by a Micro-Trac Particle Size Analyzer was -0.82 ($p<0.01$) for a hard red spring wheat.

Analysis of variance means for Hunter Color Difference values were influenced by significant interactions between the main effects. The interaction of oat form and mill type was highly significant for L-value of oat flours and b-values of oat flours. There was a greater difference in L- and b-values of flours milled from groats than in L-values and b-values of oat flours milled from flakes as illustrated in Figures 14a and 14c. The interaction of cultivar and form was significant at the $p<0.01$ level for a-value of oat flours. Figure 14b illustrates that Ogle and Porter flours milled from flakes had lower a-values (redness) than flours milled from

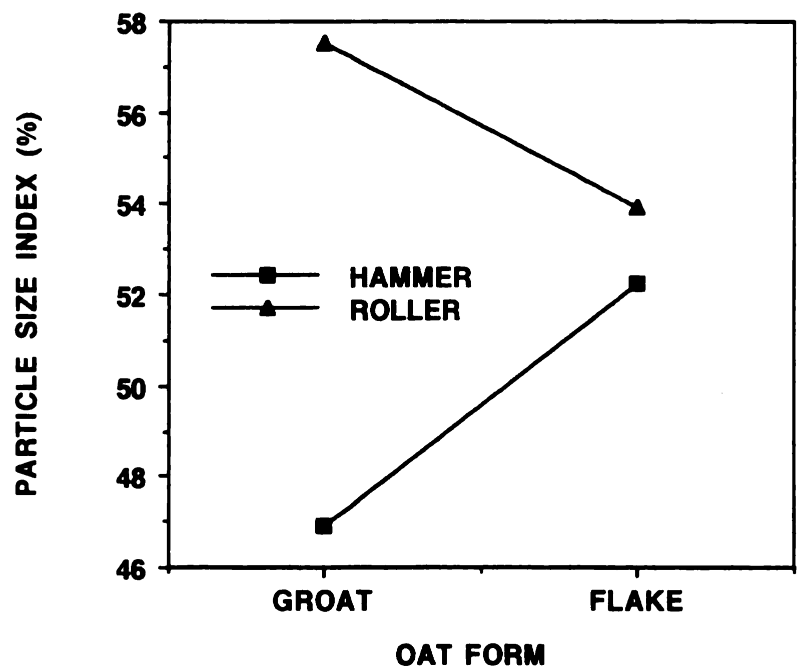
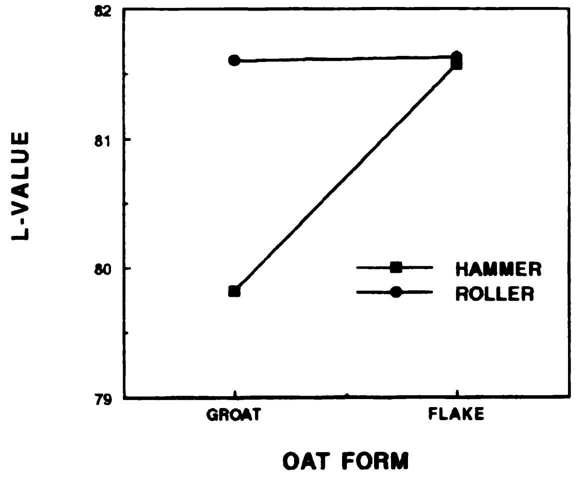
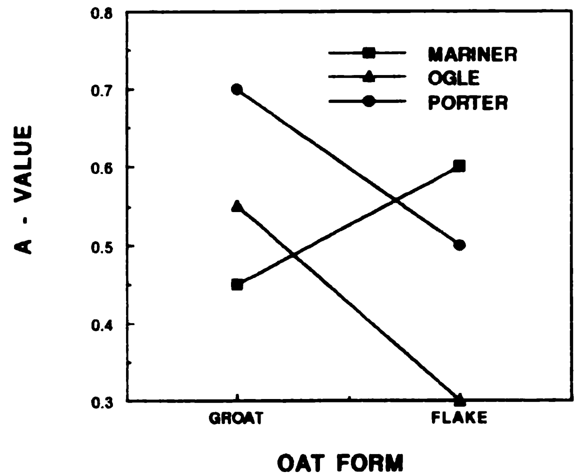


Figure 13. Interaction of Mill Type and Oat Form on Particle Size Index of Oat Flour.

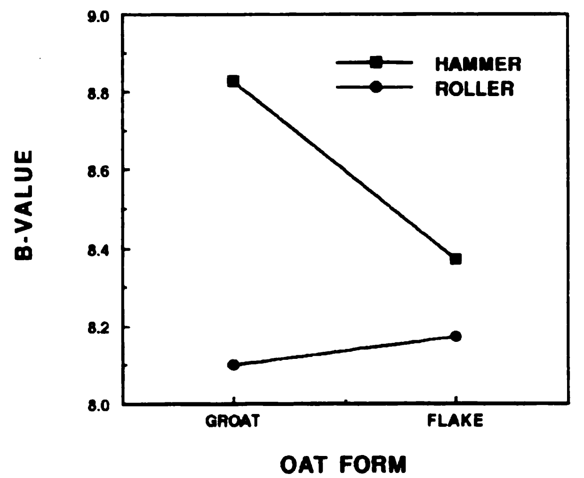
Figure 14. Interaction of Mill Type, Oat Form and Oat Cultivar on Hunter Color Difference Values of Oat Flour.



Oat Form x Mill Interaction for L-value of Oat Flour



Oat Form x Oat Cultivar Interaction for a-value of Oat Flour



Oat Form x Mill Interaction for b-value of Oat Flour groats. Mariner flours milled from flakes had higher a-values than flours milled from groats.

A significantly greater percentage of the particles of the roller milled oat flours passed through the openings of the No. 100 U.S. Screen than hammer milled oat flours as shown in Table 13. The shear and compressive forces of roller milling appeared to yield a larger number of finer oat flour particles than the impact forces of hammer milling. A visual observation of the two types of flours indicated that the roller milled groat flours contained a higher percentage of large sections of pericarp than hammer milled groat flours. A visible percentage of the pericarp did not break into fine pieces when subjected to the shear and compressive forces involved in roller milling. The L-values for roller milled oat flours were significantly higher than for hammer milled oat flours. Roller milled oat flours were lighter in color as shown in Table 13.

Kurimoto and Shelton (1988) reported that a- and b-values decreased with decreasing flour particle size in a hard red spring wheat. A positive a-value indicated redness and a positive b-value indicated yellowness. Results of analysis of variance found no significant difference between a-values for hammer milled and roller milled oat flours as shown in Table 13. However, a-values were lower for roller milled flours than for hammer milled flours indicating an agreement with the results previously reported for L-values. Roller milled oat flours had significantly lower b-values or were less yellow than hammer milled flours, in agreement with the L-values for roller milled oat flours and the results reported by Kurimoto and Shelton (1988).

Table 13. Mean color differences and particle size index values of oat flours by type of mill

Mill Type	Hunter Color Difference[1] L [3]	a [4]	b [5]	Particle Size Index[2] (%)
Hammer	80.70[b]	0.56[a]	8.63[a]	49.51[b]
Roller	81.63[a]	0.44[a]	8.14[b]	55.73[a]
Level of significance	0.01	ns	0.01	0.01

[1] n = 18
[2] n = 24
[3] L values = 0 (black) to 100 (white)
[4] a values = positive values indicate redness
[5] b values = positive values indicate yellowness
Means in the same column having a different superscript are significantly different

There was no significant difference in particle size index for oat flours milled from groats when compared to flours milled from oat flakes as shown in Table 14. Oat flours milled from oat flakes had significantly higher L-values than oat flours milled from oat groats. The lower a-values of oat flours ground from flakes indicated an agreement with the L-values. Whole oat flours milled from flakes had significantly lower a- and b-values than oat flours milled from groats. The Hunter Color Difference readings supported the visual observation of screen clogging during flour particle sizing.

Lookhart et al (1986) reported browning of oat flakes during the steaming and rolling process. The pre-existing browning of oat flakes may have influenced L-values and b-values when comparing oat flours milled from flakes to oat flours milled from groats.

Table 14. Mean color differences and particle size index values of oat flours by form

Oat Form	Hunter Color Difference[1] L [3]	a [4]	b [5]	Particle Size Index [2] (%)
Groat	80.72[b]	0.58[a]	8.49[a]	52.14[a]
Flake	81.61[a]	0.42[b]	8.28[b]	53.09[a]
Level of siginificance	0.01	0.01	0.01	ns

[1] n = 18
[2] n = 24
[3] L values = 0 (black) to 100 (white)
[4] a values = positive values indicate redness
[5] b values = positive values indicate yellowness
Means in the same column having a different superscript are significantly different

Table 15 contains analysis of variance means for comparison by oat cultivar which indicated there was also no significant difference in particle size index. Ogle oat flours had significantly higher L-values than flours from the other two cultivars. There was no significant difference in the a-values of oat flours made from the three cultivars. There was a significant difference between Ogle oat flours and Mariner and Porter oat flours as shown in Table 14.

Ogle flours had the lowest mean b-value which agreed with the higher L-value indicating a finer average particle size. There was also a significant difference in b-values measured between flours from Mariner and Porter.

Table 15. Mean color differences and particle size index values of oat flours by cultivar.

Oat Cultivars	Hunterlab Color Difference[1] L [3]	a [4]	b [5]	Particle Size Index [2] (%)
Mariner	81.00[b]	0.54[a]	8.99[a]	52.96[a]
Ogle	81.96[a]	0.44[a]	7.82[c]	53.27[a]
Porter	80.53[c]	0.51[a]	8.35[a]	51.61[a]
Level of significance	0.01	ns	0.01	ns

[2] n = 12
[3] n = 24
[4] L values = 0 (black) to 100 (white)
[5] a values = positive values indicate redness
[6] b values = positive values indicate yellowness
[1] Means in the same column having a different superscript are significantly different.

The lack of agreement in order between L- and b-values for Mariner and Porter could be attributed to the particle size range within the sample or the residual coloration from the kernel. Kurimoto and Shelton (1988) reported no significant difference in L-values among samples of larger particle size (68 to 55.9 µm). The differences in Hunter L-values were significant when the particle size was from 55.9 to 42.3 μm.

Table 16 contains the means and standard deviations for particle size index and Hunter color values for oat flours. The range of a-values for Porter oat flours influenced the statistical analysis outcome as shown in Table 15.

Figure 15 contains scanning electron micrographs that are representative of the coarse oat flour fractions produced by Particle Size index determination. The coarse oat flour fraction was the 'overs' of a No 100 screen. Flour particles consisted of sections of the pericarp which did not fracture upon milling as shown in Figure 15a and chunks containing sections of the pericarp, endosperm and aleurone layer as seen in Figure 15b. The pericarp section of the flour particle in Figure 15b still has a trichome attached after undergoing the roller milling process. A trichome is a hollow single celled projection of the pericarp. Most domestic oat cultivars have a greater degree of trichome development compared to other cereal grains (Fulcher, 1986). Figure 15c is a micrograph of the coarse flour fraction of the Porter cultivar and shows an intact layer of cuboidal aleurone cells.

Table 16. Means and standard deviations of particle size index and color difference data for oat flours.

Oat Flour	Particle Size Index[1] (%)	Hunter Color Values[2] L[3]	a[4]	b[5]
Mariner				
HM-Groat	48.00 ± 1.27	79.8 ± 0.5	0.6 ± 0.3	9.6 ± 0.3
HM-Flake	48.60 ± 3.82	81.4 ± 0.3	0.7 ± 0.1	8.9 ± 0.1
RM-Groat	58.50 ± 1.27	81.4 ± 0.4	0.3 ± 0.2	8.7 ± 0.1
RM-Flake	56.75 ± 7.00	81.3 ± 0.2	0.5 ± 0.1	8.7 ± 0.2
Ogle				
HM-Groat	48.70 ± 0.28	80.7 ± 0.2	0.7 ± 0.1	8.2 ± 0.1
HM-Flake	54.05 ± 0.77	82.4 ± 0.1	0.3 ± 0.3	7.8 ± 0.2
RM-Groat	56.75 ± 1.34	82.4 ± 0.0	0.4 ± 0.1	7.6 ± 0.1
RM-Flake	53.60 ± 4.24	82.3 ± 0.3	0.3 ± 0.1	7.6 ± 0.0
Porter				
HM-Groat	43.60 ± 2.12	79.0 ± 0.2	0.7 ± 0.1	8.7 ± 0.1
HM-Flake	54.10 ± 0.56	80.9 ± 0.2	0.4 ± 0.2	8.4 ± 0.1
RM-Groat	57.30 ± 4.38	81.0 ± 0.2	0.7 ± 0.1	8.0 ± 0.1
RM-Flake	51.45 ± 1.20	81.3 ± 0.2	0.3 ± 0.1	8.2 ± 0.2

[1] n=2

[2] n=3

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

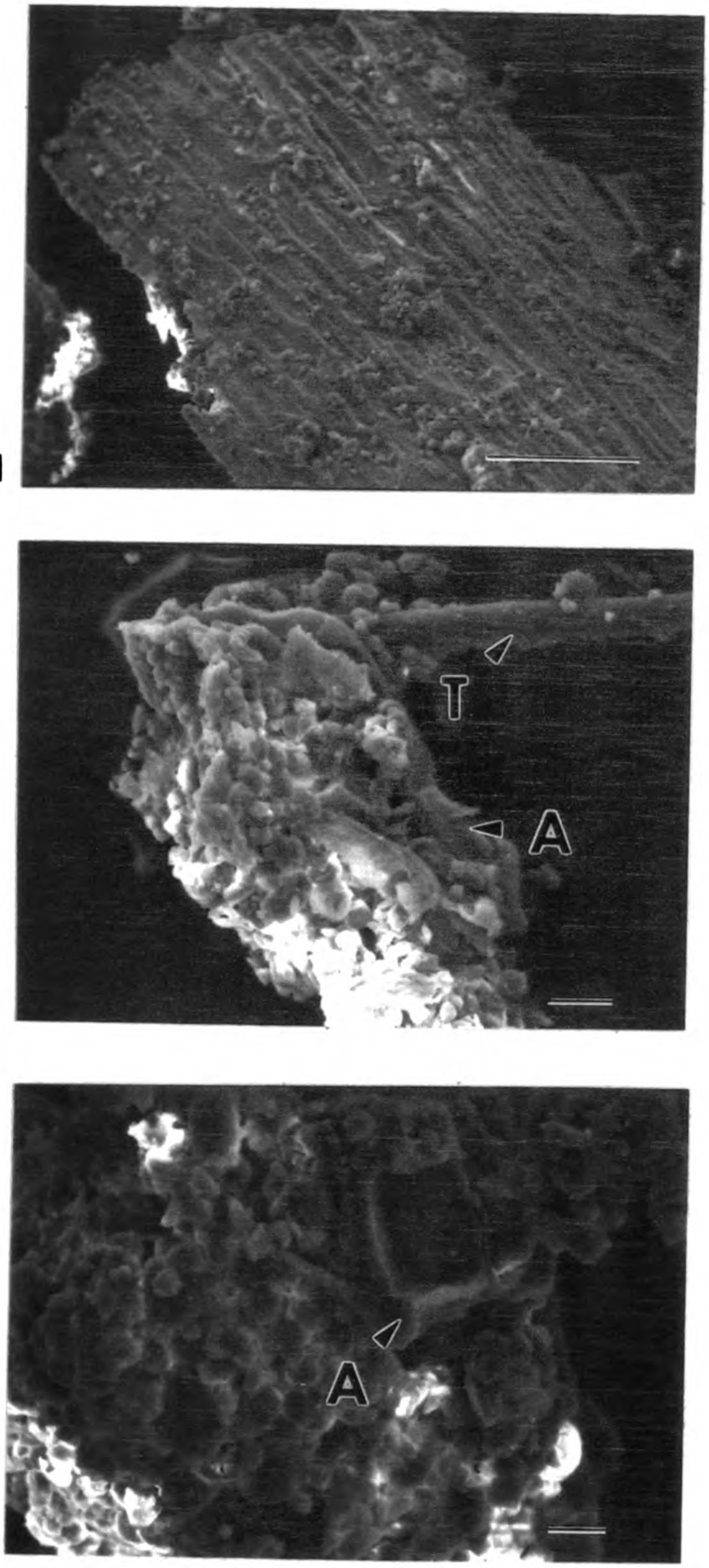
[4] a values = positive values indicate redness

[5] b values = positive values indicate yellowness

Figure 15. Scanning Electron Micrograph of the Coarse Oat Flour Fraction. a) Sections of pericarp. Bar = 100 μ.

b) Section of pericarp, aleurone layer (A) and endosperm with trichome (T) attached. Bar = 10 μ.

c) Coarse flour fraction of Porter cultivar with intact aleurone cell (A) layer. Bar = 10 μ.



a

b

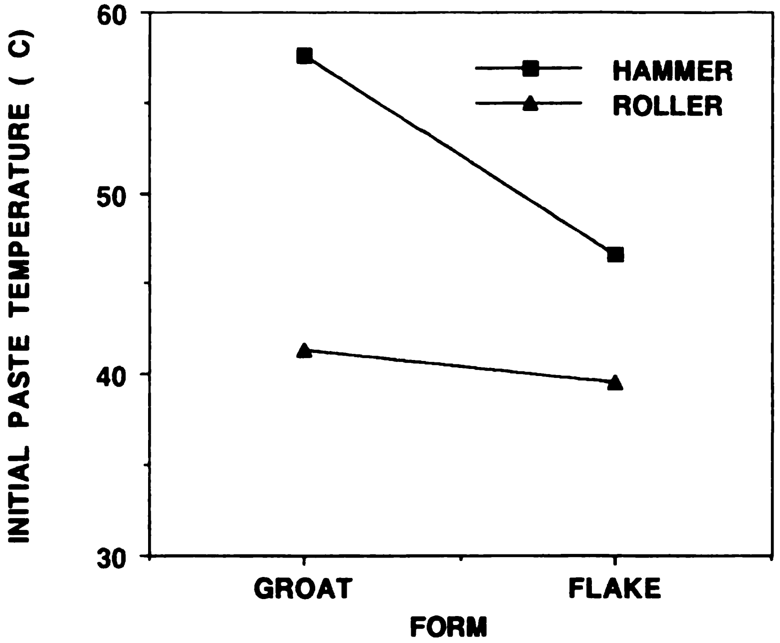
c

Viscoamylograph properties of oat flours

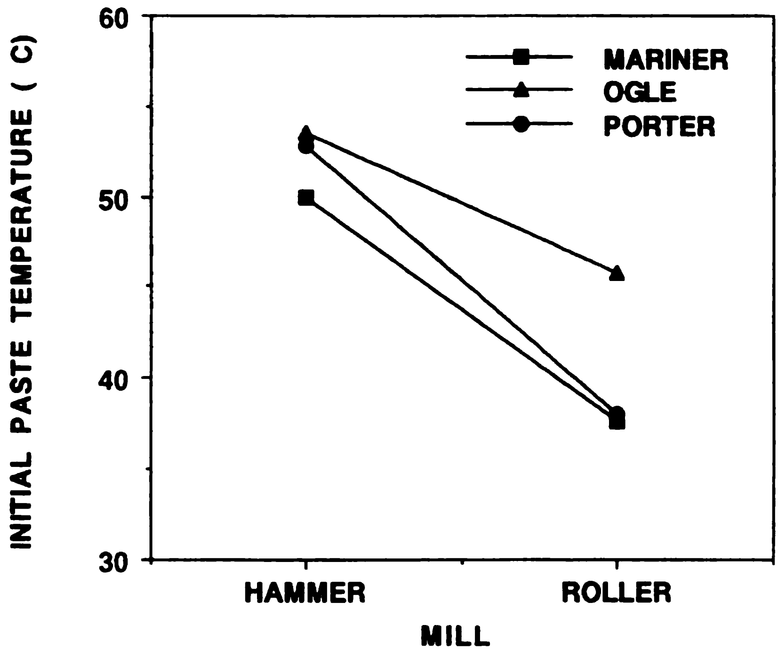
The interaction of form x mill was highly significant ($p<0.0001$) for initial paste temperature of oat flours while the interaction of cultivar and mill was significant at the $p<0.05$ level. Figure 16 illustrates there was a greater difference in initial pasting temperature of hammer milled groat flours compared to hammer milled flake flours than there was between roller milled flours from the two different oat forms. Roller milled flour of all three cultivars had lower initial pasting temperatures than hammer milled flours of the same cultivar. However, the difference was greater for Porter and Mariner flours than for Ogle flours.

Roller milled oat flour slurries had a significantly lower initial pasting temperature than hammer milled oat flour slurries as shown in Table 17. This result would suggest that roller milling did produce smaller flour particles than hammer milling which is in agreement with particle size index results and Hunter Color Difference data. A finer flour would be expected to have a lower initial pasting temperature because of the greater amount of surface area available for water absorption. Kurimoto and Shelton (1988) stated that a finer particle size allowed water to penetrate into the core of the flour particle faster and a more uniform gel may form more easily.

Figure 16. Interaction of Mill Type, Oat Form and Oat Cultivar on Initial Pasting Temperature of Oat Flour.



Oat Form x Mill Interaction for Initial Pasting Temperature of Oat Flours



Oat Cultivar x Mill Interaction for Initial Pasting Temperature of Oat Flours

Table 17. Viscoamylograph means for initial paste temperature of oat flour

Main Effect	Classes	n	Initial Paste Temperature (°C)	Level of Significance
Mill Type	Hammer	12	52.1[a]	
	Roller	12	40.5[b]	0.01
Oat Form	Groats	12	49.5[a]	
	Flakes	12	43.1[b]	0.01
Oat Cultivar	Mariner	8	43.8[b]	
	Ogle	8	49.6[a]	
	Porter	8	45.5[b]	0.01

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

Oat flours milled from groats had a higher initial paste temperature than oat flours milled from oat flakes as shown in Table 17. This indicated that the process of flaking may have contributed to producing oat flour with a finer particle size when subjected to the same forces during milling. Oat flours from the Ogle cultivar had a significantly higher initial paste temperature than oat flours from the Mariner and Porter oat cultivars.

Table 18 contains the means for peak hot viscosity of oat flours. Roller milled oat flours had a higher peak hot viscosity than hammer milled flours but the difference was only significant at the $p< 0.1$ level. Oat flours from flakes had a higher peak hot viscosity than oat flours from groats but the difference was not significant. Shabakov et al (1980) reported that steam treatment of oat flours increased amylograph peak viscosity. Oat flours from the Ogle cultivar had a significantly higher peak hot viscosity than oat flours from the Mariner and Porter oat cultivars.

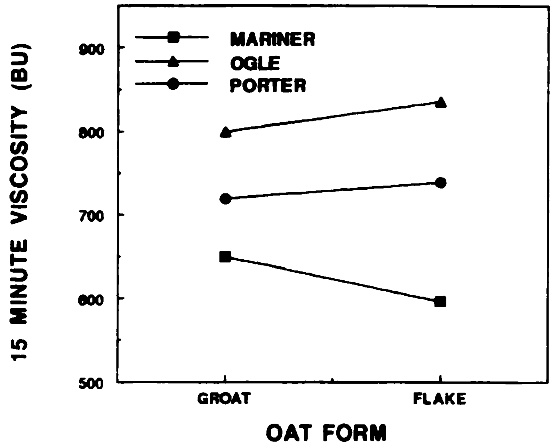
Table 18. Viscoamylograph means for peak hot viscosity of oat flour

Main Effect	Classes	n	Peak Hot Viscosity BU	Level of Significance
Mill Type	Hammer	12	1294.9^{b}	
	Roller	12	1384.0^{a}	0.1
Oat Form	Groats	12	1307.7^{a}	
	Flakes	12	1371.2^{a}	ns
Oat Cultivar	Mariner	8	1246.5^{b}	
	Ogle	8	1427.2^{a}	
	Porter	8	1344.6^{ab}	0.01

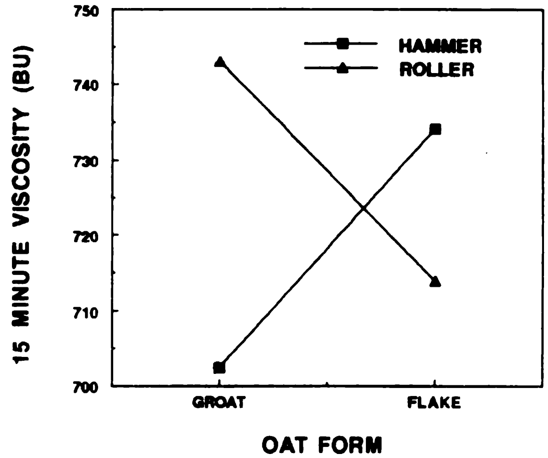
Means in the same main effect having a different superscript are significantly different.

The form x mill interaction and cultivar x form interaction were both significant at the $p<0.05$ level for 15 minute viscosity of oat flours. Figure 17 illustrates that oat flours roller milled from flakes had lower 15 minute viscosities and peak cold viscosities than flours roller milled from groats. Oat flours hammer milled from flakes had higher 15 minute viscosities and peak cold viscosities than flours hammer milled from groats. Mariner flours milled from flakes had lower mean 15 minute viscosity than flours milled from groats. Ogle and Porter flours milled from flakes had higher 15 minute viscosities than flours milled from groats

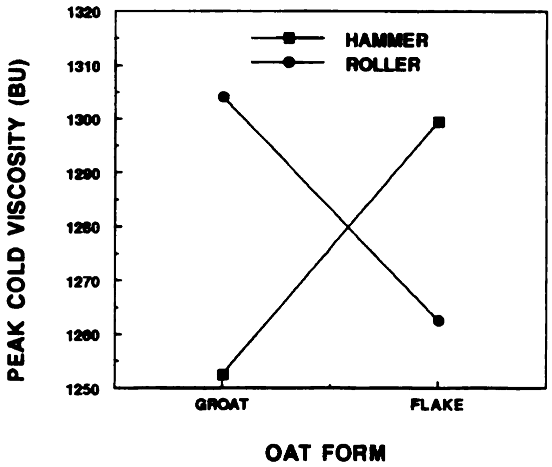
Figure 17. Interaction of Mill Type, Oat Form and Oat Cultivar on 15 Minute and Peak Cold Viscosities of Oat Flour.



Oat Cultivar x Oat Form Interaction for 15 Minute Viscosity of Oat Flours



Oat Form x Mill Interaction for 15 Minute Viscosity of Oat Flours



Oat Form x Mill Interaction for Peak Cold Viscosity of Oat Flours

The significant interactions between main effects contributed to a lack of statistically significant differences between means. There was no significant difference between hammer milled and roller milled oat flours for the parameters of viscosity at 15 minutes or peak cold viscosity as seen in Tables 19 and 20. Viscosity after 15 minutes is a measure of starch granule fragility and solubility but in oat flour it is also influenced by β-glucan solubilization. Yiu et al (1987) reported that β-glucan was a major contributor to viscosity in a gradually cooked sample of rolled oats. There was no significant difference in the parameters of viscosity at 15 minutes and peak cold viscosity for oat flours milled from oat groats or oat flakes. The oat flours roller milled from flakes tended to have larger variations in peak hot viscosity, 15 minute viscosity and peak cold viscosity.

Table 19. Viscoamylograph means for viscosity at 15 minutes of oat flour

Main Effect	Classes	n	Viscosity at 15 min BU	Level of Significance
Mill Type	Hammer	12	714.1[a]	
	Roller	12	728.4[a]	ns.
Oat Form	Groats	12	718.5[a]	
	Flakes	12	724.0[a]	ns
Oat Cultivar	Mariner	8	623.1[c]	
	Ogle	8	811.5[a]	
	Porter	8	729.1[b]	0.01

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

Table 19 shows the three oat flours had significantly different viscosities at 15 minutes. Ogle oat flours had a significantly higher viscosity at 15 minutes than the two other cultivars. Mariner oat flours had a significantly lower viscosity than Porter flours. Enzyme analysis results shown in Table 11 had indicated Porter oat flours had the highest β-glucan content among the three cultivars.

Table 20 contains viscoamylograph means for peak cold viscosity. There was no significant difference in peak cold viscosities for Porter and Ogle oat flours but Mariner oat flours did have significantly lower viscosities than the two other oat flours.

Table 20. Viscoamylograph means for peak cold viscosity of oat flour

Main Effect	Classes	n	Peak Cold Viscosity BU	Level of Significance
Mill Type	Hammer	12	1276.0[a]	
	Roller	12	1283.3[a]	ns.
Oat Form	Groats	12	1278.3[a]	
	Flakes	12	1281.0[a]	ns
Oat Cultivar	Mariner	8	1156.5[b]	
	Ogle	8	1364.4[a]	
	Porter	8	1318.1[a]	0.01

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

Table 21 contains the means and standard deviations of visco-amylograph parameters for the twelve oat flours. The oat flours

Table 21. Viscoamylograph means and standard deviations for oat flours[1]

Oat flour	Initial pasting temp °C	Peak hot viscosity BU	Viscosity after 15 min BU	Peak cold viscosity BU
Mariner				
HM-Groat	56.4 ± 0.6	1175.0 ± 77.8	625.0 ± 7.1	1142.5 ± 3.5
HM-Flake	43.5 ± 0.6	1268.5 ± 9.2	615.0 ± 7.1	1153.5 ± 12.0
RM-Groat	37.3 ± 2.3	1325.0 ± 66.5	673.5 ± 9.2	1202.5 ± 17.7
RM-Flake	38.0 ± 2.1	1217.5 ± 236.9	579.0 ± 86.3	1127.5 ± 102.5
Ogle				
HM-Groat	58.3 ± 3.8	1315.0 ± 35.3	751.0 ± 41.1	1350.0 ± 56.6
HM-Flake	48.7 ± 1.1	1470.0 ± 14.1	847.5 ± 46.0	1372.5 ± 10.6
RM-Groat	47.1 ± 0.2	1443.0 ± 9.9	822.5 ± 3.5	1370.0 ± 0.0
RM-Flake	44.4 ± 0.3	1481.0 ± 69.3	825.0 ± 7.1	1365.0 ± 7.1
Porter				
HM-Groat	58.1 ± 2.4	1216.0 ± 33.9	706.0 ± 19.8	1265.0 ± 21.2
HM-Flake	47.6 ± 3.0	1325.0 ± 7.1	740.0 ± 14.1	1372.5 ± 3.5
RM-Groat	39.7 ± 0.5	1372.5 ± 31.8	733.0 ± 4.2	1340.0 ± 14.1
RM-Flake	36.3 ± 1.1	1465.0 ± 35.3	737.5 ± 10.6	1295.0 ± 134.3

[1] n= 2

roller milled from flakes tended to have larger variations in peak hot viscosity, 15 minute viscosity and peak cold viscosity.

Visco-amylograph properties of oat starches

The visco-amylograph properties of oat starches that had been isolated from the twelve oat flours were measured. Oat flour viscosity may have been effected by flour particle size and non-starchy carbohydrates. Scalon et al (1988) described flour as a heterogeneous collection of particle sizes. That study separated roller milled wheat flour into coarse (91-136μm) and fine (<53μm) fractions and reported greater water absorption in the fine fraction when compared to the coarse fraction. The fine fractions also had reduced enthalpies(▲ H) of starch gelation when compared to corresponding composite flours. The conclusion was that starch in the fine fraction was less crystalline than in the coarser fractions due to starch damage during milling.

The major non-starchy carbohydrate that may have influenced oat flour viscosity is β-glucan. As previously stated, Yiu et al (1987) reported that β-glucan was a major contributor to viscosity in a gradually cooked sample of rolled oats. Isolation of starch from oat flour and measurement of oat starch visco-amylograph properties was one approach to measure the effect of milling on physical properties of oats. The oat starch extraction procedure of Paton (1977) used sodium carbonate to adjust the pH of the slurry to be heated and to prevent chemical gelatinization.

The process of milling wheat flour has long been known to result in mechanical damage to wheat starch (Alsberg and Griffing, 1925; Pulkki,1938). Kent (1983) stated that the degree of mechanical damage to starch granules in soft wheats is not as great as that produced in hard wheats. Oat groats are a softer grain than wheat kernels. No published literature was found that discussed susceptibility of a compound starch granule to damage during milling.

There were no significant interactions for viscoamylograph parameters of oat starches as indicated by Tables 98-102. Table 22 shows there was no significant difference in initial paste temperatures of oat starches extracted from hammer milled oat flours compared to oat starches extracted from roller milled flours. Oat starch extracted from Ogle flours had a significantly lower initial paste temperature than oat starches from Mariner and Porter oat cultivars.

Table 22. Viscoamylograph means for initial paste temperature of oat starch

Main Effect	Classes	n	Initial Paste Temperature (^oC)	Level of Significance
Mill Type	Hammer	12	88.2^a	
	Roller	12	88.0^a	ns.
Oat Form	Groats	12	87.8^a	
	Flakes	12	88.5^a	ns
Oat Cultivar	Mariner	8	88.6^a	
	Ogle	8	86.2^b	
	Porter	8	89.5^a	0.01

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

Table 23 shows there was no significant difference in peak hot viscosity for oat starches extracted from hammer milled oat flours compared to oat starches extracted from roller milled flours. Oat starches extracted from flours milled from groats were not statistically different from starch extracted from flours milled from flakes. There was no statistically significant difference between the starches from the three oat cultivars in the viscoamylograph parameter of peak hot viscosity.

Table 23. Viscoamylograph means for peak hot viscosity of oat starch

Main Effect	Classes	n	Peak Hot Viscosity BU	Level of Significance
Mill Type	Hammer	12	754.2[a]	
	Roller	12	744.0[a]	ns
Oat Form	Groats	12	742.4[a]	
	Flakes	12	755.7[a]	ns
Oat Cultivar	Mariner	8	741.4[a]	
	Ogle	8	737.1[a]	
	Porter	8	768.7[a]	ns

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

Oat starches extracted from hammer milled oat flours had a significantly higher viscosity at 30 minutes than those from roller milled flours as shown in Table 24. Hot viscosity behavior seemed to indicate that starch granules from roller milled oat flours were more fragile. A greater reduction in flour particle size during roller milling may have also influenced the pasting properties of the compound oat starch granules. Roller milling subjected the compound oat starch granules to shear and compressive forces.

Table 24. Viscoamylograph means for viscosity at 30 minutes of oat starch

Main Effect	Classes	n	Viscosity at 30 min BU	Level of Significance
Mill Type	Hammer	12	488.3[a]	
	Roller	12	474.1[b]	0.01
Oat Form	Groats	12	486.2[a]	
	Flakes	12	476.2[a]	ns
Oat Cultivar	Mariner	8	437.6[b]	
	Ogle	8	511.9[a]	
	Porter	8	494.1[a]	0.01

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

MacArthur and D'Appolonia (1979) milled the hard spring red wheat Waldron into flour with a Brabender Quadramat Jr. flour mill and a Miag Pilot flour mill. Wheat starch separated from the roller milled flour had an initial pasting temperature of 82.5°C compared to 84°C for the Miag milled product. The wheat starch isolated from roller milled flour had a lower peak viscosity, a lower viscosity at 15 minutes and a lower viscosity upon cooling to 50°C.

The peak cold viscosity of starches extracted from hammer milled oat flours was also higher than that measured for oat starches extracted from roller milled oat flours as seen in Table 25.

Porter oat starches had the highest peak cold viscosity while Mariner oat starches had the lowest peak cold viscosities. All three starches were significantly different from each other in the peak cold viscosity parameter.

Table 25. Viscoamylograph means for peak cold viscosity of oat starches

Main Effect	Classes	n	Peak Cold Viscosity BU	Level of Significance
Mill Type	Hammer	12	1308.7[a]	
	Roller	12	1247.0[b]	0.01
Oat Form	Groats	12	1290.7[a]	
	Flakes	12	1265.0[a]	ns
Oat Cultivar	Mariner	8	1181.4[c]	
	Ogle	8	1286.2[b]	
	Porter	8	1366.0[a]	0.01

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

There was no difference in any of the pasting parameters at the significance level of $p<0.01$ for oat starches extracted from groats was compared to oat starches extracted from flakes. This result would imply that the flaking process that groats were subjected to did not significantly affect oat starch viscoamylograph properties. Yiu (1986) had reported some compound oat starch granules being broken into individual starch grains by the flaking process that produced rolled oats.

Table 26 contains the means of the viscoamylograph parameters for the twelve oat starches. The range of initial paste temperature for Mariner and Porter oat starches was from 87.2 - 91.5°C. This was higher than the range for initial paste temperatures of oat starch extracted from high nitrogen oats by the same procedure previously reported by Paton (1977). Oat starch from four different oat cultivars had initial paste temperatures in the range of 65.0 - 70.0°C.

MacArthur and D'Appolonia (1979) compared oat and wheat starch and reported initial pasting temperatures for oat starches from three different cultivars ranged from 81-83.5°C compared to 82.5-84.0°C for wheat starch. The wheat starch used in the study was from the hard red spring wheat, Waldron. The oat starches exhibited a higher peak viscosity, 15 minute viscosity and viscosity upon cooling to 50°C than the wheat starch used in the MacArthur and D'Appolonia study.

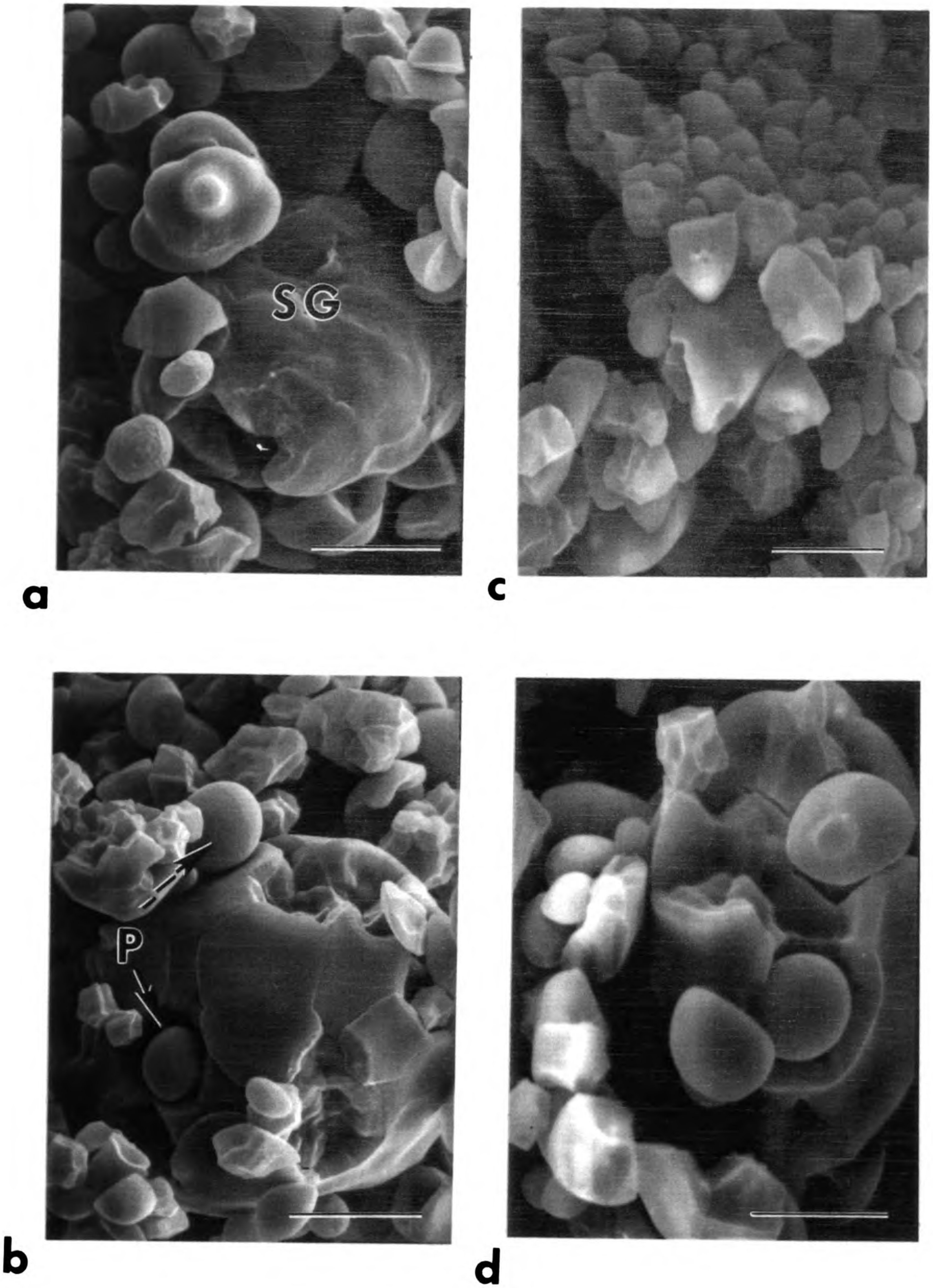
Scanning electron micrographs of three representative alkaline extracted oat starches are shown in Figure 18. Compound oat starch granules with varying degrees of loss of individual granules could be observed in samples from all twelve types of starch. Intact oat starch granule shapes in all three oat cultivars varied from elongated to rounded as seen in Figure 18a from Mariner roller milled groat flour and in Figure 18b from Porter roller milled groat flour. No attempt was made to determine the ratio of intact granules as seen in Figures 18a, b, d to individual granules as seen in Figure 18c which was from Mariner hammer milled flake flour. The micrographs demonstrate the inherent difficulty of separating oat

Table 26. Means and standard deviations for viscoamylograph data for oat starches[1]

Oat starch	Initial pasting temp °C	Peak hot viscosity BU	Viscosity after 30 min BU	Peak cold viscosity BU
Mariner				
HM-Groat	87.8 ± 0.4	767.0 ± 4.3	455.0 ± 0.0	1181.5 ± 65.8
HM-Flake	89.2 ± 0.3	734.0 ± 36.8	430.0 ± 0.0	1220.0 ± 99.9
RM-Groat	88.6 ± 0.1	747.5 ± 17.7	445.5 ± 7.8	1189.0 ± 43.8
RM-Flake	88.6 ± 0.5	717.0 ± 7.1	420.0 ± 0.0	1135.0 ± 21.2
Ogle				
HM-Groat	85.7 ± 0.1	729.0 ± 12.7	527.5 ± 6.4	1333.5 ± 4.9
HM-Flake	87.6 ± 1.4	740.5 ± 13.4	520.0 ± 0.0	1315.0 ± 21.2
RM-Groat	85.6 ± 0.9	702.0 ± 4.2	501.5 ± 2.1	1271.5 ± 54.4
RM-Flake	86.0 ± 0.1	777.0 ± 7.1	498.5 ± 29.9	1225.0 ± 7.1
Porter				
HM-Groat	89.2 ± 0.1	758.5 ± 13.4	502.5 ± 3.5	1407.5 ± 10.6
HM-Flake	89.9 ± 1.5	796.0 ± 65.0	495.0 ± 14.1	1395.0 ± 21.2
RM-Groat	89.5 ± 0.5	750.5 ±14.8	485.0 ± 14.1	1361.5 ± 4.9
RM-Flake	89.4 ± 1.8	770.0 ± 2.8	494.0 ± 8.5	1300.0 ± 70.7

[1] n =2

Figure 18. Scanning electron micrographs of freeze dried alkaline extracted oat starch granules (SG). Scale bar = 10 μ. a) Mariner oat starch isolated from hammer milled groat flour b) Porter oat starch isolated from hammer milled groat flour Protein body (P) c) Mariner oat starch isolated from hammer milled flake flour d) Ogle oat starch isolated from hammer milled flake flour.


SG
a
c
P
b
d

protein from oat starch. The size and shape of the oat protein bodies enable them to fit into intact starch granules that have lost a few individual granules as shown in Figure 18b and d.

The mean percent protein in alkali extracted oat starches is given in Table 27. Analysis of variance indicated there was a significant difference at the $p<0.01$ level in protein content of starches extracted from oat flours milled from groats when compared to starches extracted from oat flours milled from flakes. There was no significant difference in protein content between starches by milling method or oat cultivar. Oat starches extracted from oat flours milled from flakes may have contained more damaged compound granules that provided indentations in which protein bodies could lodge.

Table 27. Means and standard deviations of percent protein in alkali extracted oat starches[1]

	Oat Cultivar		
Type of starch[2]	Mariner	Ogle	Porter
HMG	0.04 ± 0.06	0.18 ± 0.17	0.02 ± 0.03
HMF	0.35 ± 0.05	0.36 ± 0.04	0.47 ± 0.08
RMG	0.10 ± 0.08	0.00 ± 0.00	0.04 ± 0.06
RMF	0.37 ± 0.03	0.42 ± 0.03	0.25 ± 0.05

[1] n= 2

[2] HMG= Hammer milled groats, HMF= Hammer milled flakes
RMG= Roller milled groats, RMF = Roller milled flakes

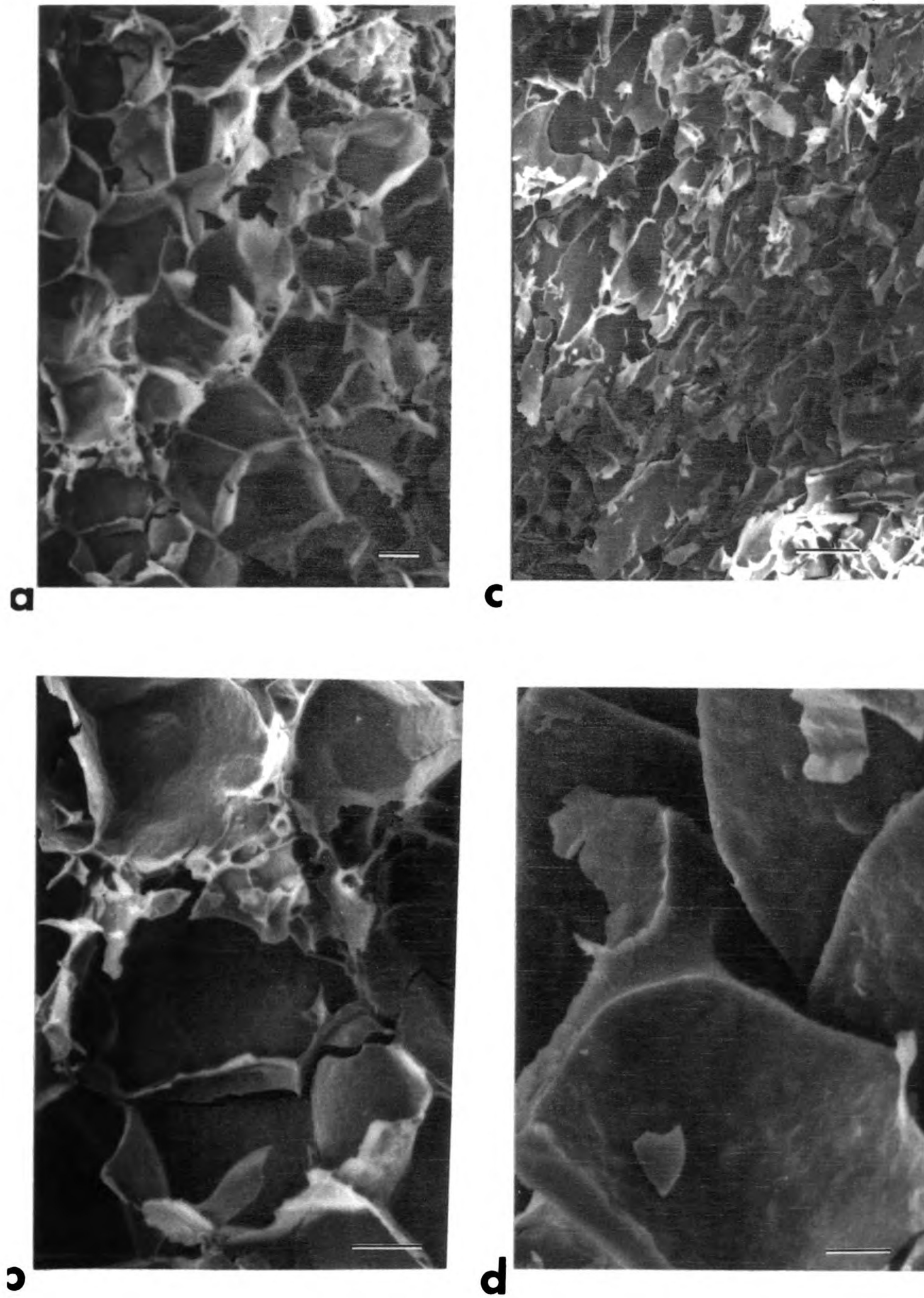
Figure 19 are scanning electron micrographs of the gelatinized groat oat starch slurry after freeze drying. The honeycomb-like structure as shown in Figure 19a and b is composed of cells with a similar five sided shape as the individual oat starch granules. Paton (1977) had reported a sponge like texture in refrigerated oat starch gels. Figure 19c is ground freeze dried Ogle hammer milled groat starch and Figure 19d is Porter hammer milled groat starch. The freeze dried oat starch gels maintained the honeycomb like structure and tended to fracture into smaller segments instead of granular particles after grinding with a mortar and pestle.

Alkaline water retention capacities of flours

Alkaline water retention capacity is a measure of the ability of a flour to retain water when subjected to centrifugal force. The test was introduced by Yamazaki in 1953. His results were that alkaline water retention capacity for soft wheat flours was highly negatively correlated with sugar-snap cookie diameter. The hydration characteristics of a flour influenced its performance in sugar-snap cookies.

The interaction of oat cultivar x mill was significant at $p<0.05$ for AWRC and is illustrated in Figure 20. The lines are not parallel with the difference in AWRC between hammer and roller milled flour being greater for Porter and Mariner oat flours compared to Ogle flours. Table 28 shows the means for alkaline water retention capacities (AWRC) of oat flours. The mean AWRC of roller milled oat flours was significantly higher than the AWRC of hammer milled oat flours. With the exception of Porter hammer milled flake flour, the

Figure 19 Scanning electron micrographs of freeze dried oat starch gels. Scale bar = 100 μ. a) Mariner hammer milled groat starch gel b) Mariner hammer milled groat starch gel c) Gelatinized Ogle hammer milled groat starch after grinding d) Gelatinized Porter hammer milled oat starch after grinding.


a
c
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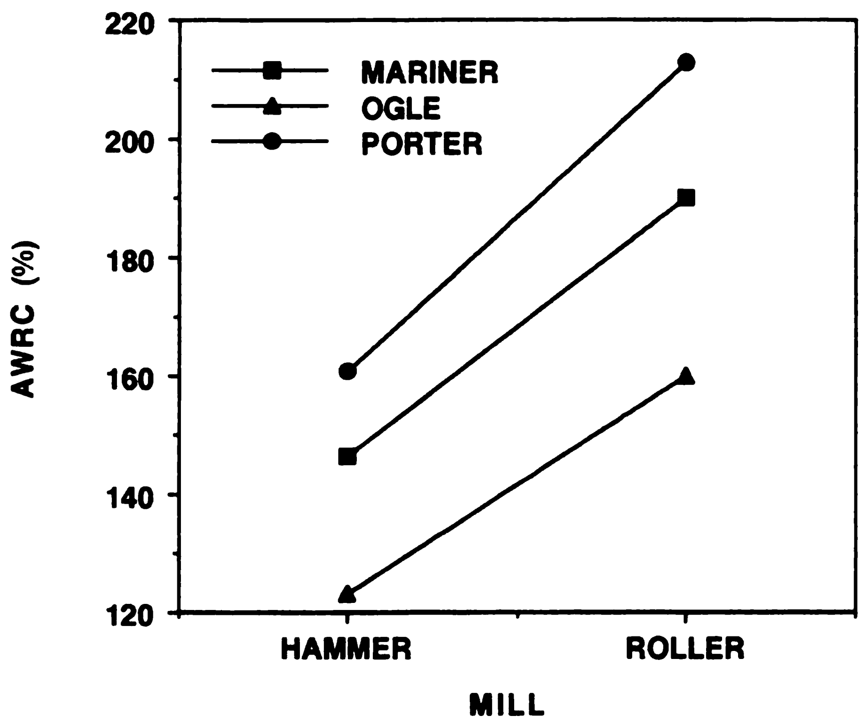


Figure 20. Interaction of Mill Type and Oat Cultivar on Alkaline Water Retention Capacity (AWRC) of Oat Flour.

roller milled oat flours had the largest standard deviations for AWRC.

Table 28. Means for alkaline water retention capacities (AWRC) of oat flours

Main Effect	Classes	n	AWRC[1] (%)	Level of Significance
Mill Type	Hammer	18	143.6[a]	
	Roller	18	187.6[b]	0.01
Oat Form	Groats	18	145.2[b]	
	Flakes	18	186.1[a]	0.01
Oat Cultivar	Mariner	12	168.3[b]	
	Ogle	12	141.9[c]	
	Porter	12	186.7[a]	0.01

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

Particle size is related to the water absorption of flour (Mailhot and Patton, 1988). A flour with finer average particle size would be expected to have greater hydration capacity due to increased surface area. The results of the physical (Hunter L-value and PSI) and functional (AWRC) tests agreed leading to the conclusion that roller milled oat flours contained finer flour particles than hammer milled oat flours.

Oat flours milled from oat flakes had a significantly higher AWRC than oat flours milled from groats. Although there was not a significant difference in Particle Size Index between flours milled from groats and flours milled from flakes from Table 14, there was a highly significant difference in alkaline water retention capacities. The size of the oat flake flours particles combined with the lipid content of the oat flours may have influenced Particle Size Index results.

Yamazaki (1969) stated that wheat and flour properties that appear to be cultivar related include flour granularity, absorption, viscosity and cookie spread potential. All three oat cultivars had significantly different AWRC when compared to each other. Porter oat flours had the highest AWRC while Ogle had the lowest AWRC of the three oat flours.

There was disagreement between physical (Hunter L-value and PSI) and functional (AWRC) test results. Porter had the lowest Hunter L-value and the smallest Particle Size Index. Particle Size Index results may have been influenced by lipid content of the Porter oat flours. As previously reported in Table 8, Porter oat flours contained a significantly higher percentage of lipid than the other two oat cultivars.

Table 29 contains the means and standard deviations of alkaline water retention capacities of the twelve types of oat flours produced in this study. The means of the roller milled oat flours were consistently higher than their hammer milled counterparts. With the exception of Porter hammer milled flake flour, the roller milled flours had the largest standard deviations for AWRC.

Table 29 Means and standard deviations of alkaline water retention capacities of oat flours [1] [2]

Type of mill and oat form	Oat Cultivars		
	Mariner	Ogle	Porter
Hammer milled			
Groat	130.5 ± 1.8	111.6 ± 0.8	132.6 ± 3.1
Flake	162.4 ± 3.9	136.0 ± 1.0	188.6 ± 12.1
Roller milled			
Groat	166.3 ± 4.4	135.5 ± 3.5	194.6 ± 4.0
Flake	213.9 ± 5.8	184.5 ± 3.0	231.0 ± 3.3

[1] n= 3

[2] 14% moisture basis

Scanning Electron Microscopy of Aleurone Cell Walls:

The aleurone and subaleurone cell wall widths were measured at the three positions on a latitudinally cut groat or kernel as shown in Figure 21. Position 1 was adjacent to the crease area, position 2 at a 90° angle to the crease and position 3 was distal to the crease. The latitudinal cut was made half way between the base and tip of the groat to avoid the oat germ at position 3. It was thought necessary to examine the oat aleurone and subaleurone cell walls at three specific locations because of previous studies by Pomeranz (1972) and Ewers (1982).

The microstructure of a oat groat from the cultivar Orbit, was previously studied by Pomeranz (1972). He reported that the distal side of the oat groat contained two lines of rectangular shaped aleurone cells while cells adjacent to the crease area were almost elliptical in shape. Pomeranz (1972) had also observed an increase

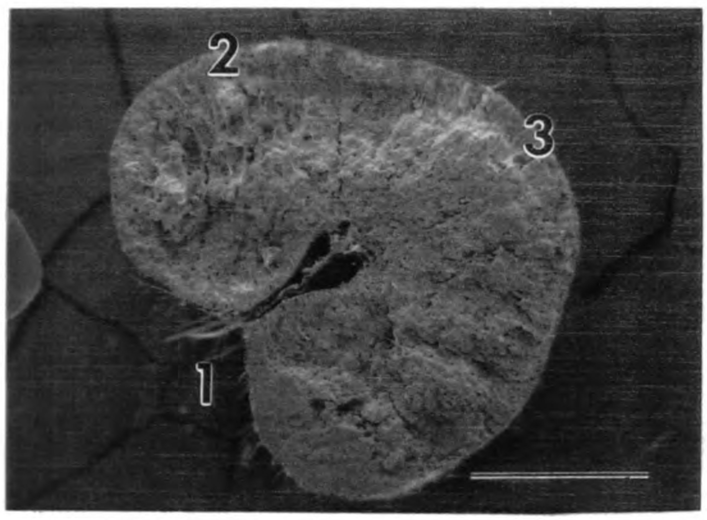


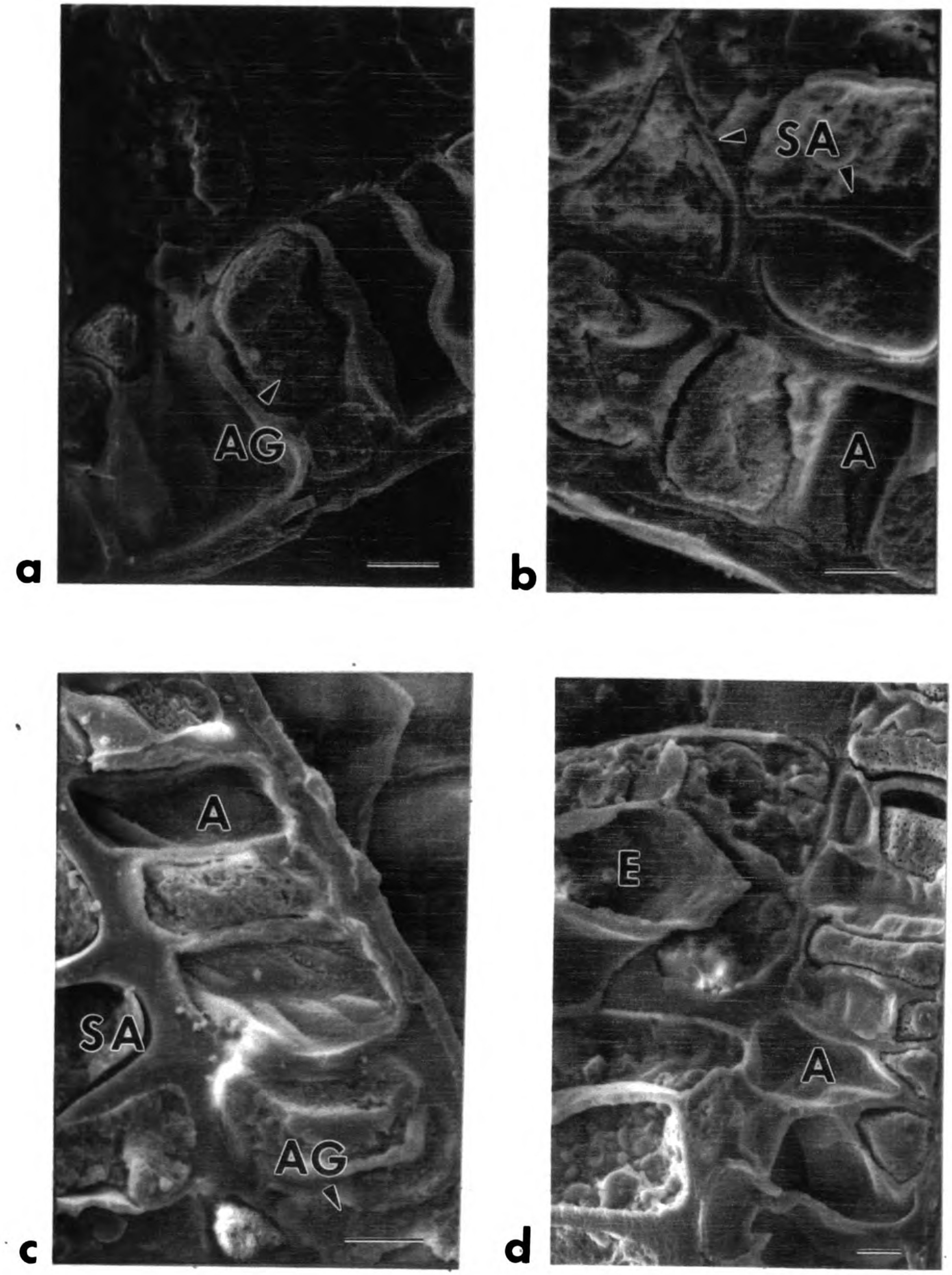
Figure 21. Scanning electron micrograph of Porter groat identifying the three positions on oat groat cross section at which measurements were taken of aleurone and subaleurone cell wall width. Scale bar = 1000 μ

in aleurone cell size at the germ end of the oat groat. Ewers (1982) reported that mean cell growth in all layers occurred halfway between the base and tip of evergreen needle leaves. A difference in cell shape may have meant possible differences in cell wall width so measurements were taken at the three distinctive positions.

Figures 22a, b, c are scanning electron micrographs of transverse latitudinal sections of groats from the cultivar, Mariner. Figure 22a was taken at position one and shows rectangular shaped aleurone cells. The center aleurone cell in this micrograph is filled with aleurone grains. The aleurone cell walls that are perpendicular to the outer cell walls are relatively small when compared to the thickness of the cell walls that separates the aleurone layer from the starchy endosperm. The average cell wall width at this position was 4.46μ At the top of the micrograph, two smaller cells packed with aleurone grains can be seen. These observations agree with Pomeranz (1972) and Bechtel and Pomeranz (1981) that two lines of aleurone cells may be found in portions of the groat.

Figure 22b was photographed at position two on a Mariner groat. The cells are still predominantly rectangular in shape but one cell is observed to be slightly elliptical in shape in the aleurone layer. In the subaleurone layer, two cells both still packed with aleurone grains have different shapes, one oval and the second triangular. Oval shaped subaleurone cells were observed in three of the five groats at position two. The average aleurone cell wall width at position two was 4.28μ, slightly smaller than cell wall width at position one. Figure 22c, also taken at position two,

Figure 22. Scanning electron micrographs of aleurone and subaleurone cell wall on latitudinal cross section of Mariner groat. Aleurone cell (a), aleurone grains (ag), Subaleurone cells (sa), Endosperm cells (e) Scale bar = 10μ a) Position 1 b) Position 2 c) Position 2 d) Double layered aleurone cells at Position 3


AG
a
SA
A
b
A
SA
AG
c
E
A
d

illustrates the variation in cell shapes and arrangements of double layered cells in this oat cultivar.

Figure 22d was photographed at position three on a Mariner groat. The aleurone cells are rectangular in shape but have a tendency to be slightly oblique. A double layer of aleurone cells were observed in two of the five Mariner groats at position three. This position had the thickest aleurone cell walls, 4.68μ.

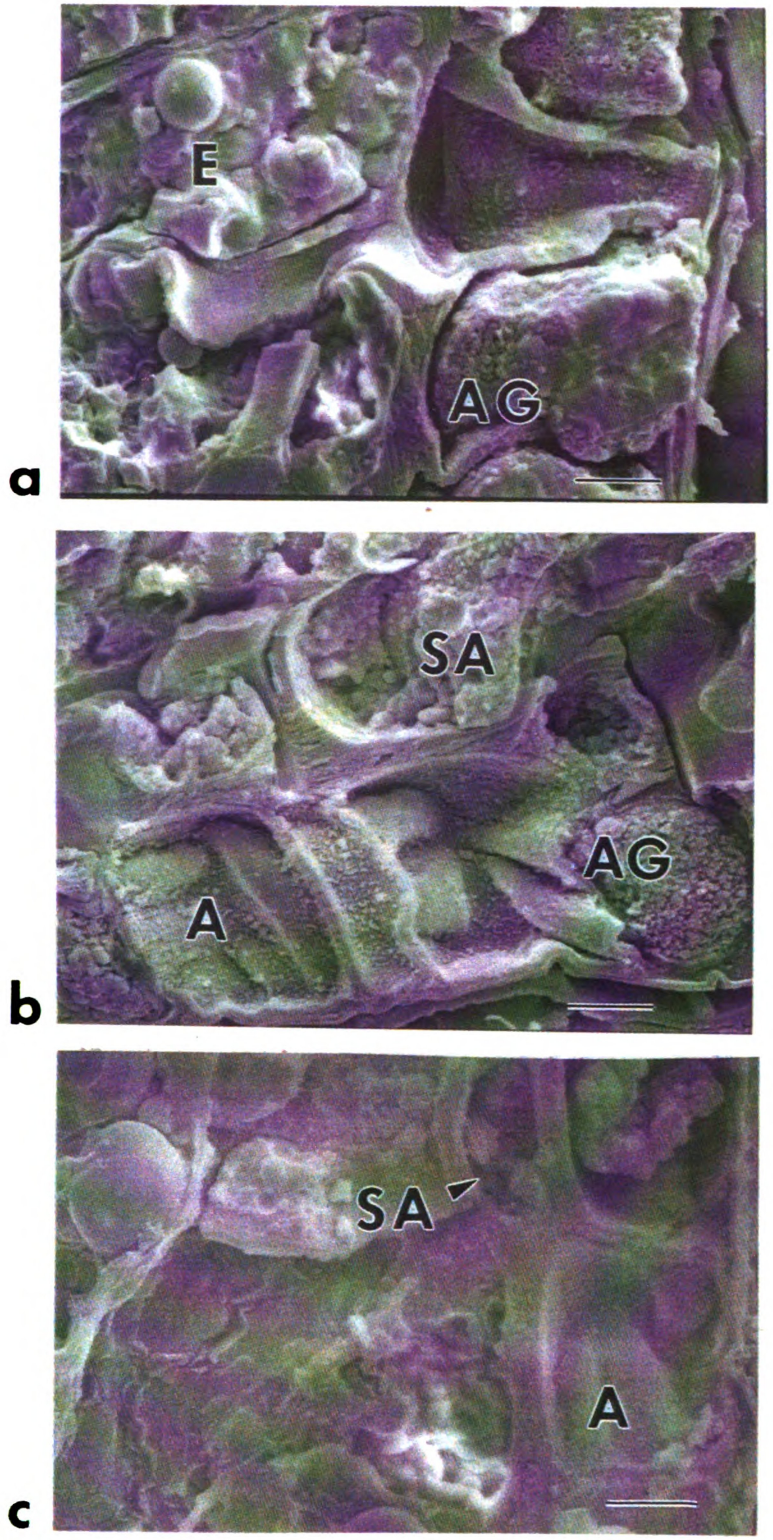
Aleurone cells located at position one on a Ogle groat are shown in Figure 23a. The cell walls at position one had an average width of 3.08μ, the smallest thickness among the three positions. The cells were mostly rectangular in shape and no subaleurone layer was present in the five randomly selected groats

Figure 23b shows aleurone cells located at position two on a Ogle groat. The aleurone cells at this position had a variety of shapes, some samples having rectangular cells while others were cubodial in appearance and perpendicular to the outer edge of the groat. The aleurone cell walls in this section had an average width of 3.38μ, the largest thickness among the three positions.

Figure 23c was photographed at position three on a Ogle groat. In contrast with position two, the cells are perpendicular to the outer edge of the groat and strongly rectangular in shape. One small oval subaleurone cell is shown in the micrograph. An average cell wall width of 3.14μ was measured at this position in Ogle groats.

Figures 24a, b, c and d are scanning electron micrographs of Porter groats. Figure 24a was taken at position one where the average aleurone cell wall width was 3.73μ. The cells had more

Figure 23. Scanning electron micrographs of aleurone and subaleurone cell walls on latitudinal cross section of Ogle groat. Aleurone cell (a), aleurone grains (ag) Subaleurone cells (sa), Endosperm cells (e) Scale bar = 10 μ a) Position 1 b) Position 2 c) Position 3.


E
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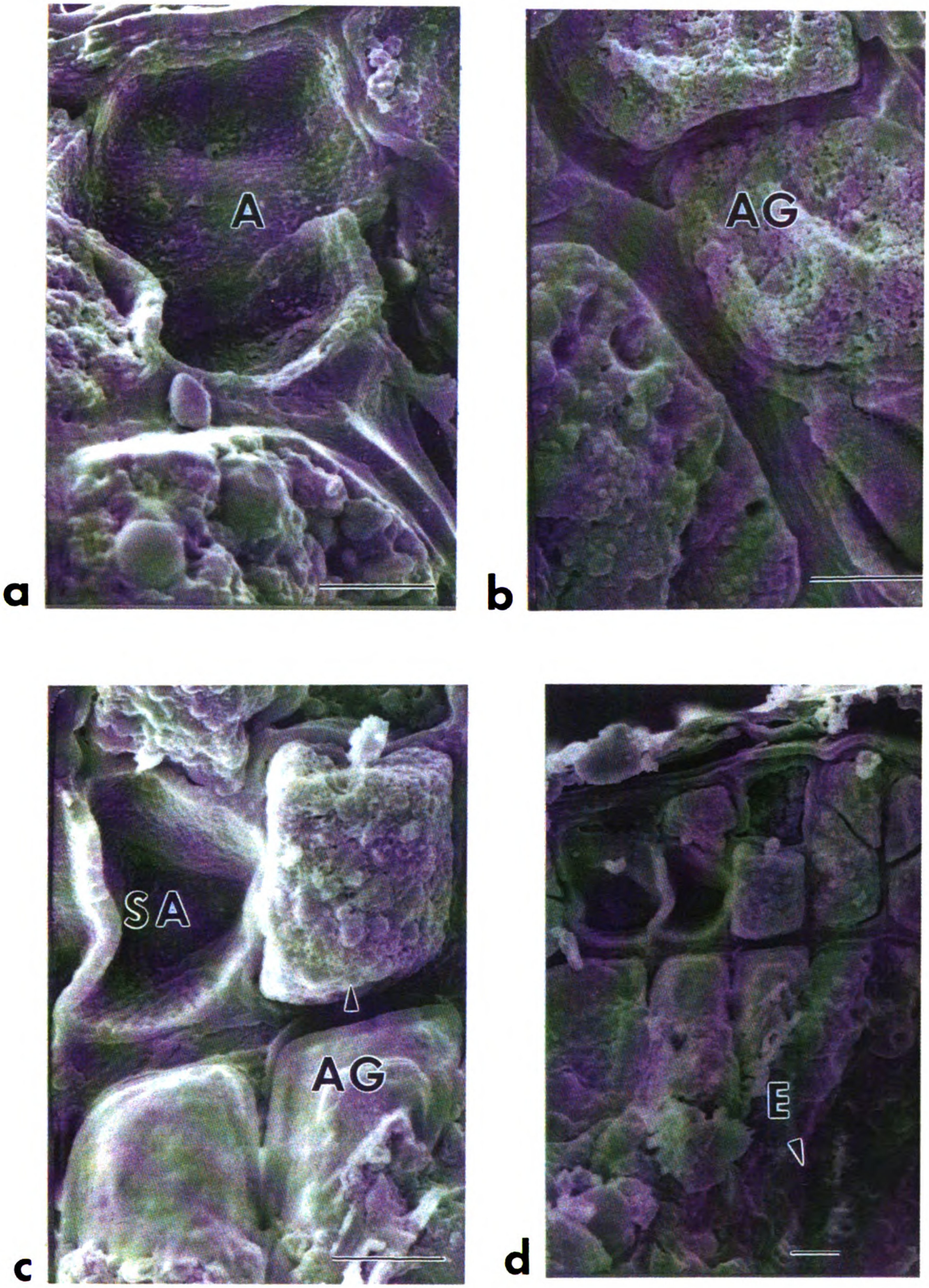
rounded corners with less of an rectangular shape when compared to Mariner groats (Figure 22a) at the same position.

Figures 24a and b indicates the Porter cultivar had similarly shaped rounded cells at positions one and two. An average aleurone cell wall width of 3.71μ was measured at position two. No sub-aleurone layer was observed in any of the five groats examined in this study. The aleurone grains appeared to be closely adhered to the cell walls when compared to aleurone grains seen in Figure 22a (Mariner) and Figure 24a (Porter).

Figure 24c shows a rectangular shaped subaleurone cell that was tightly packed with aleurone grains at position three. The cell walls located between the aleurone layer and subaleurone layer were of comparable thickness to the wall located between the sub-aleurone layer and the starchy endosperm. There was no consistent presence of a subaleurone layer at this position on Porter groats among the five samples. However, Figure 24d illustrates a section at position three that consisted of five consecutive double layered aleurone cells. The average cell wall measurement for Porter groats was 4.06m at position three.

Table 30 and Figure 25 show that examination of five randomly chosen groats from each cultivar revealed that there was no consistent relationship in aleurone cell wall thickness among these three oat cultivars. No aleurone cell wall position on the oat groat was consistently larger or smaller than another aleurone cell wall at a specific position. The three oat cultivars had different aleurone cell wall thicknesses in groats of approximately the same weight. The Mariner oat cultivar had the largest average aleurone cell wall

Figure 24. Scanning electron micrographs of aleurone and subaleurone cell wall on latitudinal cross section of Porter groat. Aleurone cell (a), aleurone grains (ag) Subaleurone cells (sa), Endosperm cells (e) Scale bar = 10μ a) Position 1 b) Position 2 c) Position 3 d) Double layered aleurone cells at Position 3


A
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thickness of the three cultivars. Ogle oat cultivar had the smallest average aleurone cell wall thickness of the three cultivars.

Table 30. Means and standard deviations of aleurone cell wall measurements[1] at three positions on the oat groat.

Oat Cultivar	Position 1	Position 2	Position 3	Mean cell wall width mm ($x10^{-3}$)
Mariner	4.46 ± 1.05	4.28 ± 1.31	4.68 ± 1.60	4.47
Ogle	3.08 ± 0.90	3.38 ± 1.13	3.14 ± 0.83	3.20
Porter	3.73 ± 1.30	3.71 ± 0.97	4.06 ± 1.14	3.83

[1] n = 5

Table 31 contains proximate analysis results for protein content of groats and total dietary fiber content for all oat flours from that cultivar. The groat protein percent varied with the average aleurone cell wall width. Mariner groats contained the highest percent of protein among the three cultivars while having the largest aleurone cell wall thickness. Ogle groats contained the smallest percentage of protein while having the smallest aleurone cell wall thickness. Fulcher (1986) observed that high protein cultivars tend to have subaleurone cell walls that are four to five times thicker than endosperm cell walls.

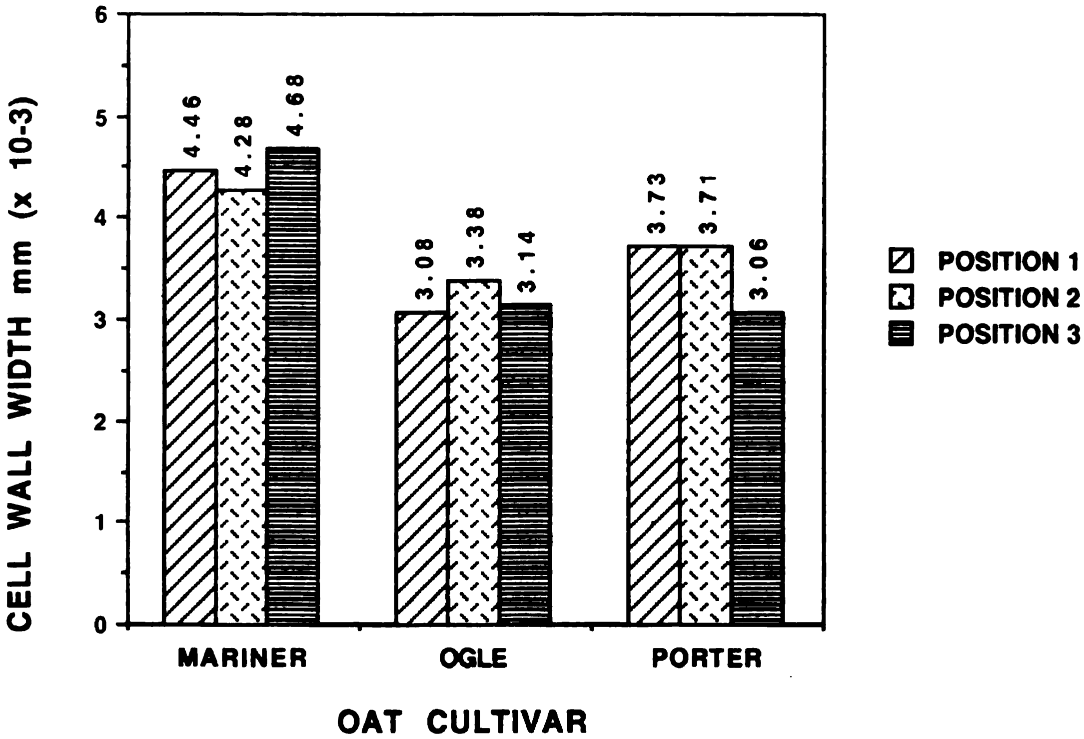


Figure 25. Aleurone cell wall measurements

Table 31. Means and standard deviations of groat protein content, total dietary fiber content of oat flours and aleurone cell wall widths.

Oat Cultivar	Groat Protein[1] (%)	Total Dietary Fiber[2] (%)	Average Cell Width mm (x 10^{-3})
Mariner	17.81 ± 0.64	12.23 ± 1.71	4.47 ± 0.20
Ogle	16.44 ± 0.27	10.98 ± 1.57	3.20 ± 0.16
Porter	16.58 ± 0.45	13.52 ± 1.80	3.83 ± 0.20

[1] n = 3, Dry weight basis
[2] n=12 Total Dietary Fiber in all four types of oat flour, dry weight basis

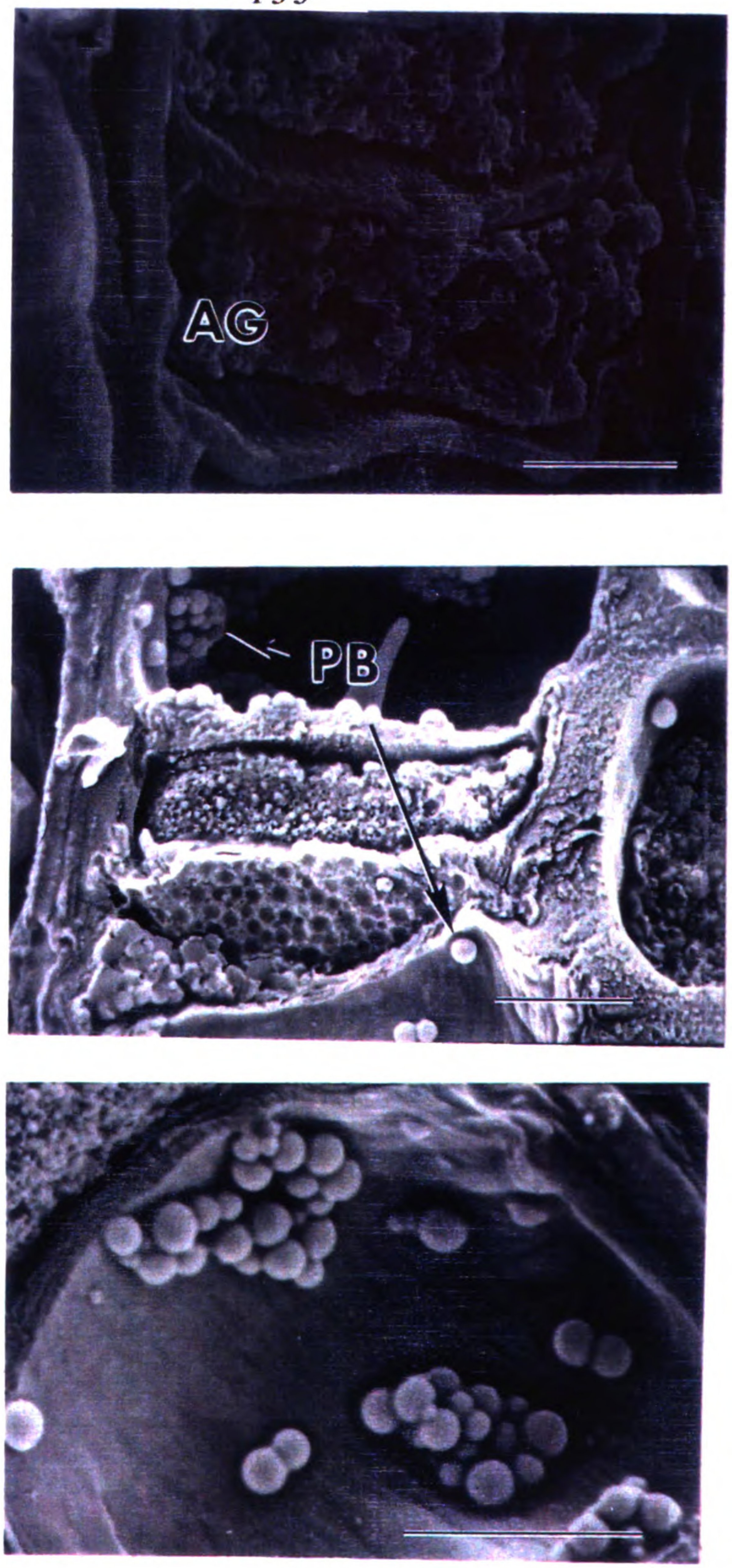
As previously mentioned in the results and discussion section concerning comparison of oat forms used in this study, the size of the groat may be influencing protein content. Ogle had the largest 1000 kernel weight of the three oat cultivars. Youngs (1972) reported that in five oat cultivars and two experimental lines of common oats, the endosperm weights varied inversely and the bran weights directly with the groat protein concentration. Oat bran being composed of the two outermost layers plus the aleurone and subaleurone cells contain a high percentage of oat protein in the form of aleurone grains and protein bodies. Bechtel and Pomeranz (1981) reported that aleurone grain contents could partially be digested by proteases. Figure 26a and b show the two forms of oat protein found in the aleurone and subaleurone cells; aleurone grains and protein bodies. The spherical protein bodies are shown to be located in clusters along the inner wall of the aleurone cells in Figure 26b and c.

The preliminary oat flour study, documented in the Appendix, measured the percentage of protein in commercial whole grain oat flour fractionated by sieving. The coarse oat flour fraction or 'overs' of a U.S. No 54 screen was predominantly composed of the aleurone and subaleurone cell fragments. This coarse flour fraction from commercial oat flour was measured to contain 24 percent protein. Youngs (1972) concluded that bran usually contains almost double the protein concentration of the starchy endosperm or about half the total groat protein.

Wood and Fulcher (1978), Fulcher and Wong (1980), Wood (1980, 1981,1982), Fulcher and Wood (1983) and Wood et al (1983) used chemically specific fluorescent dyes and light microscopy to identify location and quantify levels of β-glucan in oat cell walls. In this study the aleurone cell walls were measured because Wood (1989) and Fulcher(1989) identified β-glucan, a major component of soluble fiber in oats, to be present in large amounts in the thick aleurone and subaleurone cell walls. Fulcher (1989) also stated that the properties of the bran (pericarp, seed coat, aleurone and sub-aleurone layer) most influence the quality characteristics of oats.

Table 31 contains the results of total dietary fiber analysis on oat flours milled from groats and flakes by both kinds of mills. The level of total dietary fiber does not appear to vary with the aleurone cell wall width. Wood et al (1983) using Calcofluor and Congo red identified the endosperm cell walls as the major reservoir of β-

Figure 26. Scanning electron micrographs of cross section of Mariner oat groat showing aleurone grains and protein bodies located in the aleurone cells. a) Tightly packed aleurone grains (AG). Scale bar = 10μ b) Cluster of protein bodies (PB) located along inner walls of aleurone cell. Scale bar = 10 μ c) Protein bodies located along inner walls of aleurone cell. Scale bar = 10 μ.



a
b
c

glucan in oats. Although endosperm walls located in the mid or inner endosperm are smaller in width than aleurone cell walls, endosperm cell walls comprise a larger percentage of the oat groat. In the mature groat, the starchy endosperm contributes between 55.8 and 68.3% of the weight (Youngs, 1972; Youngs and Peterson, 1973). Fulcher (1986) theorized that the presence of β-glucans in the oat aleurone layer may substantially enhance the water binding capacity of oat bran and support its role as a source of dietary fiber.

Summary:

The results of the aleurone cell wall study indicated an agreement with previously published observations of the diversity of aleurone cell shape at different locations on the groat. There was also agreement with the relative amount of protein and aleurone cell wall thickness. The lack of agreement between cell wall thickness and total dietary fiber content may have been influenced by the presence of double layers of cells in the aleurone layer. When this occured the groat was contributing additional amounts of total dietary fiber in the form of β-glucan and this may have effected the theorectical relationship.

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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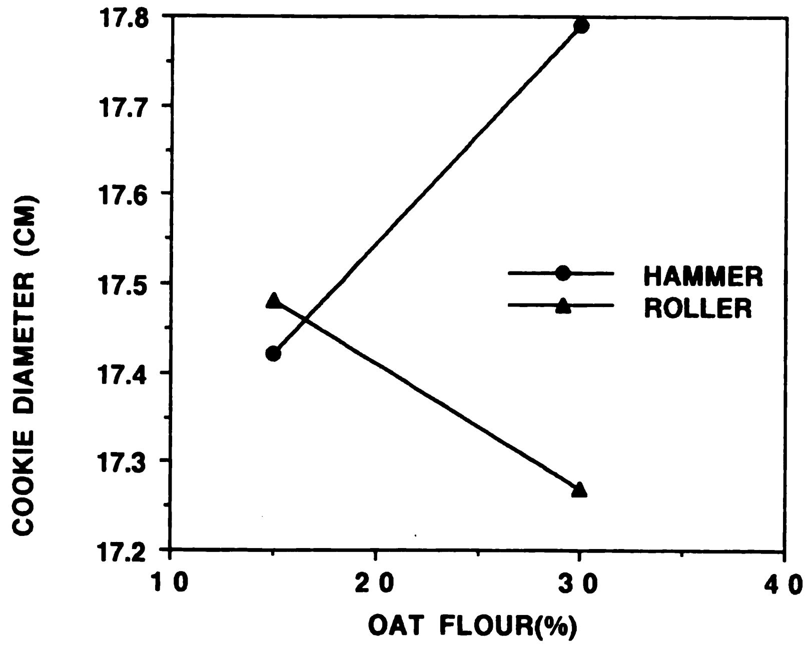
Effect of Milling on Cookie Quality

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.

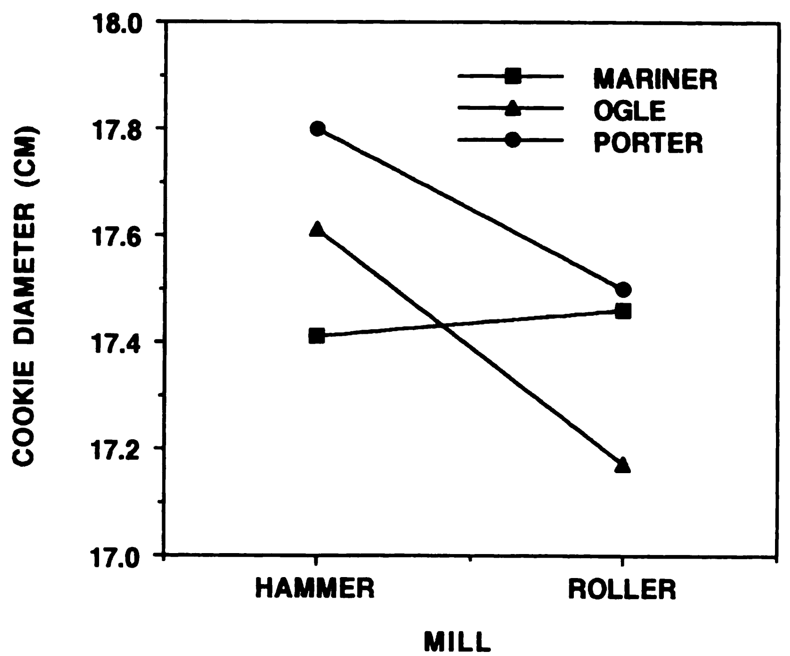
Cookie diameter and top grain scores:

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

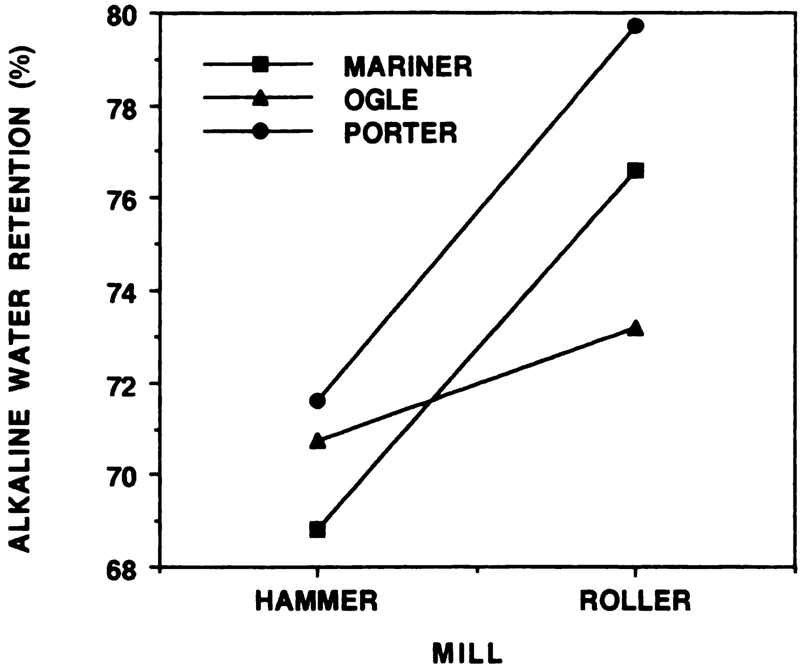


Figure 28. Interaction of Oat Cultivar x Type of Mill for Alkaline Water Retention Capacity of Hammer and Roller Milled Groat Composite Flours

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:

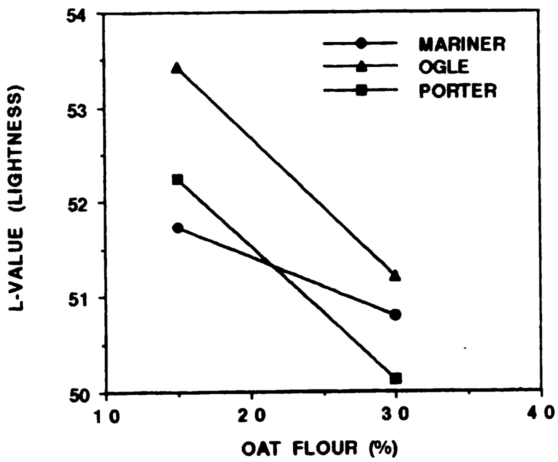
Analysis of variance means for Hunter Color Difference L-value, a-value and b-value were influenced by significant interactions for cultivar x level of oat flour as seen in Tables 105, 106 and 107. Figures 29a-c illustrate the interactions for the color parameters of the cookies. Substitution of 30 percent 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.

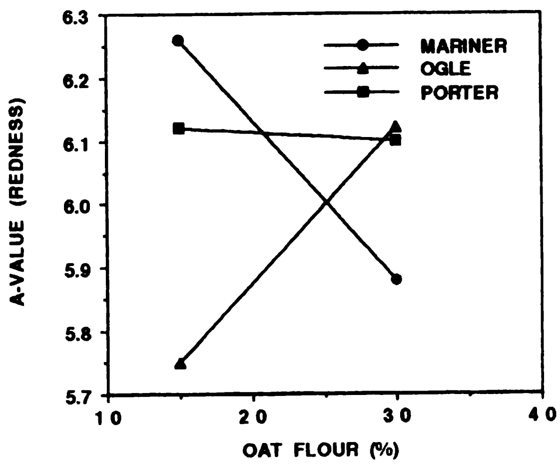
Oat-wheat composite flour	Oat flour (%)	Alkaline Water Retention[1] (%)
Hammer milled		
Mariner-Caldwell	30	74.58 ± 0.71
	15	63.05 ± 1.17
Ogle-Caldwell	30	75.98 ± 0.25
	15	65.46 ± 0.87
Porter-Caldwell	30	77.08 ± 0.18
	15	66.15 ± 0.77
Roller milled		
Mariner-Caldwell	30	83.06 ± 2.00
	15	70.12 ± 2.07
Ogle-Caldwell	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

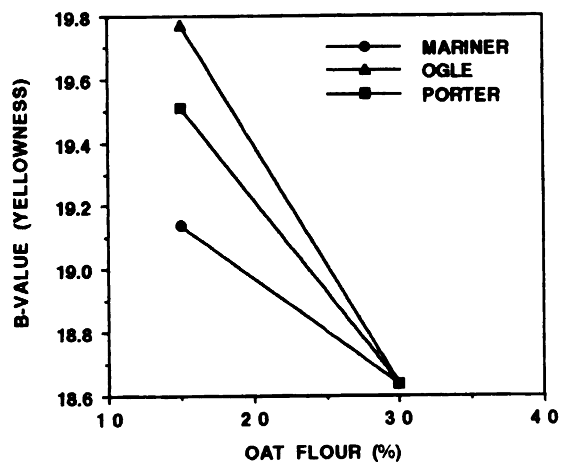
Figure 29. Interaction of Oat Cultivar x Level of Hammer and Roller Milled Groat Flour Substitution for Hunter Color Difference Values of Cookie Surface Color



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

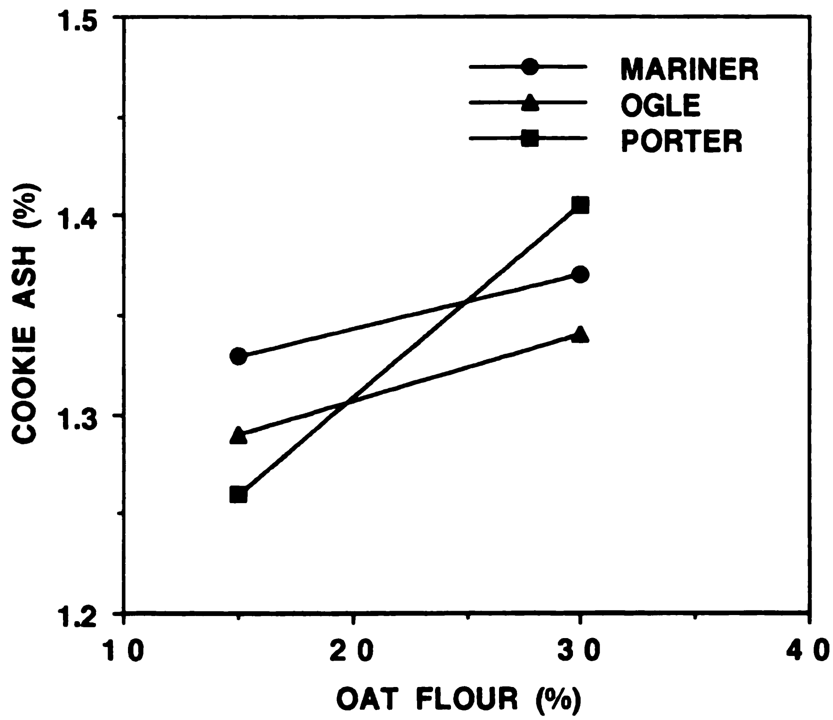


Figure 30. Interaction of Oat Cultivar x Level of Hammer and Roller Milled Groat Flour Substitution for Ash Content of Sugar-Snap Cookies

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.

Shear compression and breaking strength:

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.

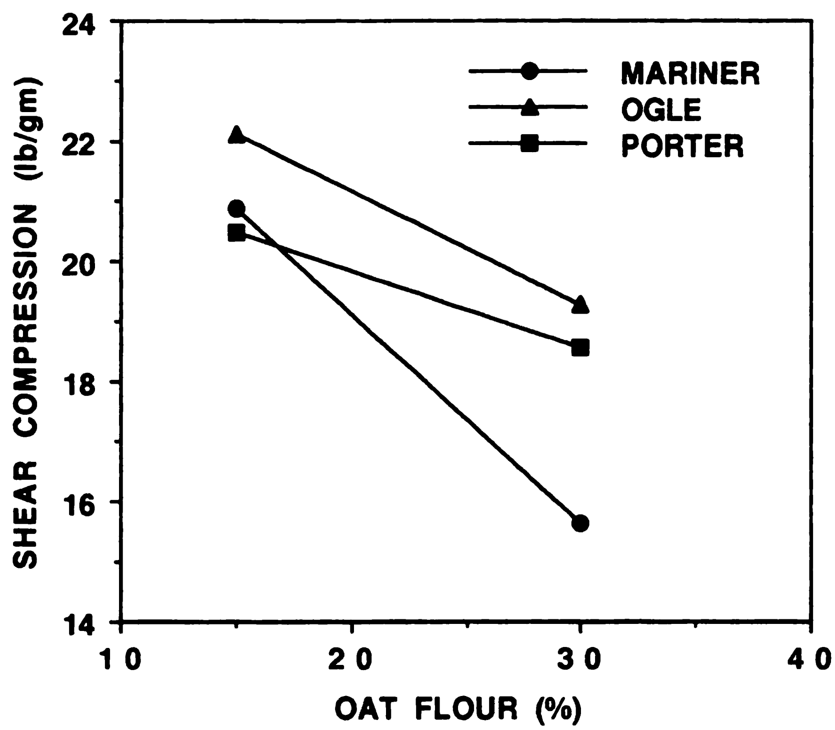


Figure 31. Interaction of oat cultivar x level of hammer and roller milled groat flour substitution for cookie shear compression

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	$16.80^{ac} \pm 3.01$	$10.64^{a} \pm 0.27$
	15	$20.98^{ab} \pm 0.22$	$12.96^{a} \pm 1.88$
Ogle-Caldwell	30	$18.87^{ac} \pm 0.71$	$10.01^{a} \pm 1.82$
	15	$21.85^{ab} \pm 1.07$	$12.21^{a} \pm 1.09$
Porter-Caldwell	30	$19.39^{ac} \pm 0.26$	$10.54^{a} \pm 0.42$
	15	$20.32^{ab} \pm 0.07$	$10.82^{a} \pm 0.12$
Flakes			
Mariner-Caldwell	30	$17.36^{ac} \pm 1.08$	$10.72^{a} \pm 3.50$
	15	$20.25^{ab} \pm 0.44$	$12.16^{a} \pm 1.46$
Ogle-Caldwell	30	$17.84^{ac} \pm 2.02$	$13.25^{a} \pm 0.35$
	15	$20.95^{ab} \pm 0.65$	$9.78^{a} \pm 0.89$
Porter-Caldwell	30	$16.86^{ac} \pm 1.06$	$11.47^{a} \pm 0.31$
	15	$20.69^{ab} \pm 3.16$	$14.26^{a} \pm 0.01$
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:

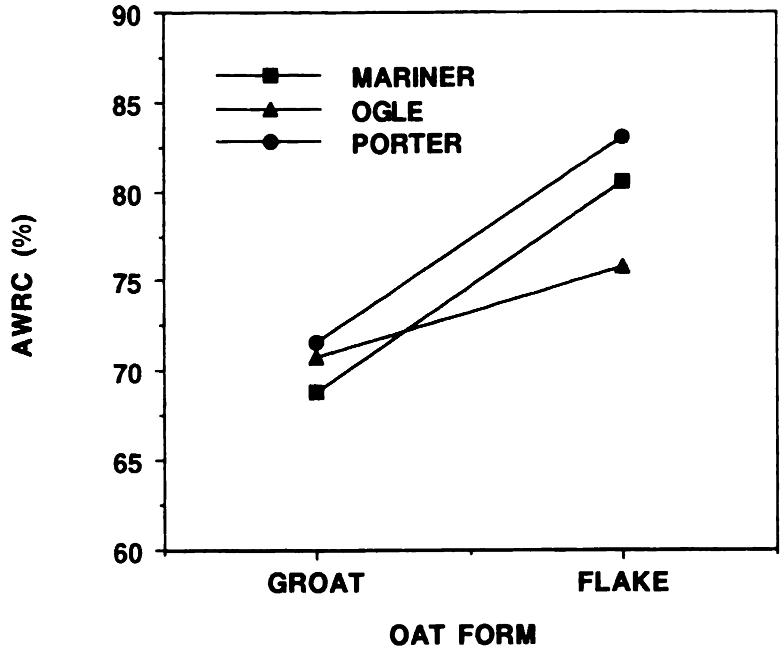
Analysis of variance means for the main effects were influenced by significant interactions between oat cultivar x form and oat cultivar x level as seen in Table 115. The interactions are illustrated in Figure 32a and b. The lines are not parallel and indicate a difference in the level of response to 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.

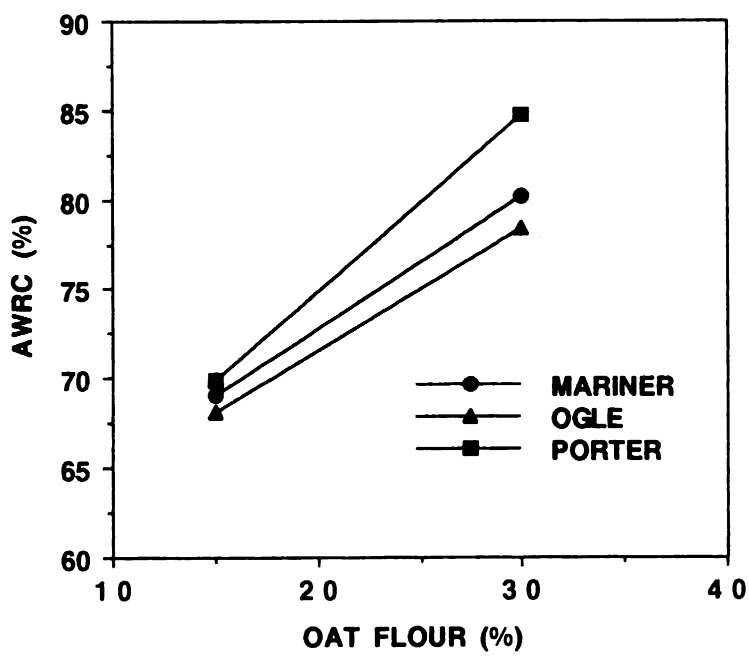
Oat-wheat composite flour	Oat flour (%)	Cookie diameter[1] (cm)	Top Grain Score
Groats			
Mariner-Caldwell	30	17.68 ± 0.26	8.7
	15	17.14 ± 0.03	8.0
Ogle-Caldwell	30	17.81 ± 0.01	8.5
	15	17.41 ± 0.05	8.3
Porter-Caldwell	30	17.88 ± 0.05	9.0
	15	17.72 ± 0.18	8.2
Flakes			
Mariner-Caldwell	30	17.13 ± 0.02	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

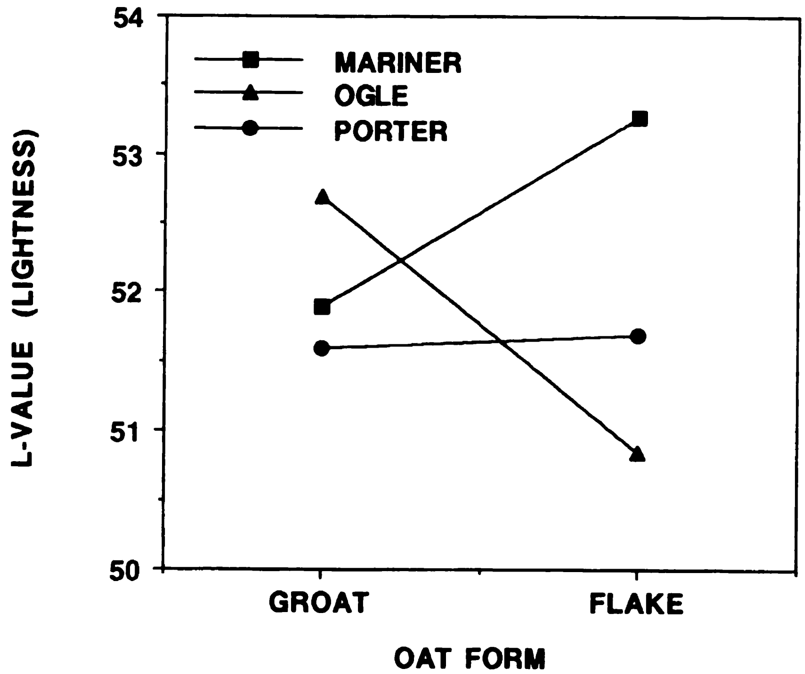
Chang and Morris (1990) heat processed (autoclaved for 15 minutes at 121°C) samples of apple fiber, corn fiber, oat bran and soy fiber and then evaluated physical structural changes in the fibers with a Scanning Electron Microscope. The results were an increase in the surface area of the fibers due to 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:

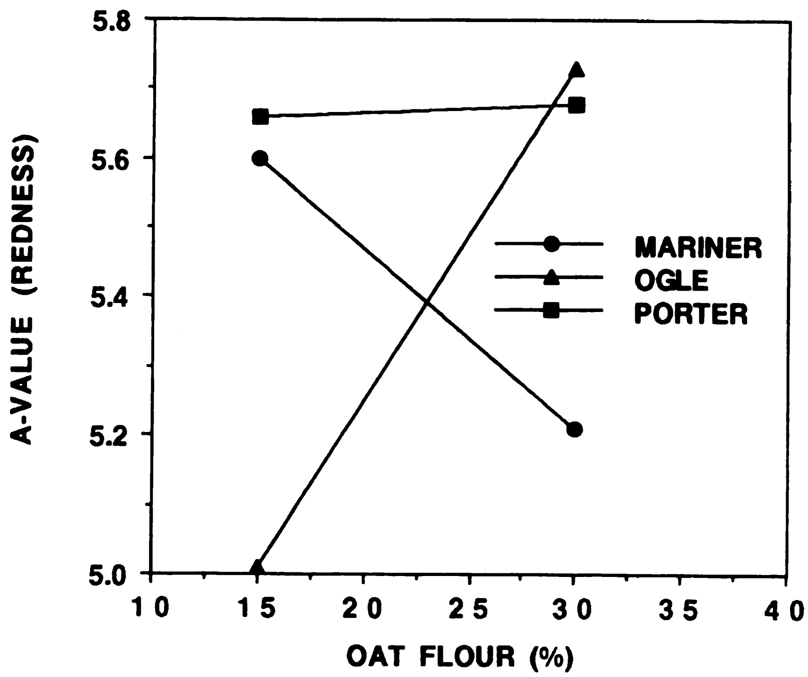
Analysis of variance means were influenced by significant interactions between cultivar x form and cultivar x level. There was a highly significant $p<0.001$ interaction between oat cultivar x form for Hunter L-value which is illustrated in Figure 33a. Processing the groats into flakes appeared to have 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

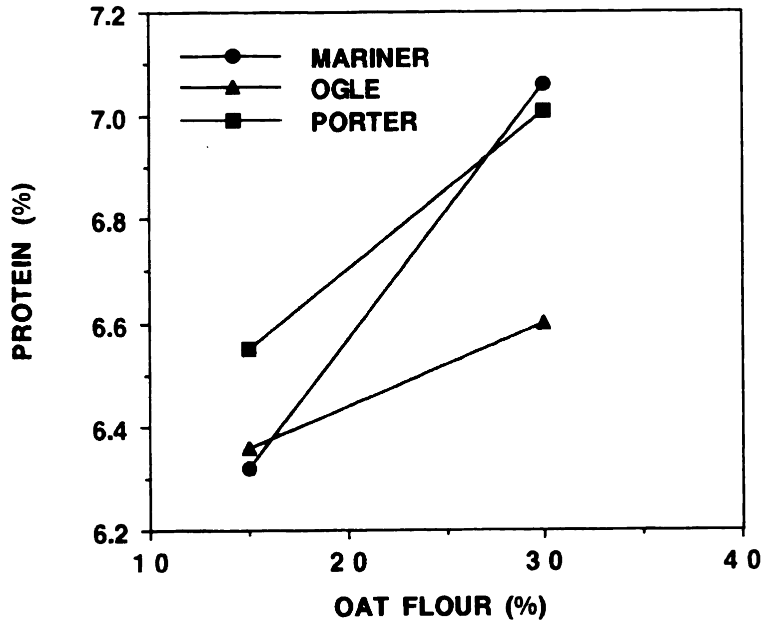
composite flours. With the exception of sugar snap cookies made from 15% Porter groat flour, cookies made from groat composite flours had a stronger reddish hue as measured by a-values. Cookies made from 30% composite flours were less yellow than the cookie containing 15% of the same oat cultivar flour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

Cookie Proximate Analyses

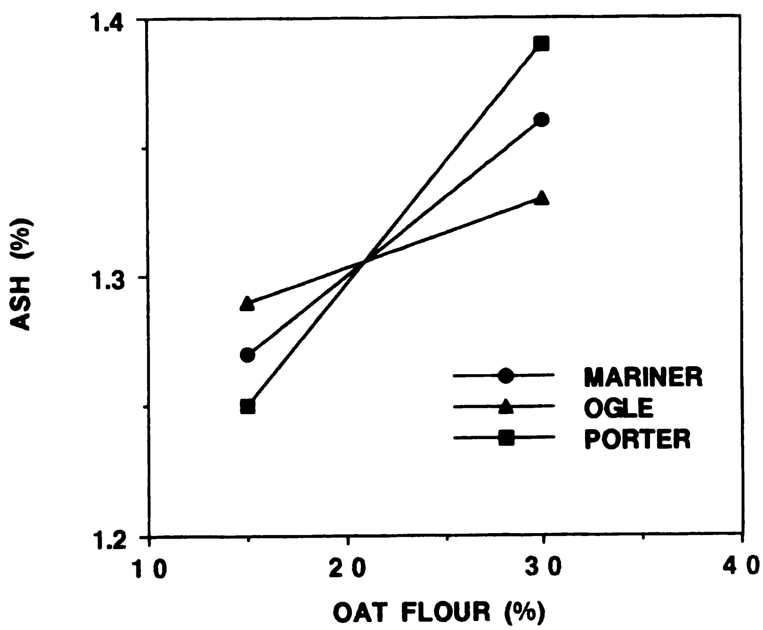
Analysis of variance means were influenced by significant interactions between cultivar x level of oat flour as seen in Tables 119 and 120. The interaction of oat cultivar and level of oat flour was significant for cookie ash content. The interactions for cookie protein and ash content are shown in Figures 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)
<u>Groats</u>				
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
<u>Flakes</u>				
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

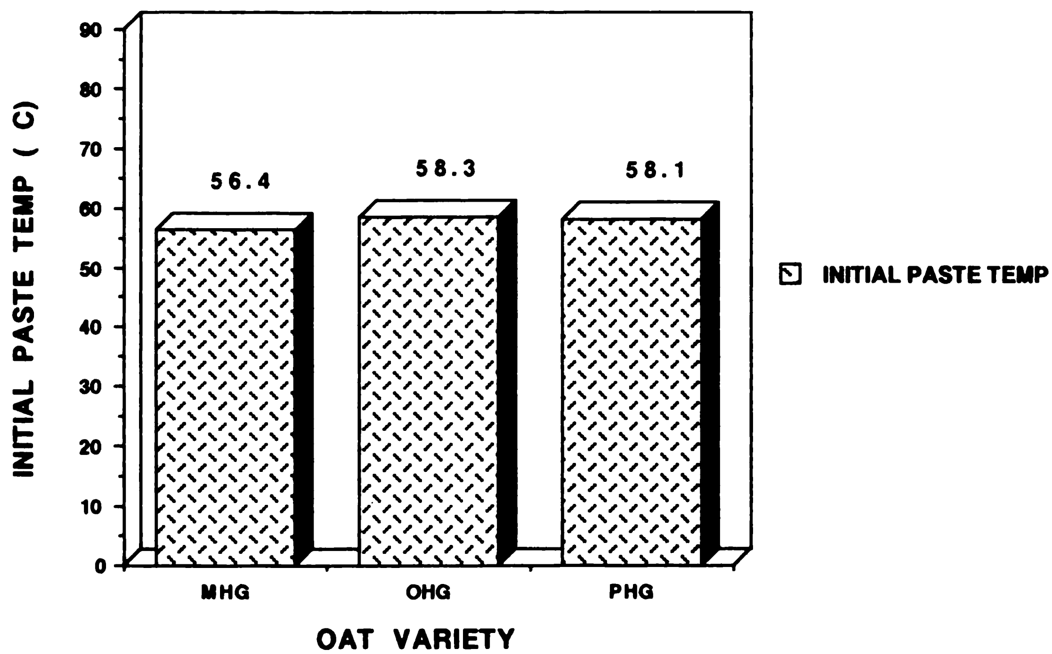
Means in the same main effect having a different superscript are significantly different.

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.

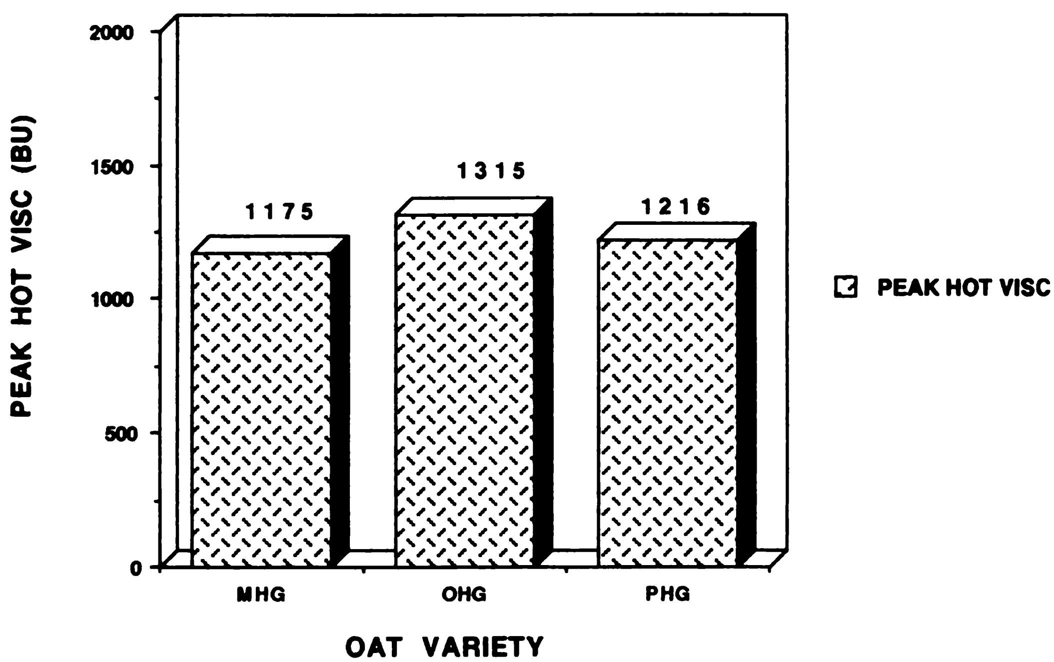
Table 65 also shows that sugar-snap cookies made with composites containing Porter oat flour had a significantly larger mean diameter than cookies made with composites of the other two oat cultivars. There was no significant difference in the diameter of cookies made with Mariner hammer milled groat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

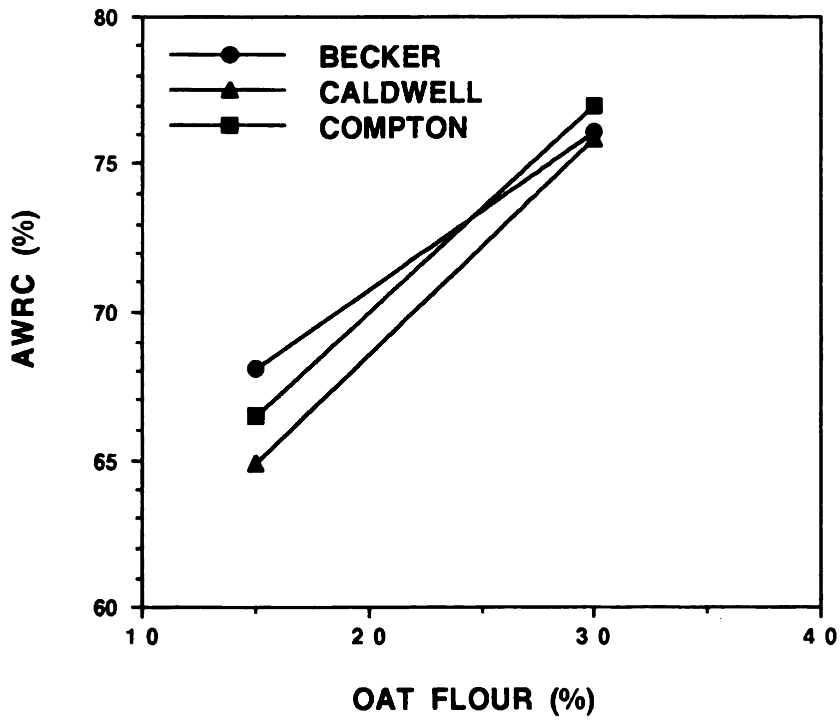


Figure 36. Interaction of Wheat Cultivar and Level of Oat Flour for Alkaline Water Retention Capacity of Composite Flours of Becker, Caldwell and Compton.

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.

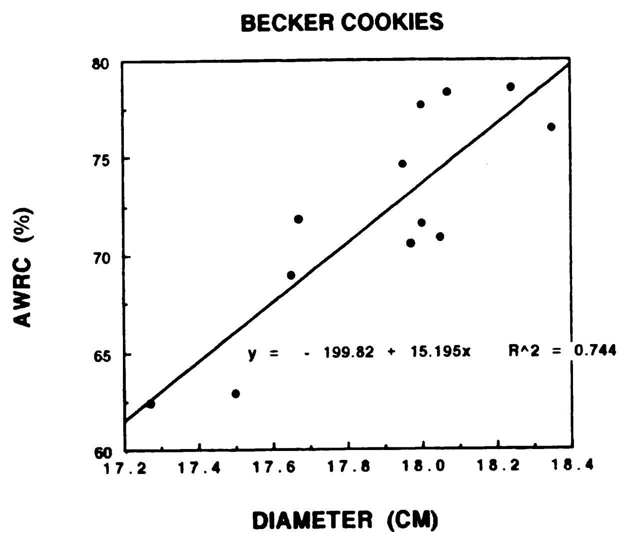
The correlations between cookie diameter and alkaline water retention capacity for the oat-wheat composite flours were all positive with a minimum level of significance of $p<0.06$. Figure 37 illustrates the correlations by wheat cultivar for cookie diameter and alkaline water retention capacity.

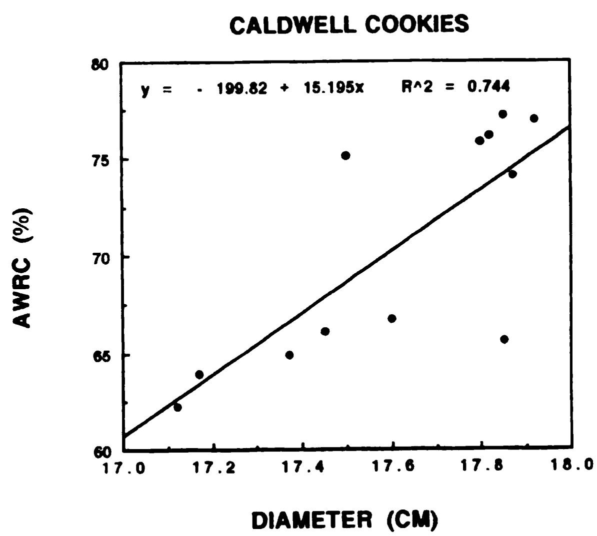
Table 67 shows Porter oat-wheat composite flours had the highest mean alkaline water retention capacity. It was not significantly different from the AWRC of Mariner oat-wheat composite flours at the $p<0.01$ level but it was significantly different at the $p<0.05$ level. The AWRC of Porter composite 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.

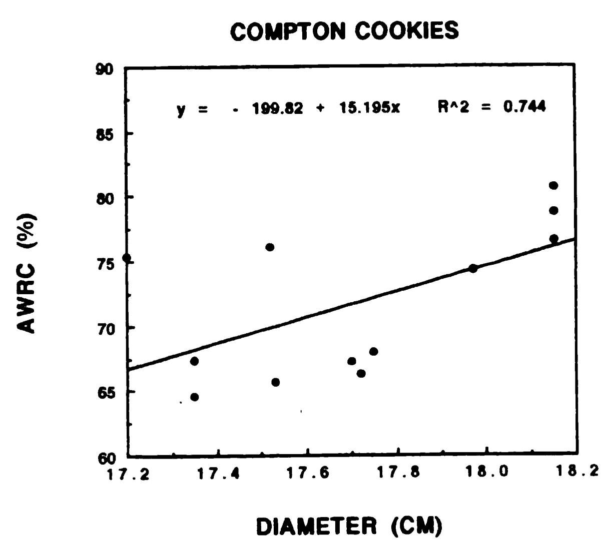
The correlation between cookie diameter of Porter composite cookies and alkaline water retention capacity was $r=0.80$ ($p<0.01$). The correlations for the two other oat flour composites were also positive and were respectively for Mariner $r=0.69$ ($p<0.02$) and for Ogle $r=0.74$ ($p<0.01$).

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
80
75
70
65
60
AWRC (%)
y = - 199.82 + 15.195x R^2 = 0.744
17.2 17.4 17.6 17.8 18.0 18.2 18.4
DIAMETER (CM)


CALDWELL COOKIES
80
75
70
65
60
AWRC (%)
y = - 199.82 + 15.195x R^2 = 0.744
17.0 17.2 17.4 17.6 17.8 18.0
DIAMETER (CM)


COMPTON COOKIES
90
85
80
75
70
65
60
AWRC (%)
y = - 199.82 + 15.195x R^2 = 0.744
17.2 17.4 17.6 17.8 18.0 18.2
DIAMETER (CM)

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

<u>Proximate analyses of cookies:</u>

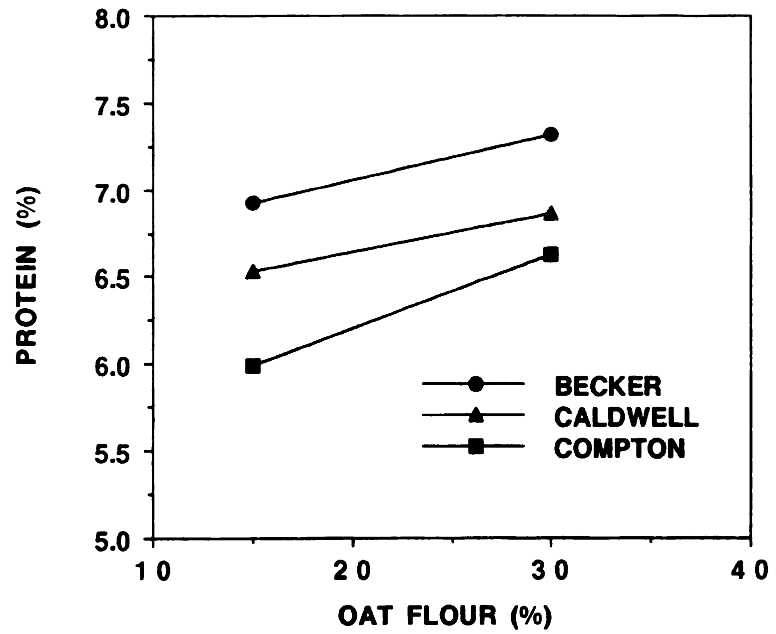
Analysis of variance means for the main effects were influenced by the interaction of wheat cultivar x level of oat flour and oat cultivar x level of oat flour. From Table 130 and Figure 38a it can be seen that the interaction of wheat cultivar x level of oat flour was significant for cookie protein 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.

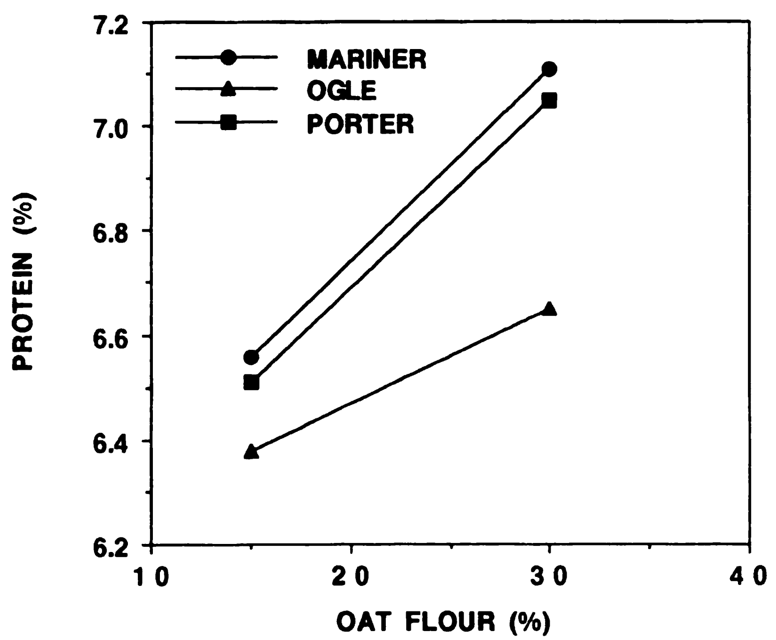
Cookie ash had a significant interaction for wheat cultivar x level of oat flour as shown in Table 131 and illustrated in Figure 39. The steeper slope for cookie ash content of cookies made with Compton composites is due to the fact that Compton contained the highest percent of ash.

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

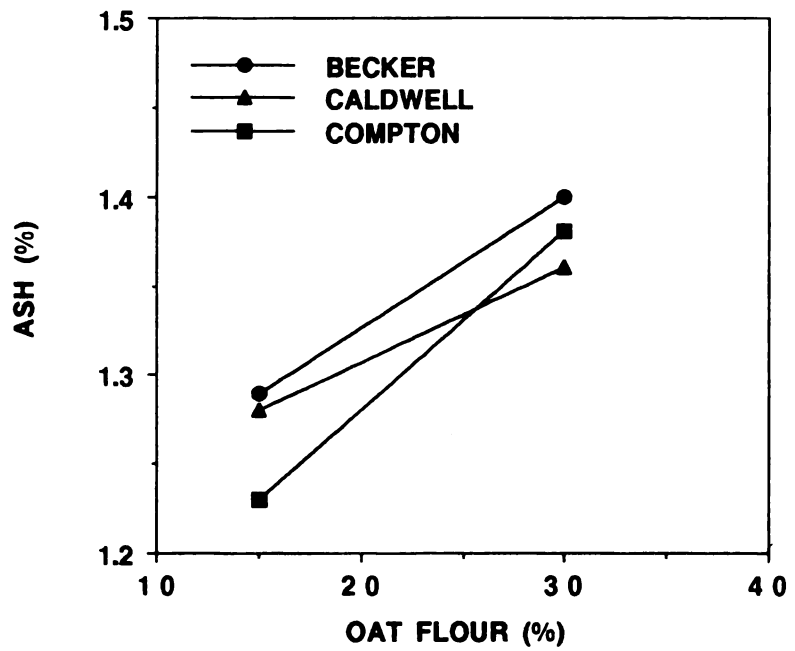


Figure 39. Interaction of Wheat Cultivar and Level of Oat Flour for Cookie Ash Content.

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.

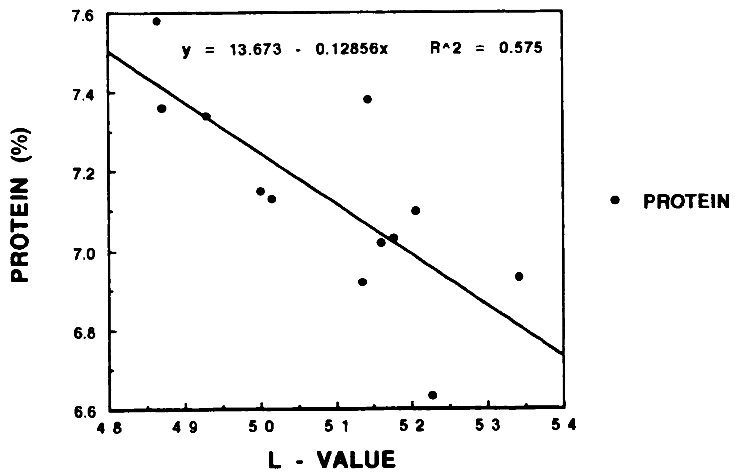
Hunter color values for sugar-snap cookies may have been influenced by composite flour protein content along with other factors. The correlation between L-value and cookie protein content for Becker composite cookies was $r=-0.75$ with $p<0.01$. The correlation for cookies made with Caldwell soft wheat 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.

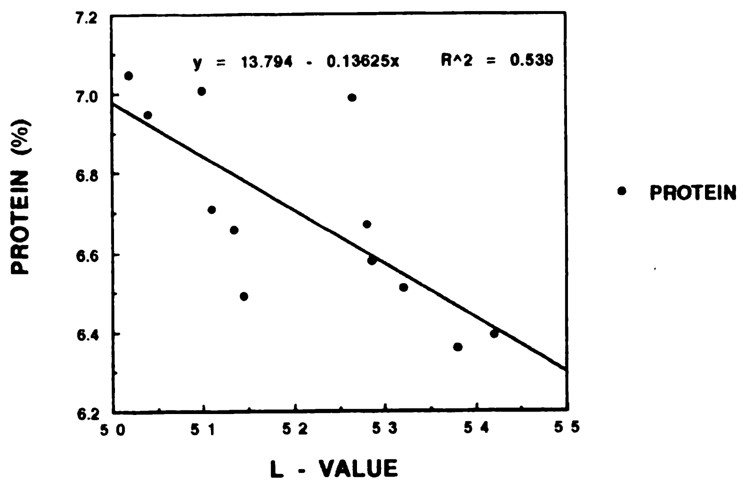
The correlations between protein content and Hunter Color Difference L- and b-values are negative and statistically significant for both levels of hammer milled groat flour substitution. The Pearson correlation coefficients between protein content and L- and b-values for cookies made with 15 percent 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

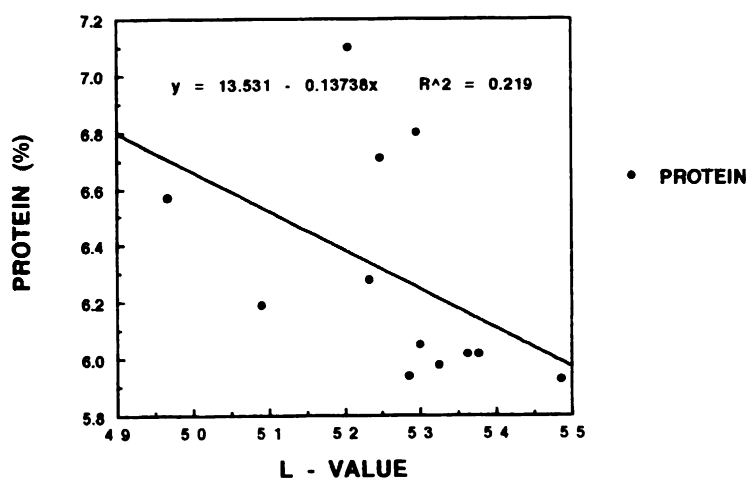
Figure 40. Correlation between Protein Content and Hunter Color Difference L-values for Cookies Made with Composites of Becker, Caldwell and Compton Soft Wheat Flours



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

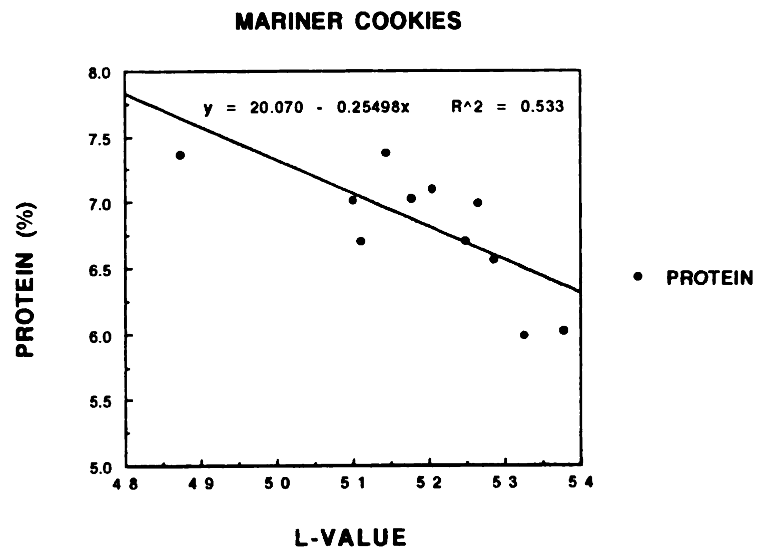


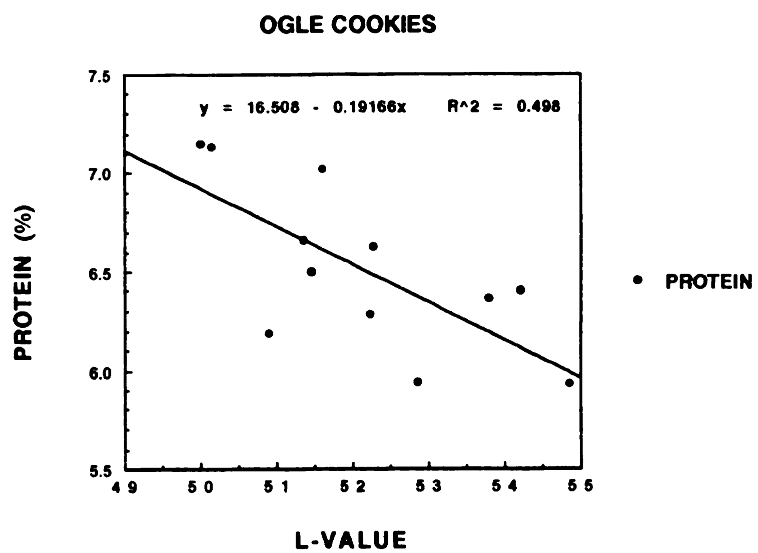
Correlation Between Protein Content and Hunter Color L-value of Caldwell Cookies

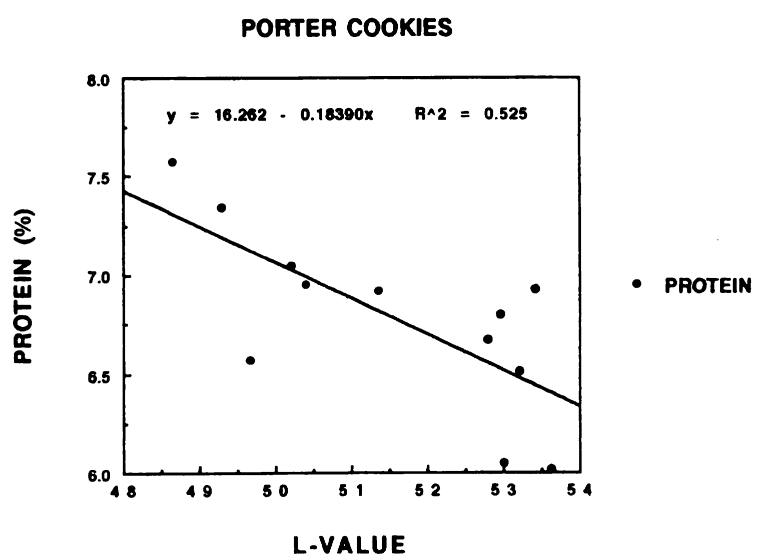


Correlation Between Protein Content and Hunter Color L-value of Compton Cookies

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 $1\text{-}1\frac{1}{2}$ 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.

<u>Effect of Course Oat Flour Fraction</u>

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
C x F	2	0.07	0.00	3.95	0.0319
C x M	2	0.01	0.01	0.80	0.4621
F x M	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
C x F	2	0.03	0.01	1.48	0.2468
C x M	2	0.03	0.01	1.51	0.2386
F x M	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
C x F	2	0.49	0.25	2.42	0.1087
C x M	2	0.20	0.01	0.99	0.3844
F x M	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
C x F	2	0.09	0.05	2.39	0.1117
C x M	2	0.04	0.02	0.93	0.4072
F x M	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
C x F	2	141.65	53.14	1.34	0.2790
C x M	2	383.58	191.79	3.63	0.0406
F x M	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
C x F	2	8.48	0.08	0.37	0.6998
C x M	2	31.96	0.13	1.38	0.2836
F x M	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
CxF	2	0.83	0.41	0.10	0.9051
CxM	2	51.49	25.74	6.25	0.0115
FxM	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
CxF	2	14893.58	7446.79	1.23	0.3230
CxM	2	10902.08	5451.04	0.90	0.4297
FxM	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
CxF	2	10920.25	5460.12	5.70	0.0155
CxM	2	346.08	173.04	0.18	0.8367
FxM	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

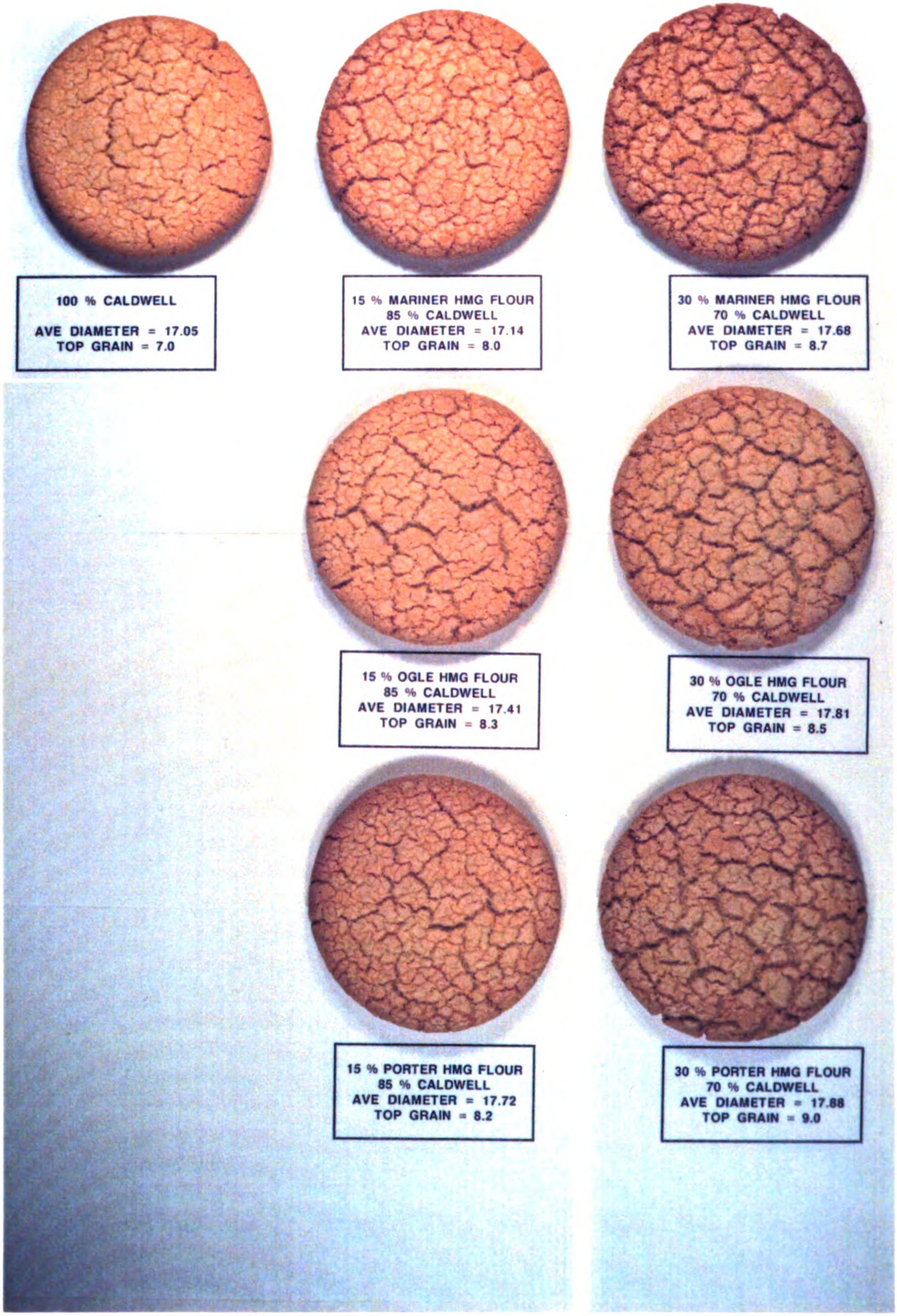

100 % CALDWELL
AVE DIAMETER = 17.05
TOP GRAIN = 7.0
15 % MARINER HMG FLOUR
85 % CALDWELL
AVE DIAMETER = 17.14
TOP GRAIN = 8.0
30 % MARINER HMG FLOUR
70 % CALDWELL
AVE DIAMETER = 17.68
TOP GRAIN = 8.7
15 % OGLE HMG FLOUR
85 % CALDWELL
AVE DIAMETER = 17.41
TOP GRAIN = 8.3
30 % OGLE HMG FLOUR
70 % CALDWELL
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

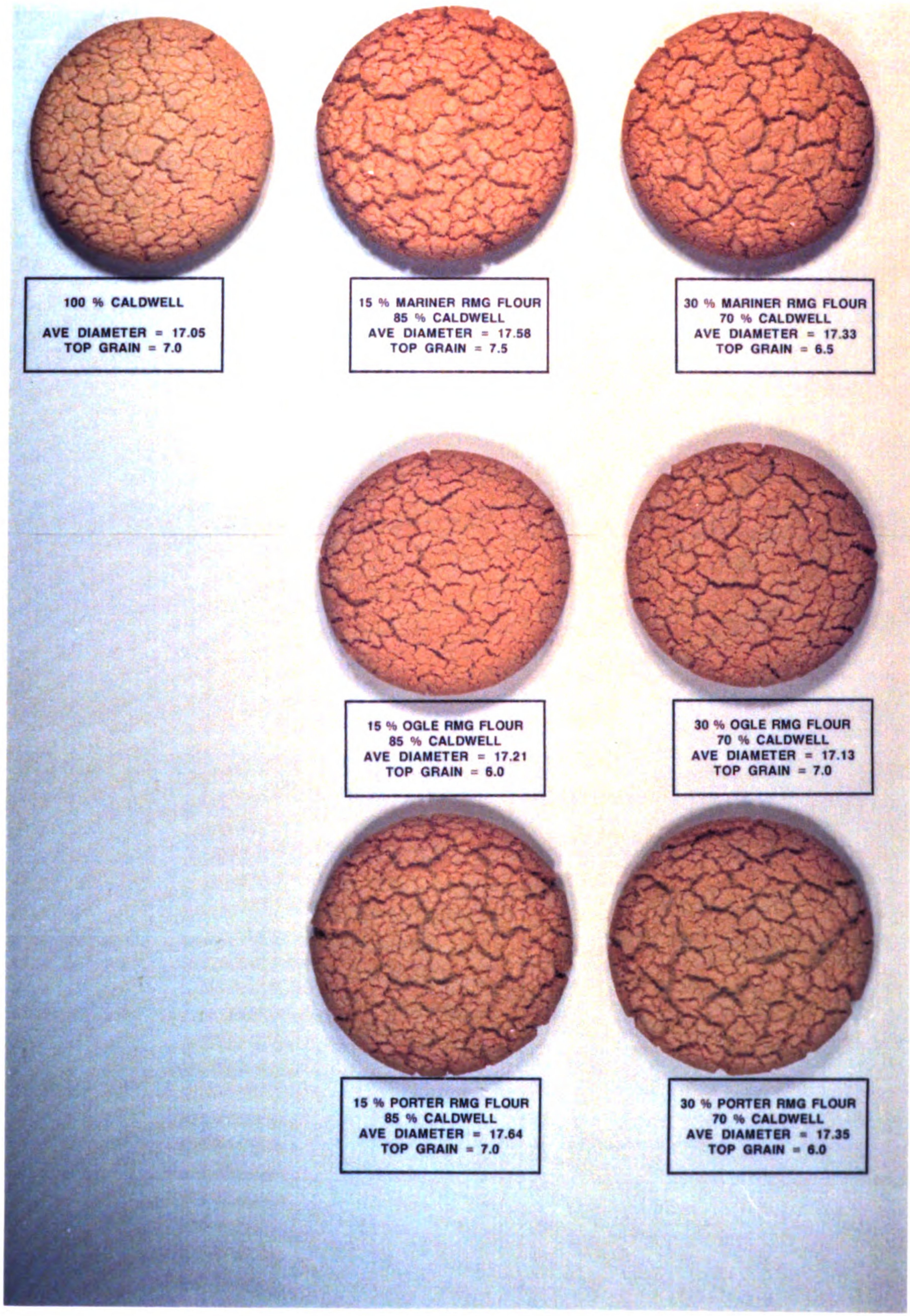

100 % CALDWELL
AVE DIAMETER = 17.05
TOP GRAIN = 7.0
15 % MARINER RMG FLOUR
85 % CALDWELL
AVE DIAMETER = 17.58
TOP GRAIN = 7.5
30 % MARINER RMG FLOUR
70 % CALDWELL
AVE DIAMETER = 17.33
TOP GRAIN = 6.5
15 % OGLE RMG FLOUR
85 % CALDWELL
AVE DIAMETER = 17.21
TOP GRAIN = 6.0
30 % OGLE RMG FLOUR
70 % CALDWELL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

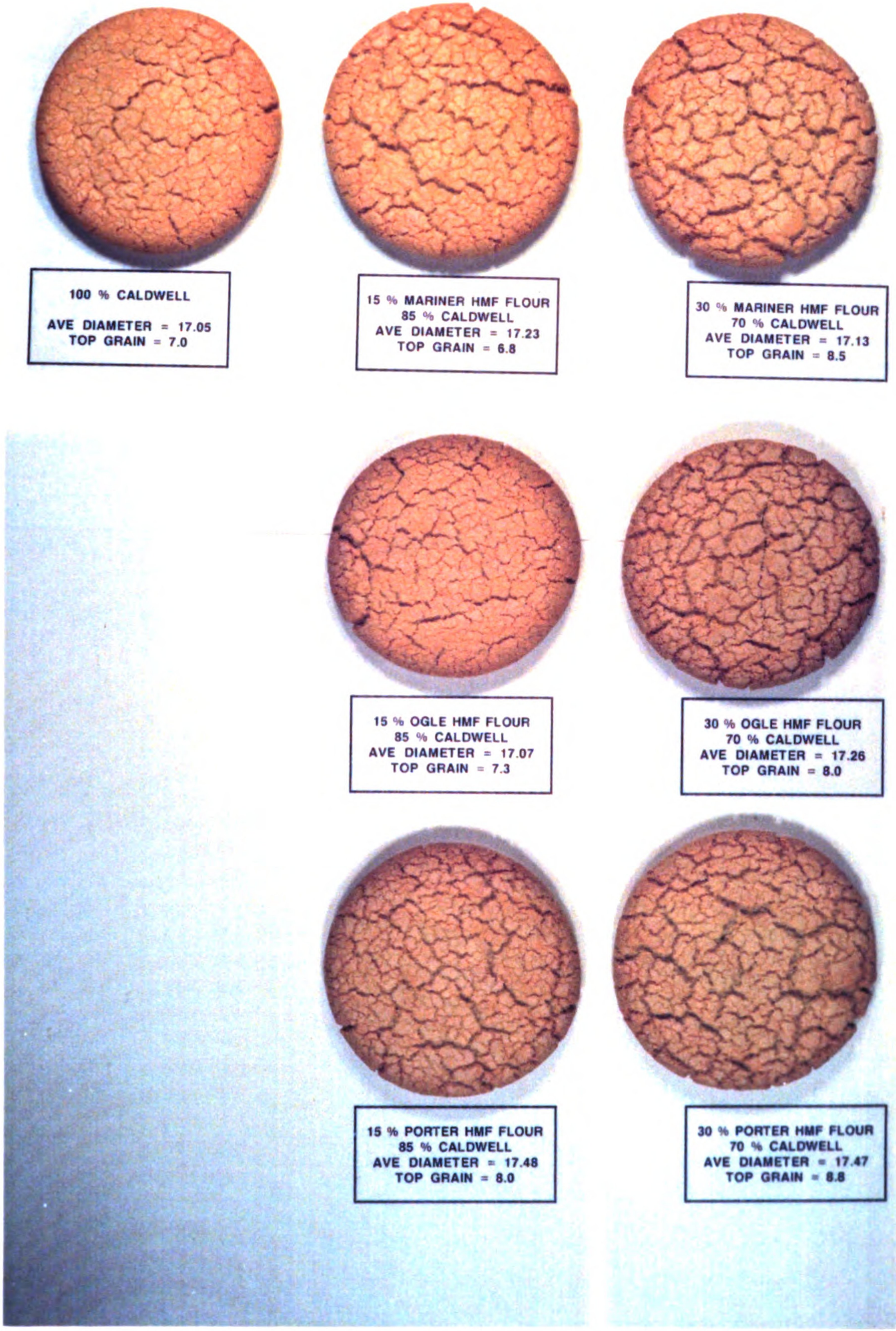

100 % CALDWELL
AVE DIAMETER = 17.05
TOP GRAIN = 7.0
15 % MARINER HMF FLOUR
85 % CALDWELL
AVE DIAMETER = 17.23
TOP GRAIN = 6.8
30 % MARINER HMF FLOUR
70 % CALDWELL
AVE DIAMETER = 17.13
TOP GRAIN = 8.5
15 % OGLE HMF FLOUR
85 % CALDWELL
AVE DIAMETER = 17.07
TOP GRAIN = 7.3
30 % OGLE HMF FLOUR
70 % CALDWELL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

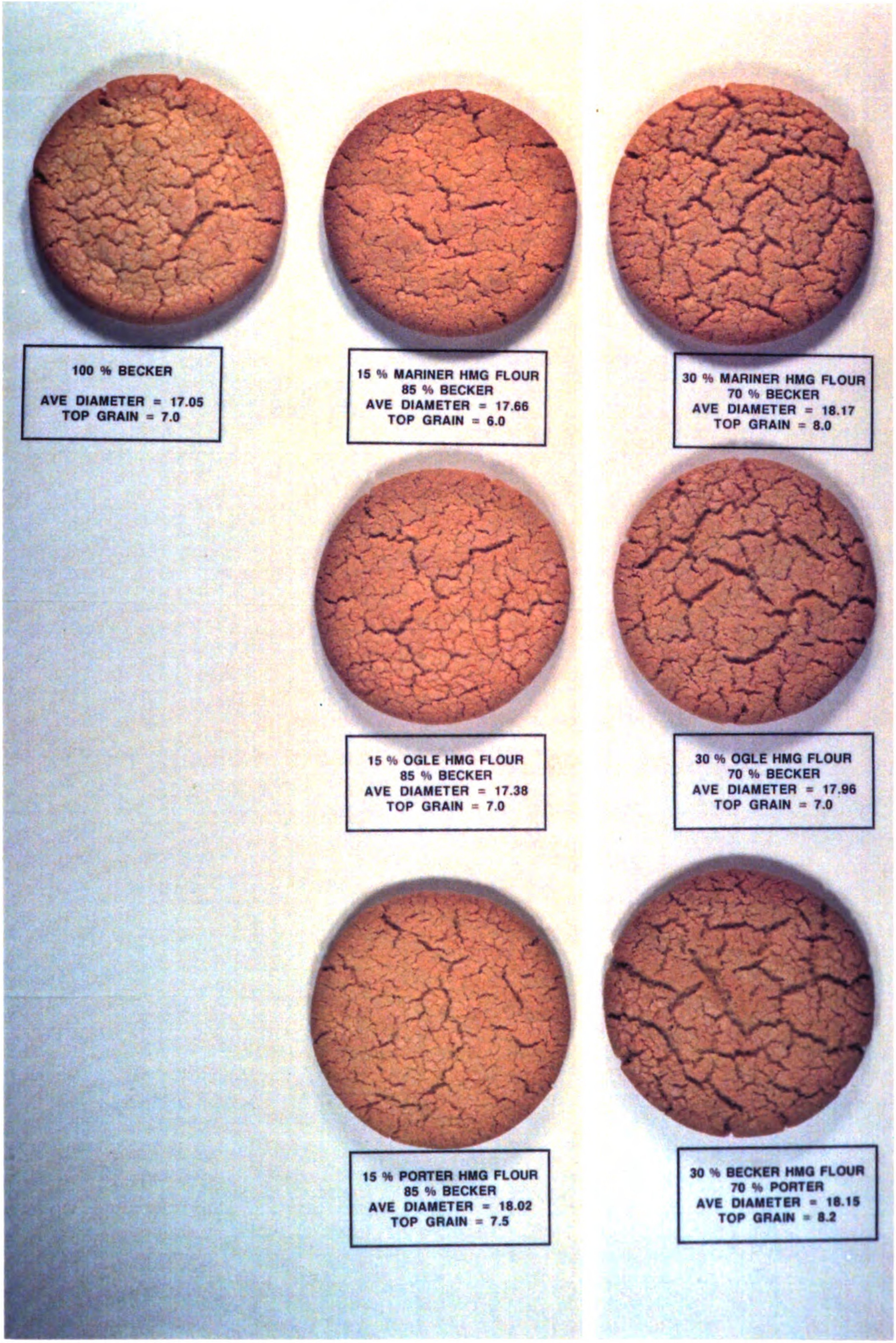

100 % BECKER
AVE DIAMETER = 17.05
TOP GRAIN = 7.0
15 % MARINER HMG FLOUR
85 % BECKER
AVE DIAMETER = 17.66
TOP GRAIN = 6.0
30 % MARINER HMG FLOUR
70 % BECKER
AVE DIAMETER = 18.17
TOP GRAIN = 8.0
15 % OGLE HMG FLOUR
85 % BECKER
AVE DIAMETER = 17.38
TOP GRAIN = 7.0
30 % OGLE HMG FLOUR
70 % BECKER
AVE DIAMETER = 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

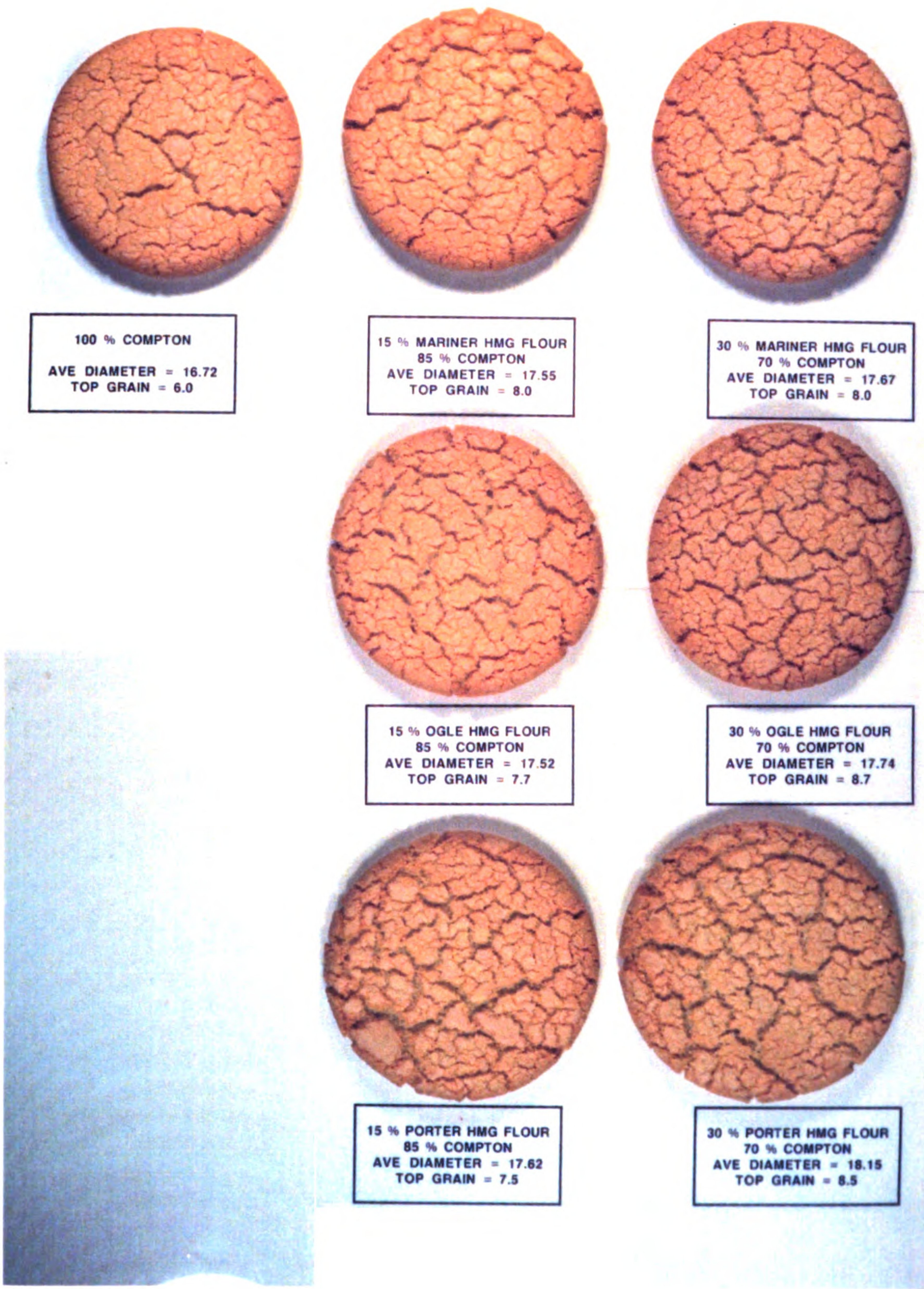
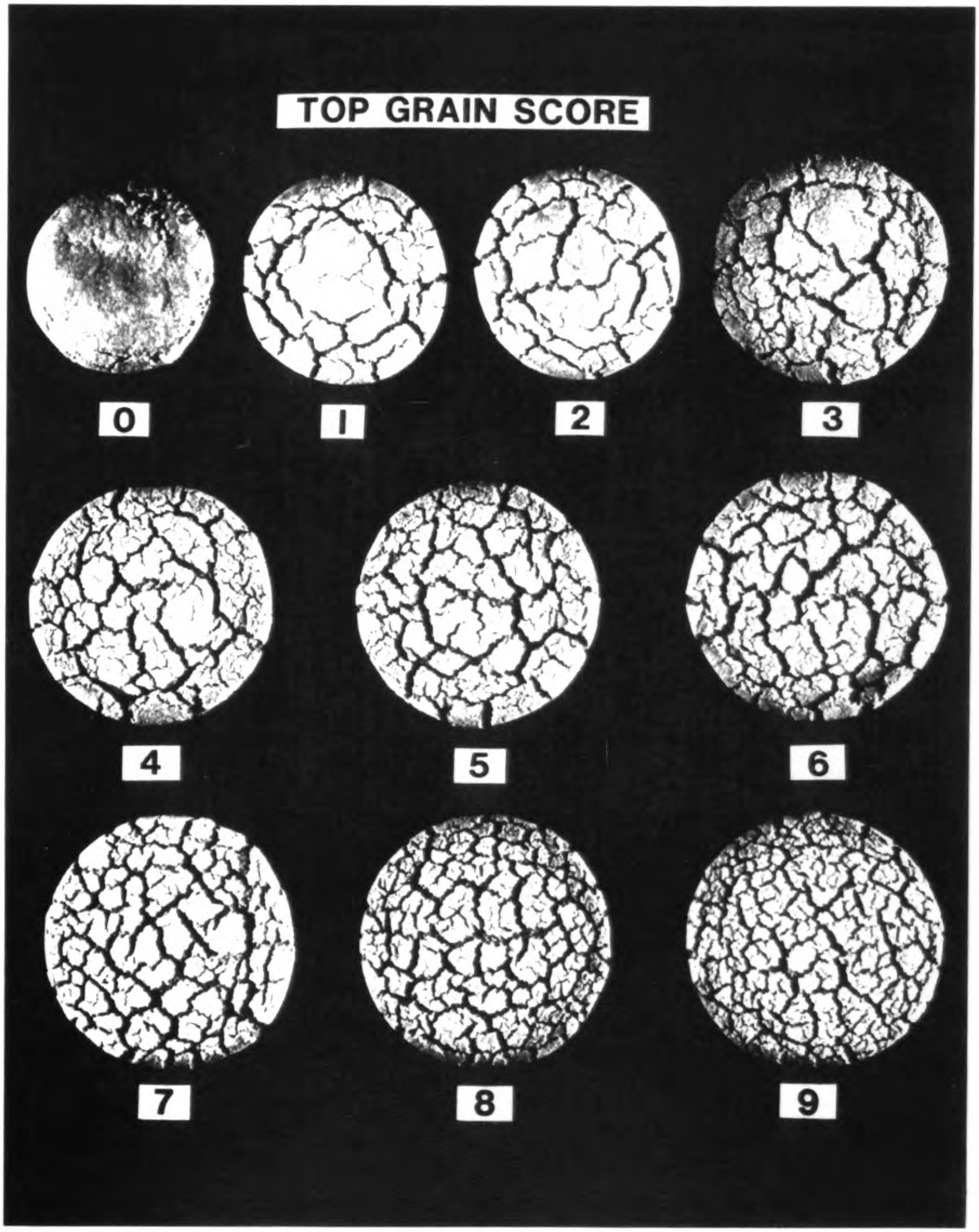

100 % COMPTON
AVE DIAMETER = 16.72
TOP GRAIN = 6.0
15 % MARINER HMG FLOUR
85 % COMPTON
AVE DIAMETER = 17.55
TOP GRAIN = 8.0
30 % MARINER HMG FLOUR
70 % COMPTON
AVE DIAMETER = 17.67
TOP GRAIN = 8.0
15 % OGLE HMG FLOUR
85 % COMPTON
AVE DIAMETER = 17.52
TOP GRAIN = 7.7
30 % OGLE HMG FLOUR
70 % COMPTON
AVE 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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