



A study of adapting soft wheat evaluation procedures to barley
by Donald Lawrence Sorum

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE
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Abstract:

The milling, baking, alkaline water retention, lysine amount in the milling fractions, and consumer reaction to barley flour cookies and biscuits were studied in Hiproly, Hiproly Normal, Compana, and Washonupana, four barley cultivars.

Hiproly had higher flour yields, lysine, alkaline water retention capacity (AWRC) than Hiproly Normal. Hiproly Normal had larger cookies and biscuits, and a more favorable taste rating for cookies and biscuits than Hiproly.

Washonupana had smaller flour yields, cookies, biscuits, similar lysine, a lower cookie taste panel score, a higher AWRC and a higher biscuit flavor panel score than Compana.

The cookie spreads, biscuit volumes, cookie consumer rating were higher for Compana than for Hiproly. Hiproly had greater flour extraction, lysine, AWRC, and a higher biscuit consumer rating than Compana.

Compana and Hiproly Normal had similar cookie spreads and biscuit volumes. Hiproly Normal had higher lysine, AWRC, consumer rating of its cookies and biscuits, and lower flour yield than Compana.

Barley can be milled using an Allis Experimental Mill. AWRC was able to predict the cookie quality of these four barley varieties.

The cookie and biscuit bake tests were sensitive to differences in the barley cultivars. Hiproly had a different milling fraction lysine distribution than the other three cultivars. Barley flour cookies were acceptable but the barley flour biscuits were not acceptable to the consumer taste panels.

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TO BARLEY

by

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A thesis submitted in partial fulfillment
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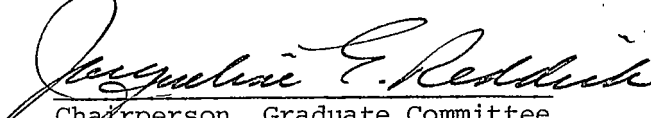
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TABLE OF CONTENTS

	<u>Page</u>
VITA	ii
ACKNOWLEDGMENTS	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	vi
LIST OF FIGURES	viii
ABSTRACT	ix
INTRODUCTION	1
REVIEW OF LITERATURE	3
Milling	4
Lysine Distribution in the Milling Fractions	7
Bake	10
Cookie Bake	10
Biscuits	14
Alkaline Water Retention Capacity Test	15
Taste Panel	18
MATERIALS AND METHODS	19
RESULTS	26
Milling	26
Lysine and Protein	32
Baking Data	38
Cookies	38
Biscuits	43
Alkaline Water Retention Capacity Test	45
Cookie Taste Panel	49
Biscuit Taste Panel	49

	<u>Page</u>
DISCUSSION	51
Milling	51
Protein and Lysine	53
Baking Results	56
Cookie Bake	56
Biscuit Bake	57
Alkaline Water Retention Capacity Test	59
Taste Panel	61
CONCLUSIONS, SUMMARY, AND RECOMMENDATIONS	62
Conclusions	62
Summary	66
Recommendations	68
LITERATURE CITED	69
APPENDIX	76

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1. Analysis of Variance - Source Table	27
2. Evaluation of Flour Extraction Means across Treatments and Cultivars	28
3. Effect of Cultivar on Fractional Ash Means Taken across all Treatments and Replications	29
4. Cultivar and Temper Treatment Effects on Fractional Ash Means Taken across all Replications	31
5. Cultivar and Fraction Protein Means Taken across over all Temper Treatments and Replications	33
6. Cultivar, Temper Treatment, and Fraction Protein Means	35
7. Fractional Lysine Means showing Cultivar Effects taken over all Treatments and Replications	36
8. The Effect of Cultivar and Treatment on Cookie Spread Means taken across all Replications	40
9. Taste Panel Evaluation of Sugar Snap Cookie Means made from the Flour of Four Barley Cultivars with Two Temper Treatments and across all Replications with a Soft Wheat Flour Control	41
10. Treatment and Cultivar Effects on Biscuit Specific Volume taken over all Replications	44
11. Taste Panel Evaluation of Self-rising Biscuit Means made from the Flour of Four Barley Cultivars, Two Temper Treatments, and across all Replications . . .	46

<u>Table</u>	<u>Page</u>
12. Alkaline Water Retention Capacity Test - Means showing Cultivar and Treatment Effects taken across all Replications	48

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
I.	Allis-Chalmers Experimental Mill Flow Diagram	21
II.	Cookies prepared from Barley Flour and Soft Wheat Flour	42
III.	Biscuits prepared from Barley Flour and Soft Wheat Flour	47

ABSTRACT

The milling, baking, alkaline water retention, lysine amount in the milling fractions, and consumer reaction to barley flour cookies and biscuits were studied in Hiproly, Hiproly Normal, Compana, and Washonupana, four barley cultivars.

Hiproly had higher flour yields, lysine, alkaline water retention capacity (AWRC) than Hiproly Normal. Hiproly Normal had larger cookies and biscuits, and a more favorable taste rating for cookies and biscuits than Hiproly.

Washonupana had smaller flour yields, cookies, biscuits, similar lysine, a lower cookie taste panel score, a higher AWRC and a higher biscuit flavor panel score than Compana.

The cookie spreads, biscuit volumes, cookie consumer rating were higher for Compana than for Hiproly. Hiproly had greater flour extraction, lysine, AWRC, and a higher biscuit consumer rating than Compana.

Compana and Hiproly Normal had similar cookie spreads and biscuit volumes. Hiproly Normal had higher lysine, AWRC, consumer rating of its cookies and biscuits, and lower flour yield than Compana.

Barley can be milled using an Allis Experimental Mill. AWRC was able to predict the cookie quality of these four barley varieties. The cookie and biscuit bake tests were sensitive to differences in the barley cultivars. Hiproly had a different milling fraction lysine distribution than the other three cultivars. Barley flour cookies were acceptable but the barley flour biscuits were not acceptable to the consumer taste panels.

INTRODUCTION

In the world today, approximately one-half of the existing population has survived a period of serious nutritional deprivation during childhood and more than half of all the children in the world are "at risk" from serious effects of malnutrition (Manocha, 1972). This malnutrition is caused primarily by lack of protein and carbohydrates that can be raised in quantity by the poor, rural agricultural populations of the underdeveloped nations. In these countries, improvement in the amino acid balance of cereal grains can materially improve the diets and the health of a vast number of people.

Of the five major cereals, only barley, sorghum, and corn have been grown with much higher levels of lysine (Mertz, 1964; Ingverson, 1972; Axtell, 1973). These cereals can by genetic manipulation be grown with higher lysine content. Lysine in cereal grains is the limiting amino acid and its level in food may limit the ability of the body to manufacture protein. The body can only manufacture protein in the amount that is determined by the essential amino acids present in the least amount. Increasing the ability of the body to utilize the protein of the cereal grains can be accomplished by increasing the lysine content.

Barley is well suited for semi-arid regions of the world, such as Montana. The best growing conditions for barley include growing temperatures of 70°F or less during daylight hours; precipitation of less

than thirty-five inches per year, and relative humidity of less than 50 percent (Matz, 1959). The barley plant is considered to be the most tolerant of the cereals to soil salinity and alkalinity (Leonard, 1963). Barley can be used to provide food from marginal areas that would not be normally used for crop production.

Barley is grown in most of the underdeveloped nations of the world. Countries such as India, Iraq, Pakistan, Turkey, and Morocco do incorporate some barley into their diets. These countries also have modern roller mills that mill wheat flour.

Milling barley into flour using the roller milling process in these countries could supply a cheaper, more nutritious alternative to the existing wheat flour in some food applications. This would aid in conserving the foreign currency reserves of these underdeveloped countries.

This thesis is concerned with the answers to five principle questions concerning barley. These questions are:

- (1) Can barley be experimentally milled on an Allis mill?
- (2) Where is the lysine found in the milling fractions?
- (3) Is it possible to develop a test that will predict, or indicate, baking quality of barley flour?
- (4) Will the biscuit, or cookie bake, be sensitive to the differences among cultivars of barley?
- (5) Can acceptable cookies and/or biscuits be baked using barley flours?

REVIEW OF LITERATURE

Civilization from time immemorial has relied on plants and animals to feed its hungry masses. As man has become more proficient at raising food and controlling the death rate of his communities, his numbers on this small planet have grown to a point where increasing numbers of people find themselves living at a subsistence level. Corn, barley, rice, wheat, and sorghum form the greatest reserves of edible protein and carbohydrate. These cereals all lack the lysine necessary to give the cereal protein the biological value of milk, eggs, or meat. The research of Mertz et al. (1964), Ingverson (1972), and Axtell (1973) has shown that corn, barley, and sorghum can be grown with much higher levels of lysine. Thus, corn, barley, and sorghum can approach the biological value of meat, milk, and eggs in the human diet.

The goal of barley research in the past has been the development of cultivars with improved agronomic characteristics but with limited regard for the human food requirement of the grain. Information is needed on the roller milling, water absorption, color, and baking properties of barley as it relates to the production of a human food product. The most efficient utilization of barley as a human food can be accomplished by objectively establishing these attributes and matching these with appropriate food formulas. Suitability of barley for specific purposes depends primarily on the characteristics of the starch and the protein.

Milling

Pomeranz and associates (1971) describe a method for milling barley and then air-classifying the mill streams. Using this method, they were able to achieve an extraction of 65 percent. The barley was tempered with 0.5 percent water. The red dog and shorts were reground on an alpine mill at 15,000 rpm to reduce particle size.

Conventional roller milling yields four major streams: 1) flour, 2) shorts, 3) tailings flour, and 4) bran. Flour comes mainly from the endosperm; shorts and tailings flour represent a mixture of aleurone, pericarp, some germ, and starch endosperm; while bran is principally hulls and pericarp. Robbins (1971) showed that the barley flour of 65 percent extraction and tailings contained a higher percentage of protein than the whole kernel. The flour had some tailing flour added to attain 65 percent extraction. This could explain why the flour protein was higher than the whole grain protein.

Wheat cultivars differ in vitreousness and hardness of their mature air-dried endosperm (Barlow, 1974). Similarly, barley cultivars differ in endosperm hardness. Hiproly was harder and had a "flinty" cut surface when compared to Hiproly Normal (Munck, 1972). Munck (1970) reported that high lysine varieties have starch grains strongly adhering to the protein tissues, and the high lysine cultivars were

found to have better separation of the starch grains in the whole grain meal preparations.

Micropenetrator hardness testing was used to indicate the hardness of the starch granule or the protein matrix to indentation by a stylus under constant pressure at a common moisture level. The length of the diagonal of the depression determines the hardness of the surface material (Barlow, 1973).

Micropenetrator hardness testing in wheat indicates little differences between the starch or the protein from different cultivars. The conclusion of the micropenetrator hardness values is that the nature of the starch and starch-protein interface differs between hard and soft varieties (Barlow, 1973). In hard wheats, fractures during milling tend to pass along endosperm cell walls to yield clean, well-defined particles. Fractures, through the starch cell in these wheats, involves both starch granules and storage protein resulting in high proportion of damaged and broken starch granules. Because of the lower adhesion between starch and protein, soft wheats tend to release starch granules more freely during milling with fractures occurring around rather than through the starch granules (Barlow, 1973). Vitreous grain grinds easier and gives a greater yield of high grade flour than a soft or mealy grain (Kuprits, 1967). Vitreous wheats give coarse, free-flowing particles which are easily sifted and dispersed between fractions (Farrand, 1974). The soft, or mealy, grain

has more free starch granules and protein particles than hard wheats. The free starch granules have a tendency to form clusters on top of the sieve (Farrand, 1972). This aggregation of starch restricts the passage of starch through the sieve openings, thus lowering the extraction of flour. This leads to more shorts and red dog being formed and a decrease in the amount of flour. As the hardness of the kernel decreases, the hardness gradient between endosperm and bran or hulls decreases. This increases the difficulty of separating the endosperm from the bran or hulls. Visually, the bran would have more white caps or specks of adhering endosperm.

Tempering, the addition of water to grain prior to milling, increases the effectiveness of the roller milling process. Tempering increases the difference in the physical properties between the bran and the endosperm. Moistening of the grain causes both the endosperm and bran to swell causing plastic deformation in the bran and endosperm. The bran becomes less brittle, is less easily crushed, and can be separated without difficulty as large flakes during the bolting of the ground products (Kuprits, 1967). Due to the specific structural features and chemical composition of the endosperm, the intermolecular bonds are damaged after water has penetrated into the intermolecular spaces and the microcracks of the grain (Kuprits, 1967). The damaged intermolecular bonds cause cracks in the endosperm. These cracks cause the endosperm to fracture into many small particles when subjected to

the stress of roller milling (Grosh, 1959). The resulting small endosperm particles form the flour.

The roller milling process makes use of the kernel structure, response to tempering, and the hardness gradient to separate the endosperm from the hulls and the germ.

Lysine Distribution in the Milling Fractions

The nutritive value of a food protein depends not only on its content of essential amino acids, but also on the physiological availability of the food protein. Amino acids are unavailable if they are in regions of a protein protected (chemically or physically) from the action of proteolytic enzymes, or if they are linked to other chemical moieties through bonds not readily broken by digestion (Finley, 1974). The location of lysine in the barley milling fractions should be important in determining the nutritional availability of lysine for human use. Lysine concentrated primarily in pericarp, hulls, and aleurone layers of the barley kernel may not be available for absorption by the human digestive system because of the fibrous nature of these components.

In cereal grains, the physiological availability of protein is determined by its location within the cereal grain structures (Eggum, 1977). Structural proteins soluble in alcohol, acid, or alkaline solutions are mainly located in the cells and in specially

differentiated particulate components, the so-called protein bodies (Wall, 1967; Christiansen, 1968). In studies conducted by Munck (1964) the protein from the embryo and aleurone layers were less digestible in vitro than the endosperm protein. The biological value of the endosperm protein was lower than the embryo, or aleurone protein. Eggum (1971), as reported in Barley Genetics II, found that lysine is the least available amino acid in barley meal when fed to rats and swine. As Munck (1964) suggests, the digestibility of the endosperm protein is greater than the protein located in the outer layers of the barley kernel (pericarp, aleurone, hulls, embryo). Therefore, any increase in the biological value of the endosperm protein which comprises 80-85% of the total barley protein will increase the value of that barley as a human and an animal food.

The lysine content of the milling fractions becomes important when judging the food value of roller milling barley for human use. Robbins and Pomeranz (1972), using a MIAG Multimill, showed that the barley milling fractions had the following protein and lysine values: 1) flour - protein - 9.8%, lysine - 4.1%; 2) red dog - protein - 11.3%, lysine - 4.1%; 3) shorts - protein - 8.8%, lysine - 4.8%; 4) bran (hulls) - protein - 3.1%, lysine - 5.0%. The whole grain barley had protein and lysine values of 9.3% and 4.2%, respectively. Stringfellow et al. (1976), using a Buhler laboratory mill, showed that triticale milling fractions had the following protein and lysine

values: 1) flour - protein - 10.4%, lysine - 2.1%; 2) shorts - protein - 14.9%, lysine - 3.7%; 3) bran - protein - 17.3%, lysine 4.4%. The whole triticale grain had protein and lysine values of 12.0% and 3.4%. In the data above, the lysine decreases from the hulls, or bran, to the center of the kernel. This decreasing lysine gradient in cereal grains becomes important in evaluating the food value of grains bred for lysine values. Brandt (1976) indicates that the barley mutant, Risø 1508, has a lysine content 45% greater than its parent cultivar, Bomi. Much of this higher lysine is located in the endosperm. Brandt (1976) found that this was due to a decrease in the lysine poor hor-dein and the lysine poor components of glutelin and an increase in the lysine rich components of glutelins and albumines. The increased level of lysine in the endosperm of high lysine barley cultivars means that the proteins of endosperm will have a potentially increased biological value and net protein utilization by humans. This is supported by the research of Newman et al. (1977) on pig diets. Pigs fed the Hiproly diets gained weight faster than pigs fed the Hiproly Normal or Compana diets regardless of the protein supplementation. In comparing the growth performance of pigs and rats fed diets containing waxy Compana and Compana, Calvert et al. (1977) reported that unsupplemented waxy Compana increased weight gain, and improved feed efficiency over that of the unsupplemented Compana barley. The report of the 1972 CIMMYT Symposium on Production and Utilization of Quality

Protein in Maize states that the true digestibility of Hiproly compared to normal barleys is increased due to the increase in the lysine rich albumins in Hiproly.

Bake

Cookie Bake

The sugar snap cookie test has been used to distinguish between wheat cultivars (Yamazaki, 1959), small cereal grains (Badi, 1976; Kissel, 1976), flour fractions (Sollars, 1956), and flour granularity (Yamazaki, 1959).

The sugar snap cookie test is a standardized procedure of the American Association of Cereal Chemists. The sugar snap cookie test has been used to evaluate a variety of cereal flours including hard wheat (Tsen, 1975), sorghum and millet (Badi, 1976), and Triticale (Kissel, 1976). If barley flour is to be used as a partial or total substitute for soft wheat flour, barley flour's cookie baking qualities should be evaluated. The sugar snap cookie has proven to be a sensitive test that can and does distinguish between cultivars and milling treatments in soft wheat (Yamazaki, 1959).

The cookie spread potential of a wheat flour appears to be related to the wheat cultivar (Yamazaki, 1969). Yamazaki (1959) showed that the wheat variety influenced the granularity and the cookie quality. The harder varieties produced coarse and fine fractions that

differed very little in cookie spread. The softer cultivars produced larger cookie spreads from the fine fractions than from the coarse fraction (Yamazaki, 1959). As the granularity of the flour decreased, the differences in protein levels between the coarse and fine flour fractions increased (Yamazaki, 1959). As the softness of a flour increased, the differences in protein values between the coarse and fine fractions also increased.

Udy (1956) reported that the hard wheat varieties, Rio and Kharkof, have a high intrinsic viscosity and produce cookies of small diameter. Soft wheat varieties have a low intrinsic viscosity and produced cookies having an acceptable cookie spread. Although proteins imbibe considerable water, differences in water uptake of a good and a poor cookie flour at the same protein level are presumably the result of differences in the amount and size of the polysaccharides which imbibe water. The degree of swelling, or solvent uptake in high polymers, is related to their size and structure.

The protein content of the flour does not seem to be related to either the amount of soluble polysaccharides present, or their molecular size. This was shown by constancy of the intrinsic viscosity value within a given variety. Consequently, the average size of the soluble polysaccharide molecules is a specific varietal characteristic (Udy, 1956).

Yamazaki (1969) lists the properties of wheat and flour that appear to be varietal: 1) flour granularity, 2) water absorption, 3) dough viscosity, and 4) cookie spread potential. In 1969, Yamazaki observed that cookie doughs with a rapid increase in dough viscosity spread less during baking than those whose viscosities increased slowly.

Cookies made from grain sorghum or millet flour did not spread during baking, had a poor top grain character, and were dense and compact (Badi, 1976). When the sorghum and millet flours were hydrated, air-dried, and baked with 0.6% soybean oil, they produced cookies with spread characteristics similar to wheat flour cookies (Badi, 1976). Kissel (1976) reported that five Triticale flours produced poor cookies but when the flours were hydrated, dried, and baked with 1-2% soy lecithin, the cookie spread and top grain appearance were equal to the soft wheat flour cookies. It appears that the addition of soy lecithin increases Triticale dough viscosity.

Sollars (1956) fractionated the wheat varieties Rio and Elgin into water soluble, gluten, wheat starch tailings, and prime starch. Rio is a hard wheat yielding poor cookies and Elgin is a soft club wheat with good cookie quality. The reconstituted flours equaled the original flour in cookie quality. By interchanging one fraction at a time, it was concluded that the tailings fraction influenced the cookie diameter to the greatest extent. Water-solubles had a small

but consistent effect on diameter, and influenced top grain appearance. The starch influenced cookie quality very little. Wheat gluten produced an erratic effect on cookie quality.

Yamazaki (1955) reported that the soft wheat starch tailings had a deleterious effect on cookie quality. The purified starch tailings were very hydrophilic, rich in pentosans, and consisted of cell wall material, bran and some aleurone cells. Yamazaki (1955) concluded that the effect of starch tailings on cookie spread was related to the physical absorption of large quantities of water. Sollars (1959) reported that the wheat flour water-solubles fraction with low molecular weight substances had a negligible effect on cookie diameter. The high molecular weight fraction of the water-solubles containing 40-70% pentosans greatly reduced cookie diameter. Thus, he concluded that most of cookie diameter reduction caused by the water-solubles can be traced to the polysaccharides of high pentose content.

Yamazaki (1977) showed that soft wheat prime starch did not show varietal effects in the cookie bake tests.

Sollars (1971) reconstituted flours with starches from rye, barley, corn, rice, and potatoes. Reconstituted flours produced very good cookies and had viscosities close to those flours containing wheat starch. The substitution of barley starch for soft wheat starch increased the water requirements of the cookie dough. It was concluded from these experiments that barley starch substituted for soft

wheat starch gave cookie baking results equivalent to those of wheat starch.

Biscuits

Few reports appear in the literature on the biscuit bake test for detecting differences between flours of varying quality. Schellenberger (1942) reported that the biscuit test does not appear to be very critical, and did not differentiate adequately between flours of the same general character. The 1938-1939 subcommittee on methods of testing self-rising flour of the American Association of Cereal Chemists stated that biscuit test was not sufficiently sensitive to detect subtle differences in protein and/or viscosities of doughs (Gookins, 1940). Elling and Milner (1951) indicated that the biscuit test does differentiate between varieties as to baking quality.

Zaehring (1956) studied the interaction of starch, gluten, amyloextrins, and water-solubles on biscuit quality. She used one pastry flour and one bread flour and exchanged the components one at a time. From this study, she concluded that hard wheat gluten biscuits were larger, and less tender than soft wheat gluten biscuits; hard wheat starch gave a larger volume, and a browner, more tender crust than soft wheat starch; hard wheat water-solubles were harmful to biscuit volume and crust tenderness; and hard wheat amyloextrins produced smaller and darker biscuits than soft wheat amyloextrins.

These differences in properties between hard and soft wheat supported the findings of Elling and Milner (1951). They showed that soft wheat flour gave a lighter, more tender biscuit with better crust color, but with smaller volume than hard wheat flour.

Alkaline Water Retention Capacity Test

Yamazaki (1953) described the Alkaline Water Retention Capacity (AWRC) test for soft wheat flour which was negatively correlated with cookie diameter. The correlation factor was -0.847 for 506 samples covering a period of six years (1944-49) with eleven different soft winter wheat cultivars. When Yamazaki (1953) computed the correlation coefficient of six selected AWRC varietal means against mean cookie diameter, he found $r = -0.95$. This indicates the test reflects the varietal response of soft wheat flour to the cookie bake.

In 1954, Yamazaki established that the AWRC reflects water absorption properties of the cookie flours. The AWRC vs. dough absorption correlation was 0.97 based on eleven varietal means. The correlation between dough absorption and cookie spread was -0.97 . In the study he also showed that protein influenced AWRC very little. This corresponds to the findings of Finney (1945) that protein is not a good index of water absorption when the flour protein content falls below 10%. Water absorption is not only a function of protein content but also of other hydrophilic agents for both soft wheat flour and low

protein hard wheat flour. Since AWRC and water absorption are measuring the hydration properties of flour-water systems and both correlate highly with cookie diameter, it would appear that cookie quality is a function of the water absorption.

Factors influencing cookie spread as well as AWRC include the quality and amount of gluten, starch tailings, and starch (Yamazaki, 1977). The gluten, starch, and starch tailings were shown to influence cookie diameter in relation to their water retention properties. Tailings with the greatest AWRC values decreased the cookie spread to the greatest extent. Gluten with the next highest AWRC values gave mixed results depending on whether the gluten was from a hard or soft wheat. Shawnee, a hard wheat, had the highest AWRC values with the lowest cookie spread. Thorne and Blackhull, soft red winter wheats, had similar AWRC values and similar cookie spreads.

The tailings influence may in part be explained by its composition. Examination of the tailings fraction under a microscope reveals a preponderance of cellulose material from the bran, aleurone, and endosperm cell walls (Yamazaki, 1955). When the endosperm cell walls were separated from the bran and aleurone cells, it was found that the endosperm cell walls contributed the most to the AWRC values for this fraction. B-glucans have been identified as polymers of glucose which form part of the endosperm cell wall of barley (Bathgate, 1975). B-glucans in combination with water form a high molecular

weight viscous material. Greenburg (1972) reported a correlation of 0.89 between the B-glucans and the viscosity of barley brewery extracts. Bourne (1970) and Sparrow (1969) have reported that the amount of B-glucans in barley appears to be a cultivar characteristic. Yamazaki (1956) reported that the size and the amount of water-soluble polysaccharides is a varietal characteristic of soft wheat. He also speculated that the size and amount of water-soluble polysaccharides influenced the amount of water absorbed by the flour. Polysaccharides, perhaps the B-glucans, in the starch tailings may influence the water absorption properties of a flour.

The proteins of barley and wheat are different. When the proteins of barley and wheat are extracted with formic acid, the water absorption of wheat was 65%, and barley absorption was 55.2% (Cunningham, 1955). Barley gluten was found to be tougher, firmer, and absorb water slowly when compared to wheat gluten (Cunningham, 1955). When wheat gluten is wet it behaves like a gel whereas barley gluten behaves like a crystalline protein. It is not as elastic, or as fluid as wheat gluten (Cunningham, 1955). Barley proteins darkened in color more rapidly than wheat proteins when air-dried (Cunningham, 1955).

Sollars (1956) and Yamazaki (1977) have reported that the starch fraction in soft and hard wheats have the lowest AWRC values of the three major fractions. The quality of the starch does not appear to be a varietal trait (Yamazaki, 1977).

Taste Panel

To judge consumer acceptability, a consumer reaction panel is used. Since the purpose is to obtain consumer reaction, a trained panel is not needed, and perhaps should be avoided (Kramer, 1961). These tests are designed to measure the reaction of a food in contrast to an analytical test which tests for the existence of an element.

A limited number of tastings per sitting is used to avoid mental and palate fatigue. The number of tastings was usually between three and nine; three samples tasted were superior to nine (Kramer, 1961). Keffler and Christie (1960) indicate that most of their tasting sessions were limited to four taste samples per sitting. Tsen (1976) used a consumer taste panel composed of grade school children to evaluate protein fortified sugar and oatmeal cookies. Badi and Hoseney (1976) used five untrained taste panelists to evaluate chocolate chip cookies made from soft wheat flour and sorghum flour. In each of the above cases, the number of taste panelists used were too few to give statistical significance to the differences between the samples. Trends were indicated as to which sample cookies might be acceptable to the general consumer.

MATERIALS AND METHODS

This study was limited to four barley cultivars: Hiproly, Hiproly Normal, Washonupana, and Compana. These cultivars were chosen because they are often considered isogenetic pairs, and were available in sufficient quantity to make the desired tests. These samples represent bulk field grown seed. They were grown at only one site, the Montana Agricultural Experiment Station, Bozeman, Montana, during the 1975 crop year. Field replications were not possible. Replications show testing, treatment, and cultivar variation only, not field variation.

The data from this thesis were analyzed using standard analysis of variance procedures (Snedecor, 1967). Two milling treatments were used: 1) dry, no additional water; 2) wet, tempered to 13.5% moisture, thirty minutes prior to milling. Each treatment was replicated five times. All experiments and analyses were made using a completely randomized design. All correlations were made to check the significance of the relationship between any two single factors.

Prior to milling, each of the four barley cultivars were cleaned using the Carter Day laboratory cleaner Model LXT2 in Cereal Quality Laboratory (CQL) of Montana State University. The chaff, stones, wheat and weed seed present in the samples were removed and discarded.

Each of the four barley cultivars was blended through a grain divider to assure uniformity. The grain was blended from a sack into three five-gallon buckets. A scoop of grain from each bucket was

passed through the divider back into the sack. This procedure was repeated until test weights of the grain taken from two different portions of the sack were equal.

A sample was taken from each of the four cleaned cultivars to determine protein, ash, moisture, thousand kernel weight, and lysine (AACC, 1962; Waters, 1975).

The four barley cultivars were milled on an Allis-Chalmers experimental mill that was supplied by Con Agra, Great Falls, Montana. It has a pair of corrugated rolls and a pair of smooth rolls with a sifter box capable of holding four sieves. The mill flow diagram is in Figure I. The explanation of the diagram is given in the following paragraphs.

For the purposes of this thesis, the corrugated rolls are the rolls referred to when breaks, or sizings, are used. The smooth rolls are being used when mention is made of the middlings, tailings, and low grade streams.

The clean barley was passed through the first break at a setting of 0.020 in. and collected in a tray under the corrugated rolls. The contents of this tray were emptied into the sifter box containing a 20 wire (20 openings per square inch, opening size 910 microns), 30 grit gauze (32 openings per sq. in., opening size 630 microns), 70 grit gauze (82 openings per sq. in., opening size 210 microns), and 183 nitex (90x100 openings per sq. in., opening size 183 microns).

21
ALLIS - BARLEY FLOW

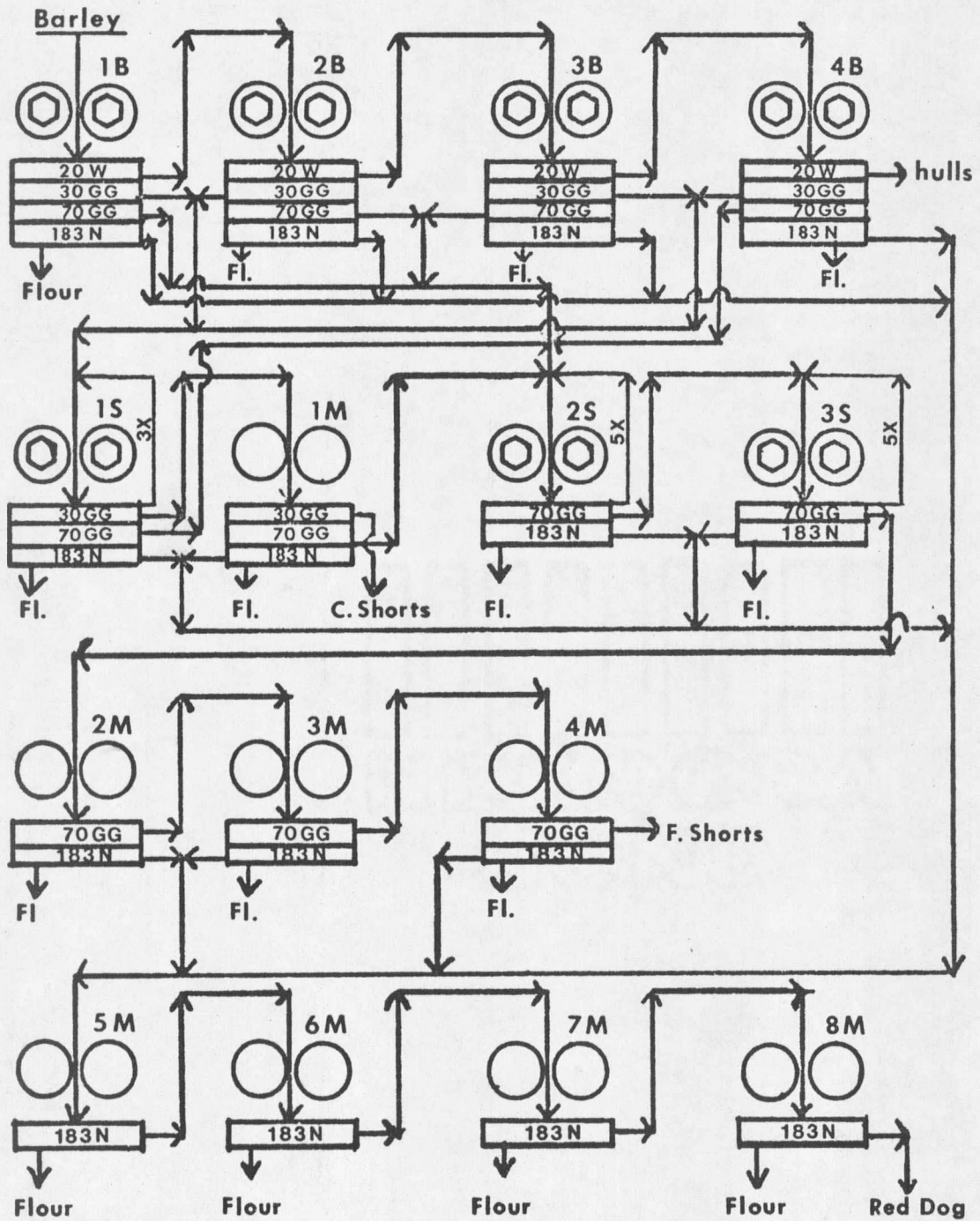


Figure I. Allis-Chalmers Experimental Mill Flow Diagram

The sample was sifted for two minutes. The contents of the 20 wire were run through the corrugated rolls (second break) with a clearance of 0.012 in. The sample was collected in a tray and emptied into the 20 wire of the sifter box. It was again sifted for two minutes. The residue of the 20 wire was passed through the third break rolls, setting 0.006 in., collected, and resifted for two minutes. The overs of the 20 wire were ground again through corrugated rolls (fourth break), setting 0.004 in., collected, and sifted for two minutes. The overs that remains on the 20 wire were weighed and recorded as bran (hulls).

The overs of the 30 grit gauze (30GG) form the first sizings stream. The first sizings were passed through the corrugated rolls (1 sizings) set at 0.003 in. four times. The product was sifted for two minutes on a 30GG sieve. The overs of the 30GG (1 middlings) were passed through the smooth rolls (1 middlings) set at 0.025 in. The product was collected and placed into the sifter box and sifted for two minutes. The overs of the 30GG were weighed and recorded as coarse shorts.

The overs of the 70 grit gauze (70GG) form the second sizings. The second sizings are ground six times through the corrugated rolls (second sizings) set at 0.002 in., collected and sifted for two minutes. The overs of the 70GG were reground six more times, collected and resifted for two more minutes. The overs of the 70GG (2 middlings)

(2 middlings) were milled by the smooth rolls, at 0.015 in. The second middlings were collected and sifted for two minutes. The overs of the 70GG were reground by third middlings rolls and resifted. The overs of the 70GG were reground again by the fourth middlings rolls and resifted for two minutes. The overs of the 70GG were then weighed and recorded as fine shorts.

The overs of the 183 nitex (fifth middlings) were passed through the fifth middlings rolls once and sifted for two minutes. The sixth middlings (overs 183 nitex) were milled by the sixth middling rolls, sifted, and reground on the seventh middlings rolls. The seventh middlings were sifted and passed through the eighth middlings rolls. The product from the eighth middlings rolls was sifted through the 183 nitex. The overs of the 183 nitex were weighed and recorded as red dog.

The throughs of the 183 nitex (flour) were weighed and recorded. The percentage of flour (extraction) was calculated by dividing the flour weight by the weight of the total recovered product (hulls, flour, shorts, red dog).

Each of the five fractions from each milling were saved for lysine, protein, ash, and moisture analysis. The flour was analyzed for alkaline water retention and baking quality in addition to the above tests.

The lysine was analyzed using the microbiological assay method of Waters (1975).

The protein, ash, and moisture were determined using the American Association of Cereal Chemists (AACC) standard methods (AACC, 1962).

After the samples for chemical analysis had been taken, the flour samples were used to bake cookies and biscuits. The cookies were baked by the Micro Method III of Finney et al. (1950). To aid in the rolling of the cookie dough, the dough was rolled between sheets of wax paper.

The two modifications of the standard biscuit method were: 1) roll the dough between sheets of wax paper, 2) add additional water due to the increased water absorption of the barley flour.

The cookies and biscuits were placed into plastic sample bags designating cultivar and milling treatment prior to freezing. All samples were frozen at 0°C after each day's bake to preserve sample integrity as much as possible for the taste panel.

When the baking had been completed, the Alkaline Water Retention Capacity test (AWRC) was used to check for water absorption of the flours. The micro AWRC determinations were by the procedure as outlined by Yamazaki et al. (1968).

Separate taste panels were used to evaluate the cookies and biscuits. The taste panel members were Montana State University students

selected from volunteers to participate. Each panel was composed of eight students. Each panel was divided into two subgroups of four members each. To the first subgroup (A) of four panelists, thawed cookies made from dry milled barley flour were given in random order. In subgroup (B) panelists were given the cookies made from tempered barley flour in a random order. On the following day at the same time, the presentation to the two subpanels, A and B, was reversed. Group A received the cookies with the tempered treatment and group B received the cookies with the dry milling treatment in a random order.

The biscuit taste panels used the same procedure as the cookie taste panel.

Each panelist was asked to evaluate each sample for flavor, texture, color, overall appearance, and overall palatability by use of a scale of one to five on the evaluation form in the Appendix, page 79. One would be unacceptable and five would be excellent.

RESULTS

Milling

Analysis of variance (Table 1) revealed that there was a difference among cultivars for seven different characteristics. Dry milling produced higher average yields than tempered milling (Table 2) ($p < .001$). The largest yields came from Hiproly and Compana followed by Hiproly Normal and Washonupana. Duncan's multiple range test ranked the four cultivars in the same descending order as the flour yield whether they were milled dry or tempered. In the dry milling treatment, Hiproly Normal and Washonupana were not statistically different, but in the tempered milling treatment, Hiproly Normal and Washonupana were different statistically ($p < 0.05$). Hiproly Normal and Compana produced the same flour yield tempered or dry-milled. Hiproly produced less flour when milled tempered. The flour yield from tempered Washonupana was significantly less ($p < 0.05$) than the dry milled Washonupana flour yield.

The data in Table 1 show a very significant treatment-cultivar interaction ($p < .001$).

Data in Table 3 show definite differences in the ash content among and within the cultivar sieve fractions. Differences in the ash values of each fraction are similar from one cultivar to another. The ash of the overs of the 20 wire (w) and the ash of the throughs of the 183 nitex (N) of Hiproly was significantly less ($p < 0.05$) than the

Table 1. Analysis of Variance - Source Table

Source	Yield			Ash			Protein			Lysine			Biscuit			Cookie			AWRC				
	DF	MS	F	DF	MS	F	DF	MS	F	DF	MS	F	DF	MS	F	DF	MS	F	DF	MS	F		
Cultivar	3	24.75	xxx	3	26.33	xxx	3	52.76	xxx	3	3.36	xxx	3	.12	xx	3	268.6	xxx	3	.21	xxx	91.3	
Fraction				4	109.07	1198	4	250.16	xxx	4	9.31	xxx											
Treatment	1	78.96	xxx	1	0.41	x	1	8.83	xxx	1	0.16	0.5	1	.06	x	1	22.9	x	1	.005	2.2		
CxF				12	11.55	xxx	12	46.04	xxx	12	2.29	7.5											
TxF				4	.22	2.4	4	5.66	xx	4	0.16	0.5											
TxC	3	25.19	x	3	1.35	xxx	3	2.11	x	3	0.26	0.8	3	.02	1.7	3	9.2	x	3	.044	xxx	19.1	
Error	32	8.95		172	0.091		172	0.772		172	0.307		32	.012		32	3.38		32	.0023			

x - significant at $p < .05$; xx - significant at $p < .01$; xxx - significant at $p < .001$.

Table 2. Evaluation of Flour Extraction Means across Treatments and Cultivars

Cultivar	Temper Treatment		Varietal Mean
	Dry	Tempered	
	%		
Hiproly	a 63.49	abcd 59.38	61.51 ¹
Hiproly Normal	bcde 55.28	de 54.96	55.12
Compana	ab 60.0	abc 59.94	59.97 ¹
Washonupana	de 53.84	47.24	50.54
Treatments	58.19	55.38	

abc . . . means with the same superscript letter are not significantly different ($p < .05$).

1 means with the same superscript numeral are not significantly different ($p < .05$).

Table 3. Effect of Cultivar on Fractional Ash Means Taken across all Treatments and Replications

Fractions	Cultivar				Fractional Means
	Hiproly	Hiproly	Compana	Washonupana	
	% Dry Matter				
Overs 20 w	3.607	3.884 ^b	7.854	7.144	5.620
Overs 30GG	4.146 ^{ab}	4.071 ^{ab}	6.800	4.302 ^a	4.830
Overs 70GG	4.141 ^{ab}	3.090	4.209 ^{ab}	2.521 ^c	3.490
Overs 183N	2.307 ^c	2.333 ^c	2.436 ^c	1.904 ^d	2.240
Thrus 183N	1.602 ^e	1.719 ^{de}	1.813 ^{de}	1.808 ^{de}	1.740
Whole grain	2.450 ¹	2.353 ¹	2.760	2.552 ¹	

abc . . . means with the same superscript letter are not significantly different ($p < .05$).

1 means with the same superscript numeral are not significantly different ($p < .05$).

overs of the 20 w and throughs of the 183 nitex (N) of Hiproly Normal. The overs of the 70 grit gauze (GG) of Hiproly are significantly higher in ash content ($p < .05$) than the overs of the 70GG of Hiproly Normal. Washonupana and Compana differ significantly ($p < .05$) at all sieve fractions with the exception of the throughs of 183N. The flour ash (thrus 183N) of the four barley cultivars were not significantly different. The whole grain ash of Compana was significantly greater ($p < .05$) than the ash of the other three cultivars. The whole grain ash of Hiproly and Washonupana was higher than the whole grain ash of Hiproly Normal.

Tempering Hiproly and Hiproly Normal (Table 4) increased the ash of the first three sieve fractions and lowered the ash in the last two fractions, the red dog and the flour. Milling tempered Compana and Washonupana yielded lower ash in all five fractions. Tempering Hiproly did not significantly change ash values from the dry milled barley. The ash values of the 30GG of Hiproly Normal, tempered, were significantly different ($p < .05$) from Hiproly Normal, dry. Dry or tempered milling treatments of Hiproly Normal produced no significant differences between the other milling fractions. Tempering did not change the fractional ash values of Compana significantly. The hulls (overs 20 w) and coarse shorts (overs 30GG) were significantly less ($p < .05$) in ash in the tempered Washonupana than in dry milled Washonupana. The other milling fractions did not show any significant

Table 4. Cultivar and Temper Treatment Effects on Fractional Ash Means Taken across all Replications

Fraction	Cultivar							
	Hiproly		Hiproly No.		Compana		Washonupana	
	Dry	Temp.	Dry	Temp.	Dry	Temp.	Dry	Temp.
Overs 20 w	hij 3.407	efgh 3.809	fghi 3.650	defg 4.118	a 8.016	a 7.694	a 7.627	b 6.621
Overs 30GG	efg 3.987	de 4.306	ghi 3.558	cd 4.584	b 6.852	b 6.752	c 4.800	efgh 3.803
Overs 70GG	defg 4.085	def 4.197	j 3.001	ij 3.180	def 4.218	def 4.200	k 2.566	klm 2.479
Overs 183N	kl 2.516	klmnopq 2.078	klm 2.451	klmnop 2.217	k 2.564	klmno 2.308	klmnopq 2.026	opq 1.782
Thrus 183N	q 1.644	q 1.569	opq 1.791	pq 1.647	lmnopq 1.936	pq 1.690	nopq 1.893	
Treatment* Means	2.250 ³	2.233 ³	2.278 ³	2.266 ³	2.947 ¹	2.870 ¹	2.345 ²	2.392 ²

abc . . . letters denote nonsignificant difference among the fractional means ($p < .05$).

* treatment means take into consideration the amount of each fraction times the percentage of ash for each cultivar and treatment.

1 numerical superscript denotes nonsignificance between treatment means ($p < .05$).

differences due to the addition of water to Washonupana prior to milling.

The ash treatment means were different for each barley cultivar. Compana treatment ash means were significantly higher ($p < .05$) than the treatment ash means of Hiproly Normal and Hiproly. Hiproly and Hiproly Normal did not differ significantly in treatment ash means.

The dry and tempered treatments of each cultivar were not significantly different.

Lysine and Protein

The statistical analysis of protein and lysine analytical data (Table 1) show highly significant main effects for cultivar and fraction ($p < .001$). Temper treatment was statistically significant ($p < .001$) for protein and was not significant for lysine. The protein data shows significant cultivar-fraction ($p < .001$) treatment-fraction ($p < .01$) and treatment-cultivar ($p < .05$) interactions. The statistical analysis of the lysine analytical data showed only a highly significant ($p < .001$) cultivar-fraction interaction.

The protein means are shown in Table 5. The fractional protein means taken across all treatments, cultivars, and replications are significantly ($p < .05$) different from one sieve fraction to another. The highest protein fraction was the fine shorts (overs 70GG) and the lowest protein was in the hulls fraction (overs 20GG). Hiproly and Hiproly Normal differ significantly ($p < .05$) in protein at every protein level. The difference in the whole grain protein between Hiproly and Hiproly Normal was 1.7%. This difference in protein levels of the whole grain explains the considerably higher protein in the various milling fractions of Hiproly compared to Hiproly Normal. In Hiproly, the highest protein concentration was located in the fine shorts

Table 5. Cultivar and Fraction Protein¹ Means Taken over all Temper Treatments and Replications

Fraction	Hipoly	Hipoly Normal	Compana	Washonupana	Fraction Means
% Dry Matter					
Overs 20 w	hijk 13.80	m 12.52	6.79	7.43	10.08
Overs 30GG	bc 17.09	defg 15.34	m 12.09	jkl 13.33	14.39
Overs 70GG	a 18.12	fgh 14.53	ab 17.74	def 15.41	16.45
Overs 183N	def 15.83	hij 14.21	abc 17.37	def 15.57	15.75
Thrus 183N	fghi 14.51	hijkl 13.52	15.96	d 16.11	15.03
Whole grain	15.23	13.56	15.84	16.00	

abc . . . means with the same superscript letter are not statistically different ($p < .05$).

1 protein factor used was Nx6.25 as determined by Kjeldahl procedure.

fraction (overs 70GG) whereas in Hipoly Normal the highest protein was in the coarse shorts (overs 30GG) fraction. The protein in Hipoly drops very sharply from the fine shorts to the flour (thrus 8XX). In Hipoly Normal, the protein drops much less from the coarse shorts to the flour. The flour protein in Hipoly was less than the whole grain protein. In Hipoly Normal, the flour protein was the same as the whole grain protein. The fine shorts fraction of Compana has the highest protein and the bran has the lowest protein. In Washonupana,

the protein increased from the hulls to the flour with the flour protein having the highest protein level and the hulls having the lowest level of protein. The flour protein of Compana, Washonupana and Hiproly Normal was equivalent to the whole grain protein. The whole grain protein of Washonupana was not significantly higher than its flour protein. The protein in the hulls of Hiproly and Hiproly Normal was significantly greater than the protein in the hulls of Compana and Washonupana.

Temper did not significantly affect the protein distribution of Hiproly Normal and Compana (Table 6). In Washonupana and Hiproly, the tempering significantly ($p < .05$) influences protein separation when taken over all fractions. The protein in the hulls of Washonupana, tempered, and Compana, tempered, are significantly greater ($p < .05$) than the hulls of Washonupana, dry, and Compana, dry. In both temper treatments, the protein increases from the outside of barley kernel to the inside of the kernel. Compana and Washonupana show the greatest difference between interior protein and exterior protein. Hiproly and Hiproly Normal showed no significant difference ($p < .05$) between interior and exterior protein.

The lysine statistical data in Table 1 show significant ($p < .001$) cultivar and fraction effects with the cultivar-fraction interaction being the significant interaction ($p < .001$). In Table 7 the fraction means taken over all replications and cultivars show that lysine as a percentage of protein decreased from the outside of the kernel to the

Table 6. Cultivar, Temper Treatment, and Fraction Protein Means*

Fractions	Cultivar								Fractional Means
	Hiproly		Hiproly Normal		Compana		Washonupana		
	Dry	Tempered	Dry	Tempered	Dry	Tempered	Dry	Tempered	
	% Dry Matter								
Overs 20 w	ijklmnp 14.09	nopq 13.51	pqrs 12.37	pqr 12.67	6.32	7.26	5.49	9.36	10.08
Overs 30GG	cdefgh 16.33	abc 17.85	ghijklmno 14.98	efghijklm 15.67	s 11.57	qrs 12.09	rs 11.97	ghijklmno 14.68	14.39
Overs 70GG	ab 18.00	a 18.25	hijklmno 14.57	hijklmno 14.55	abcde 17.23	a 18.26	efghijklm 15.53	fghijklmno 15.29	16.45
Overs 183N	efghij 15.89	efghijkl 15.80	ijklmno 14.33	ijklmnp 14.09	abde 17.69	bcdef 17.05	efghijk 15.82	fghijklmn 15.32	15.75
Thrus 183N	ijklmnp 14.30	ghijklmno 14.73	nopq 13.60	opq 13.44	efghi 16.08	efghijk 15.82	bcdefg 16.49	efghijklm 15.73	15.03
Treatment ¹	15.17 ⁴	15.56 ^{1,2}	13.96 ⁵	13.93 ⁵	15.40 ³	15.45 ^{1,2,3}	15.64 ¹	15.08 ⁴	

* means of 5 replications

abc . . . means with the same superscript letter are not significantly different (p < .05).

1,2 . . . means with the same numerical superscript are not significantly different (p < .05).

35

Table 7. Fractional Lysine Means showing Cultivar Effects taken over all Treatments and Replications

Fraction	Cultivars ¹				Fractional Means
	Hiproly	Hiproly Normal	Compana	Washonupana	
% Protein					
Overs 20 w	3.53	3.36	4.38	4.92	4.016
Overs 30GG	3.91	3.09	3.83	3.26	3.544
Overs 70GG	3.92	2.94	2.81	2.76	3.197
Overs 183N	3.34	2.75	2.53	2.68	2.88
Thrus 183N	3.38	2.93	2.61	2.63	2.84
Varietal Means	3.47	2.93	2.80	2.83	
Whole Grain	3.94	2.95	2.59	3.09	

1 all means that differ by LSD value of 0.149 are significantly different ($p < .05$).

2 varietal means were weighed according to the amount of product in each fraction times the percentage of lysine and together to give the variety lysine percentage.

inside of the kernel. The hulls contain the greatest percentage of lysine as a percentage of protein followed by the coarse shorts, fine shorts, red dog, and the flour. The red dog and flour do not differ significantly in lysine using the least significant difference (LSD) to compare fraction means. LSD was chosen to compare means in Table 7 because some lysine values were lost during the lysine analysis.

The data in Table 7 indicate that Hiproly does not differ significantly in lysine content from the hulls to the flour. The other three cultivars do vary statistically ($p < .05$) from the outside of the

kernel to the inside of the kernel in lysine. The hulls (overs 20 w) of Washonupana contain statistically greater ($p < .05$) lysine as percent of protein than either the hulls of the other cultivars, or the other fractions of this variety. Washonupana coarse shorts (overs 30GG) are significantly greater ($p < .05$) than the finer fractions of Washonupana. The fine shorts (overs 70GG), red dog (overs 183N), and the flour (thrus 183N) are all statistically the same. Washonupana's flour lysine was less than its whole grain lysine.

In Compana (Table 7), the hulls contain a significantly greater ($p < .05$) percentage of lysine than the coarse shorts. The lysine in the coarse shorts was significantly larger ($p < .05$) than the lysine in the finer milling fractions. The fine shorts contain an appreciably greater ($p < .05$) lysine content than the red dog or flour fractions. The flour and red dog were statistically the same. The flour lysine of Compana was statistically the same as its lysine in the whole grain.

In Hiproly Normal, the hulls contain the greatest percentage of lysine followed by the coarse shorts, fine shorts, flour, and red dog. The coarse shorts have significantly greater ($p < .05$) lysine than the finer milling fractions. The fine shorts have significantly greater ($p < .05$) lysine than the red dog, and essentially the same lysine as the flour. The red dog lysine was significantly less ($p < .05$) than the flour lysine. The flour lysine percentage was statistically the same as its whole grain lysine.

Hiproly contains the highest whole grain lysine followed by Washonupana, Hiproly Normal, and Compana (Table 7). The flour lysine was represented in Table 7 in this order: Hiproly > Hiproly Normal > Washonupana = Compana. The cultivar-fraction interaction was significant ($p < .001$; Table 7). The lysine in each milling fraction of each cultivar was different. The same milling fraction differed in lysine values among all cultivars. In each fraction at least one, or more, cultivars varied significantly in lysine from the other cultivars. The flour fraction was an example of this. In Hiproly the flour lysine was significantly greater ($p < .05$) than the flour lysine of Hiproly Normal, Compana, and Washonupana. The flour lysine of Hiproly Normal was significantly greater ($p < .05$) than the flour lysine of Compana and Washonupana. Compana and Washonupana flours had similar lysine levels.

The correlation factor, r , of % lysine/% protein vs. % protein was 0.6228 ($p < .01$) taken over all fractions, replications, and cultivars. When the Hiproly lysine values were dropped out of the correlation, the r values became -0.91 ($p < .01$). Hiproly and Hiproly Normal did not have significant r values.

Baking Data

Cookies

The significant main effects of cookie diameter evaluation in Table 1 were the cultivar ($p < .001$) and temper treatment ($p < .05$).

The interaction of cultivar-treatment was significant ($p < .05$). Using yield as the concomitant variable in analyzing the cookie spread data, the interaction between temper and cultivar becomes nonsignificant. Cultivar and temper treatments were retained as the significant main effects when yield was used as the subordinate variable in covariate analysis of the cookie diameter data.

Duncan's multiple range test was used to compare the cookie diameter means in Table 8. The cookie bake test did differentiate between cultivar means. Hiproly Normal and Compana are not significantly different in cookie diameter, but were statistically larger ($p < .05$) than either Hiproly or Washonupana. Hiproly's cookie diameter was significantly larger ($p < .05$) than Washonupana's cookie diameter. The temper treatments were differentiated by the sugar cookie test. The temper treatment cookie diameters averaged over all cultivars were appreciably larger ($p < .05$) than the dry cookie diameter averaged over all cultivars. The cookie bake test failed to differentiate between the dry and temper treatments of Hiproly and Washonupana. The cookies of the tempered Hiproly were not significantly larger than the cookies from dry Hiproly. Tempering Washonupana did not increase the cookie spread. The cookie spreads of tempered Hiproly Normal and Compana were significantly larger ($p < .05$) than dry milled Hiproly Normal's and Compana's cookie spreads.

The physical appearance of the cookies was graded by a consumer taste panel. The results of the taste panel are tabulated in Table 9. A scale of one to five was used. One was unacceptable; three was acceptable but needs improvement; and five was excellent. Color and overall appearance were the two categories used to judge visual appearance. Figure II illustrates the difference between the four barley

Table 8. The Effect of Cultivar and Treatment on Cookie Spread Means taken across all Replications.

Cultivars	Treatment ¹		Cultivar ² Means
	Dry	Tempered	
MM			
Hiproly	c 144.2	c 143.7	144.0
Hiproly Normal	b 147.95	a 151.15	149.5 ¹
Compana	b 147.4	a 150.55	149.0 ¹
Washonupana	d 138.55	d 138.30	138.4
Treatments	144.5	146.0	

1 means with the same superscript letter are nonsignificantly different ($p < .05$).

2 means with the same numerical superscript are not significantly different ($p < .05$).

cultivars and also between the cultivars and the soft wheat cookie control. The control cookie was given a color rating of 4.33 and an overall appearance rating of 4.80. The Hiproly Normal, tempered, and the

Table 9. Taste Panel Evaluation of Sugar Snap Cookie Means made from the Flour of Four Barley Cultivars with Two Temper Treatments and across all Replications with a Soft Wheat Flour Control

Cultivar	Flavor ^{4,5}	Texture	Color	Overall appearance	Overall palatability	Total score
<u>Hiproly</u>						
Dry ¹	2.75	3.62	3.12	2.71	2.62	14.97
Tempered ²	2.86	3.86	3.00	2.86	2.86	15.29
<u>Hiproly Normal</u>						
Dry	3.50	3.75	3.62	3.62	3.25	17.74
Tempered	3.29	3.71	3.43	3.71	3.14	17.28
<u>Compana</u>						
Dry	2.50	3.50	3.38	3.38	3.00	15.76
Tempered	3.00	4.00	2.86	3.43	3.14	16.43
<u>Washonupana</u>						
Dry	3.00	3.38	3.00	2.50	3.12	15.00
Tempered	2.86	3.29	2.71	2.57	3.14	14.57
Control ³	4.33	4.33	4.67	4.80	4.27	22.60

1 mean from 8 replications

2 mean from 7 replications

3 mean from 15 replications

4 no significant difference between means within columns ($p < .05$)

5 the scale used was from one to five with one being unacceptable, and five being excellent

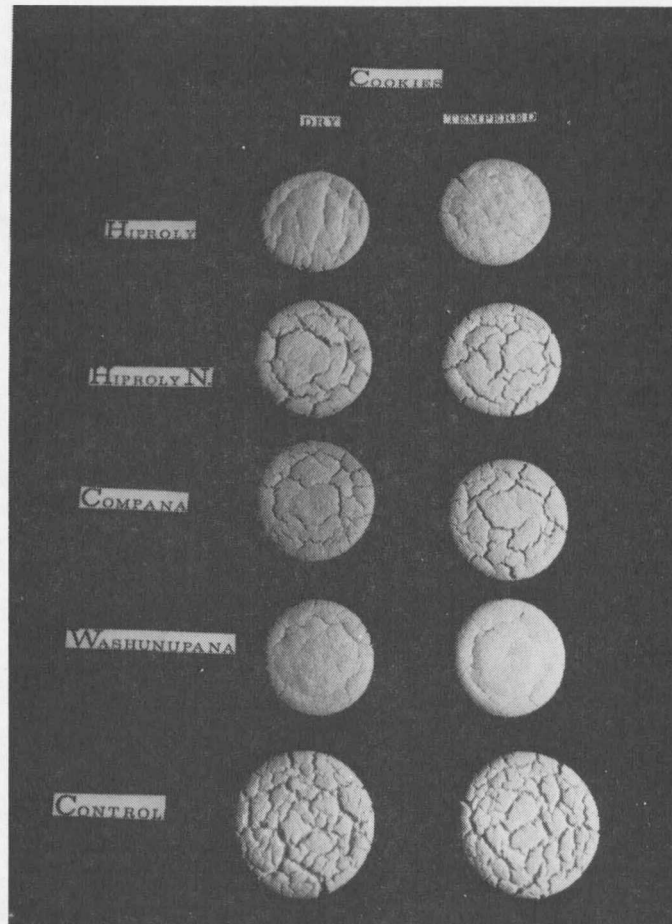


Figure II. Cookies prepared from Barley Flour and Soft Wheat Flour. Control cookies were made from a commercial pastry flour. The scale used was from one to five with one being unacceptable and five being excellent

Hiproly, Dry:	Color - 3.12,	Overall appearance - 2.71
Tempered:	" - 3.00,	" " - 2.82
Hiproly N, Dry:	" - 3.62,	" " - 3.62
Tempered:	" - 3.43,	" " - 3.71
Compana, Dry:	" - 3.38,	" " - 3.38
Tempered:	" - 2.86,	" " - 3.43
Washonupana, Dry:	" - 3.00,	" " - 2.50
Tempered:	" - 2.71,	" " - 2.57

Hiproly Normal, dry treatment, cookies had an overall appearance rating of 3.71 and 3.62, respectively, and a color rating of 3.62 and 3.43. The descending order of color and appearance for both the dry and tempered milling treatments were Hiproly Normal, Compana, Hiproly, and Washonupana. Those cookies with many deep cracks on the surface were rated higher by the panelists than the cookies having very few surface cracks.

Biscuits

The statistical analysis of the biscuit specific volume (Table 1) identified the significant main effects as cultivar ($p < .01$) and temper treatments ($p < .05$). No meaningful cultivar-temper treatment interactions occurred.

The evaluation of biscuit specific volumes (Table 10) indicated that Hiproly was significantly smaller ($p < .01$) in specific volumes than the other three cultivars. Differences in the specific volumes of Washonupana, Compana, and Hiproly Normal were not significant when averaged over all treatments. The tempering of the barley cultivars when taken across all cultivars significantly ($p < .05$) increased the biscuit specific volume. Tempered Hiproly Normal increased significantly ($p < .05$) over nontempered Hiproly Normal in specific volume. Tempering Washonupana and Compana increased the biscuit specific volume, but not significantly. Hiproly, tempered, decreased slightly.

Table 10. Treatment and Cultivar Effects on Biscuit Specific Volume taken over all Replications

Cultivars	Treatments ¹		Cultivar ² Means
	Dry	Tempered	
cc/g			
Hiproly	efg 2.20	efg 2.16	2.18
Hiproly Normal	def 2.28	abc 2.44	2.36 ¹
Compana	abcd 2.37	a 2.46	2.42 ¹
Washonupana	abcde 2.30	abc 2.45	2.38 ¹
Treatments	2.29	2.38	

1 means with the same superscript letter are not statistically different ($p < .05$).

2 means with the same numerical superscript are not statistically significant.

Covariate analysis using yield as the concomitant variable did not change significance of the main effects, cultivar, and temper treatment. The interaction of cultivar-temper remained nonsignificant. Hiproly was still significantly ($p < .01$) different from the other three cultivar means. The differences in biscuit specific volume among Washonupana, Hiproly Normal, and Compana were nonsignificant. The tempering of these four barleys increased the biscuit specific volume significantly ($p < .05$).

The biscuits' physical appearance was judged by a consumer taste panel. The results of the consumer taste panel are tabulated in Table 11. A one to five rating scale was used with one being unacceptable, three being acceptable, and five being excellent. Color and overall appearance were the two categories used to judge appearance. Figure III shows visually the difference in the biscuits among the four barley cultivars, dry and tempered, and the soft wheat flour biscuit control. The color and overall appearance ratings of the control biscuit were 4.14 and 3.93, respectively. Nontempered Hiproly biscuits had a color and appearance rating of 3.17 and 3.00. The color and appearance of Hiproly tempered biscuits were scored 3.12 and 2.62, respectively. The descending order of biscuit color and appearance was Hiproly, Washonupana, Hiproly Normal, and Compana. Compana was graded barely acceptable by the panelists and Hiproly was graded slightly better than acceptable.

Alkaline Water Retention Capacity Test

The cultivar and cultivar-temper treatment interaction were very highly significant ($p < .001$; Table 1). The AWRC test could not detect any significant differences in the temper treatments taken over all four barley cultivars.

Alkaline water retention capacity test means are shown in Table 12. The cultivar means taken across both treatments shows that Washonupana had significantly higher ($p < .05$) AWRC values than the other

Table 11. Taste Panel Evaluation of Self-rising Biscuit Means made from the Flour of Four Barley Cultivars, Two Temper Treatments, and across all Replications

Cultivar ¹	Flavor ⁵	Texture	Color	Overall appearance	Overall palatability	Total score
<u>Hiproly</u>						
Dry ²	2.67	2.33	3.17	3.00	2.67	13.84
Tempered ³	2.75	2.88	3.12	2.62	2.75	14.12
<u>Hiproly Normal</u>						
Dry	2.86	2.71	3.00	2.71	3.00	14.28
Tempered	3.25	3.12	3.12	2.62	3.00	15.11
<u>Compana</u>						
Dry	2.83	2.00	2.50	2.67	2.83	12.83
Tempered	2.62	2.62	2.62	2.50	2.75	13.11
<u>Washonupana</u>						
Dry	3.17	2.83	3.17	2.67	3.00	14.84
Tempered	2.75	2.25	3.00	3.12	2.62	13.74
Control ⁴	3.57	3.57	4.14	3.93	3.79	19.00

1 no significant difference among means within a column (p < .05)

2 means from 6 replications

3 means from 8 replications

4 means from 14 replications

5 the scale used was from one to five with one being unacceptable, and five being excellent

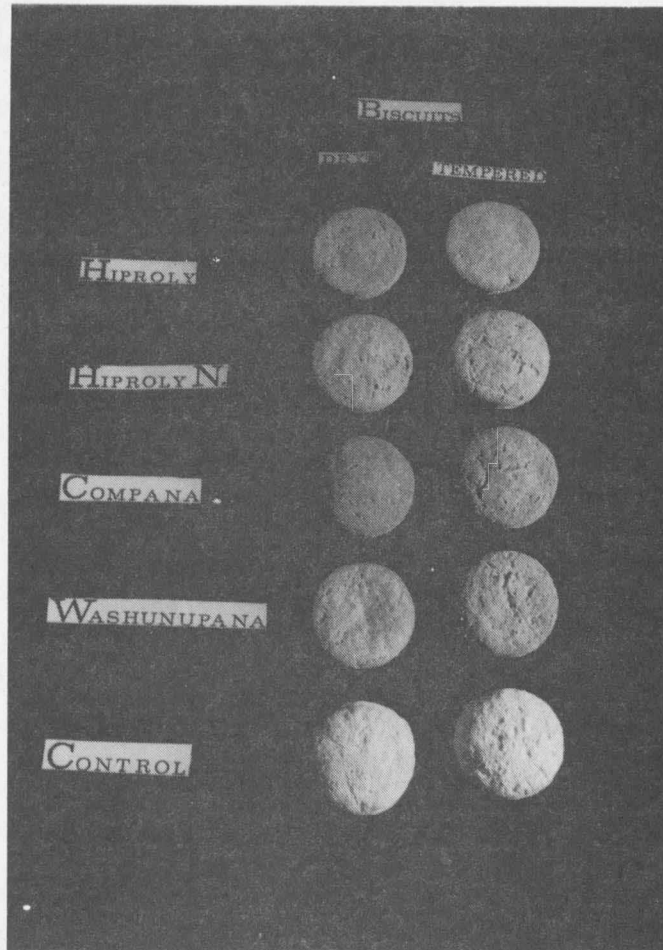


Figure III. Biscuits prepared from Barley Flour and Soft Wheat Flour. Control cookies were made from a commercial pastry flour. The scale used was from one to five with one being unacceptable and five being excellent.

Hiproly, Dry:	Color - 3.17,	Overall appearance - 3.00
Tempered:	" - 3.12,	" " - 2.62
Hiproly N, Dry:	" - 3.00,	" " - 2.71
Tempered:	" - 3.12,	" " - 2.62
Compana, Dry:	" - 2.50,	" " - 2.67
Tempered:	" - 2.62,	" " - 2.50
Washonupana, Dry:	" - 3.17,	" " - 2.67
Tempered:	" - 3.00,	" " - 3.12

three barley cultivars. There was a nonsignificant difference in AWRC values between Hiproly and Hiproly Normal. The AWRC values of Hiproly Normal and Hiproly were significantly greater ($p < .05$) than the Compana AWRC values. The tempering of these four barley cultivars had no significant effect. The AWRC values of Hiproly and Hiproly Normal

Table 12. Alkaline Water Retention Capacity Test - Means showing Cultivar and Treatment Effects taken across all Replications

Cultivar	Treatment		Cultivar Means
	Dry	Tempered	
% 14% Moisture Basis			
Hiproly	118.2	121.5 ^a	119.85 ¹
Hiproly Normal	115.9	121.1 ^a	118.50 ¹
Compana	104.6	102.8	103.70
Washonupana	140.6	136.9	138.75
Treatments	119.8 ²	120.6 ²	

a . . . means with the same letter superscripts are not significantly different ($p < .05$).

1,2. . . means with the same numerical superscript are not significantly different.

increased significantly ($p < .05$) with tempering. Tempering Compana and Washonupana significantly ($p < .05$) decreased the AWRC values. The tempered AWRC means of Hiproly and Hiproly Normal were not significantly different. All other cultivar dry and tempered means were statistically ($p < .05$) different.

To negate the yield variability, yield was used as a concomitant variable in covariate analyses of the AWRC analytical data. The results of the original statistical analysis were supported by the covariate analysis results.

Biscuit specific volume and cookie diameters were correlated with AWRC using standard correlation procedures. The correlation coefficient, r , for biscuit specific volume versus AWRC was -0.011 which is nonsignificant. The cookie diameter versus AWRC correlation factor was -0.76 which is highly significant ($p < .01$).

Cookie Taste Panel

When the control cookies were excluded from the statistical analyses of the cookie panel data, the panelists were not able to distinguish among the four barley cultivars, or between the two temper treatments (Table 9). When the control cookies were included in the statistical analyses of the taste panel data, the control cookies scored significantly higher ($p < .01$) than any of the four barley cultivars in all categories. The differences in the four cultivars and two temper treatments were nonsignificant in all rating categories.

Biscuit Taste Panel

The control biscuit data were excluded from the statistical analysis of taste panel's findings to see if the taste panelists were able to differentiate between the four barley cultivars and the two temper

treatments (Table 11). The panelists were not able to detect any significant differences among the barley cultivars, or between the two temper treatments in any of the five scoring categories. When the control biscuits were included in the statistical analysis, the panelists were able to distinguish between the control and the four barley biscuits.

DISCUSSION

Milling

Experimentally milled soft wheats exhibited endosperm fracturing properties characteristic of the variety (Yamazaki, 1972). Cheigh et al. (1975) found that naked and covered barley yielded different amounts of flour using a Buhler experimental mill. In this study using an Allis experimental mill with one corrugated roll stand and one smooth roll stand, a cultivar difference was found. The difference between yields of a hulled barley and a hulless barley was not found in this experiment. Instead, this experiment showed that the difference in the milling results of Hiproly, Hiproly Normal, Compana, and Washonupana were due to some factors in addition to hulled or hulless. Hiproly, a naked variety, yielded more flour than Compana, a covered variety. Compana yielded significantly more flour than Hiproly Normal, a naked variety. Washonupana, a hulless variety, yielded the least flour. Washonupana's endosperm has nearly 100% amylopectin (Goering, 1976). The alteration in the amylose content of Washonupana from 24-27% amylose to near zero percent may explain why this barley was difficult to mill (Whistler, 1965). Washonupana yielded the highest percentage of fine shorts of all the barley cultivars. This suggests that the particle size of the endosperm was not reduced by the repeated grindings between the corrugated and between

the smooth rolls. Washonupana endosperm appears to be more friable than the other three cultivars.

Cheigh et al. (1975) states that the hulls of covered barley are higher in ash content than the hulls of naked varieties. The ash results of this study support that statement (Table 3). The hulls of Compana were significantly higher in ash than the hulls of the other three barley cultivars. Washonupana's hulls, a naked variety with a large amount of unthrashed kernels, had an ash value that approached the ash of Compana's hulls.

The difference in the ash of the overs of the 70GG (fine shorts) can be explained by the variation in the yield and the amount of endosperm in the fraction. Hiproly and Compana had essentially the same ash and the same amount of fine shorts. The amount of fine shorts for Hiproly and Compana were 15.7% and 14.9%, respectively. The fine shorts ash value of Hiproly Normal was much lower than the fine shorts ash of Hiproly and Compana. The amount of Hiproly fine shorts was 25.8%. Washonupana had the largest percentage of fine shorts and the lowest fine shorts ash, 29.7% and 2.521%.

The differences in the ash between the overs of 183N and the throughs of 183N were of the same significant magnitude. The ash difference between Washonupana's red dog and flour was not significant. Again, this was probably due to the inability to free the endosperm from the hulls, and thus was retained on top of 183N sieve.

The effectiveness of tempering cereal grains is characterized by a decrease in the flour ash, and a change in the ash distribution of the milling products. The flour ash of all four tempered barley cultivars in this study were lower than the ash of the dry treatment. When the results are taken over all fractions and cultivars, the effect of temper on the four barley cultivars was significant ($p < .05$). The lowered ash values of the barley flour were partially the result of lower flour yields of the tempered barley. This could be due to the short temper time of 30 minutes. Cheigh et al. (1975) used tempering times of 24 hours for covered barleys and 48 hours for naked cultivars to optimize the tempering effect. Perhaps the use of the short tempering time caused only the bran and aleurone cells to become moist. Maybe the moisture in these areas of the kernel contributed to the increase in the amount of product retained over the 20 wire, 30GG, and 70GG in each of the four barley cultivars.

Protein and Lysine

Robbins and Pomeranz (1972) reported that the MIAG Maltomat mill's four major barley flour streams had a different percentage of protein and lysine. The hulls had the highest lysine and the lowest protein of the four major fractions. The flour shorts had the next lowest protein and the next highest lysine of the major milling fractions. The flour and flour tailings had the same lysine, but the

flour tailings had more protein. The flour had some tailings flour added to attain 65% extraction. This may explain why the flour protein was higher than the whole grain protein.

This experiment yielded similar results. The hulls contain the highest lysine and the lowest protein. The coarse shorts of Washonupana and Compana had the next highest lysine and the next lowest protein. In Hiproly Normal, the coarse shorts had the highest protein and the next highest lysine. The coarse shorts of Hiproly had a lower protein, and about the same lysine as the fine shorts of Hiproly. The fine shorts of Compana, Hiproly, Hiproly Normal, and Washonupana were higher in protein and lysine than the red dog and flour fractions. The flours of Compana, Hiproly Normal, and Washonupana were similar to the whole kernel barley in protein and lysine. The flour of Hiproly was lower in protein and lysine than the whole grain Hiproly barley. The difference in Hiproly's milling response to lysine and protein distribution may be due to the genetic alteration in the protein synthesis.

The variation in the protein and lysine contents of the flour milling fractions reflects the differences in the distribution of the protein and lysine within the kernels. The hulls and shorts were high in lysine probably due to the presence of the aleurone cells and germ in the three fractions.

The correlation coefficient, r , of % lysine/% protein versus % protein was -0.63 ($p < .01$) for 60 different whole barleys

(Toft-Viuf, 1972). The correlation coefficient of this experiment of % lysine/% protein versus % protein was -0.623 ($p < .01$). Although the r values are similar, the r value of this study was influenced by the differences in the lysine of the milling fractions. Toft-Vief's r value was not. When the lysine values for Hiproly were removed from the correlation data of this experiment, the r value becomes -0.91 ($p < .01$). Munck (1971) reported an increase in the negative value of r when Hiproly was removed from his correlation data.

Since protein is a function of the amino acids present, the amino acid composition plays an important role in the nutritive value of that protein. In barley the first limiting amino acid is lysine. Munck (1964) has suggested that the endosperm protein has a greater nutritional value than the protein from the pericarp, aleurone, and embryo. The flour protein and lysine for Washonupana, Compana, and Hiproly were essentially the same as the whole grain protein and lysine. For these three barley flours, there was no loss in nutritional value of the protein. If barley endosperm protein is more nutritional as Munck (1964) suggests, then the nutritional value of the barley protein for these three barley cultivars may have been increased. The flour protein and lysine in Hiproly was lower than its whole grain protein and lysine. But the increased level of lysine in the Hiproly protein and the increased digestibility of the endosperm protein probably would lead to a greater nutritional value of the Hiproly flour

protein compared to its whole grain protein. The flour protein from Washonupana, Compana, and Hiproly Normal was not as high in lysine as the Hiproly flour protein. Therefore, it seems that the Hiproly flour protein would be the most nutritional of the four barley flours.

Baking Results

Cookie Bake

When the soft wheat control cookies and the four barley flour cookies were made using the Micro Method III of Finney et al. (1950), the control cookies had a higher taste panel rating in every category and a larger cookie spread than any of the barley cookies. The control cookies had an overall taste panel rating of 22.6. The overall rating of the best barley cookies, tempered Hiproly, was 17.74. The control cookie spread was 166 mm, and Hiproly Normal's cookie spread was 149.5 mm (Table 8). The lower results of the barley cookies were similar to results obtained by Badi (1976) for sorghum and millet flour, and Kissel (1976) for Triticale.

Yamazaki (1959) reported that the wheat cultivar influenced the cookie spread and cookie quality. Also, he reported that as the softness of a flour increased, the cookie quality improved. The barley cultivars in this study influenced the cookie spread. Hiproly and Hiproly Normal were known to be different in endosperm hardness (Munck, 1972). Hiproly Normal with a softer endosperm than Hiproly

yielded better cookies (Tables 8 and 11). Hiproly Normal and Compana yielded almost the same cookie spread, but Compana was scored lower than Hiproly Normal by the taste panel. Washonupana and Hiproly had similar ratings from the taste panel. The cookie spread of Washonupana was significantly ($p < .05$) lower than the cookie spread of Hiproly. The differences in the taste panel scores and cookie diameters may be related to the softness of the endosperm. In Washonupana, the difference in cookie spread and cookie quality may be in the lowering of the amylose in the starchy endosperm from 24-27% to near zero.

Biscuit Bake

Four different barley flours were used to make self-rising biscuits using the standard AACC self-rising biscuit method (AACC, 1962). Soft wheat pastry flour was used to make the control biscuits.

In comparing the soft wheat biscuits with the barley biscuits, the control biscuits had a higher specific volume of 2.73 cc/g. The barley flours had these specific volumes: 1) Compana - 2.42 cc/g, 2) Washonupana - 2.38 cc/g, 3) Hiproly Normal - 2.36 cc/g, 4) Hiproly - 2.18 cc/g (Table 9). The flavor test panel judged the control biscuits significantly better than in all categories than the barley flour biscuits.

Elling et al. (1951) showed that the biscuit test could differentiate between those cultivars of hard and soft wheat that made good

biscuits from those cultivars that did not make good biscuits. Hard wheat flour biscuits were rated superior to the soft wheat flour biscuits. In this study Hiproly was inferior to the other three cultivars in specific volume. The taste panel graded Hiproly higher than Compana, but lower than Hiproly Normal and Washonupana. The differences in the taste panel ratings of the four barley cultivars were not significant.

Hiproly was the cultivar with the altered protein composition and reduced carbohydrate levels yielded high lysine and a shrunken endosperm (Munck, 1964). The endosperm of Washonupana was changed to nearly 100% amylopectin. The endosperm of Hiproly Normal and Compana was not known to be changed from 73% to 76% amylopectin. The proteins of Washonupana, Compana, and Hiproly Normal were known to be similar in composition. The difference in volume response of Hiproly compared to the volume response of the other three cultivars could be due to the differences in the makeup and the functionality of the Hiproly proteins.

The biscuit doughs made from barley flours had a much higher water absorption than the soft wheat flour doughs. The soft wheat flour had a dough absorption of 71.8%. Barley flour dough absorption was 89.2%. The reasons for the higher barley flour water absorption could be higher starch damage, a higher amount of gums, pentosans, and cellulose material in the barley flours.

The dough handling properties of the barley flour biscuits and soft wheat flour doughs varied considerably. The barley flour doughs were much stickier than the soft wheat flour doughs. The stickiness of the barley flour may be explained by the higher dough absorption and the presence of B-glucans and pentosans, non-starchy, gummy polysaccharides (Preece, 1952). Luchsinger et al. (1958) reported barley was composed of 5% B-glucans. B-glucans form a very viscous solution when mixed in an aqueous solution (Bourne, 1970). The B-1-3-glucanase and B-glucans appear to be associated with aleurone cells. The B-glucans are part of the aleurone cell wall. The B-glucanases are retained within the aleurone cell (Bathgate, 1975). The B-glucanase can be released when the aleurone cells are ruptured by milling (Palmer, 1973). The B-glucanases release the B-glucans from the aleurone cell wall to form a gummy viscous product.

Alkaline Water Retention Capacity Test

The correlation value of AWRC versus barley flour cookie spread was -0.76 ($p < .01$) based on 40 observations. Yamazaki (1953) reported the correlation value of AWRC versus soft wheat flour cookie spread of -0.778 ($p < .01$) based on 56 different cookie bakes of the 1944 soft wheat crop.

The AWRC test indicated the order of the cookie spreads correctly for three of the four barley cultivars. The test was not able to

distinguish between Hiproly and Hiproly Normal. The cookie test indicated considerable difference. Hiproly has been shown to be different from Hiproly Normal in the lower carbohydrate level and the altered protein composition (Munck, 1964; Robbins, 1972). Although Hiproly and Hiproly Normal were different in protein composition, and carbohydrate content, the AWRC was not able to detect any differences.

The correlation factor of AWRC versus biscuit specific volume was -0.011. This relationship was not significant. There are three possible reasons why AWRC did not correlate to biscuit specific volume. The first probable explanation was that factors in addition to the absorption of water influences biscuit volume. The second possible explanation was that the biscuit test could not differentiate adequately between three of the barley cultivars, Hiproly Normal, Compana, and Washonupana. The third explanation was that biscuit volume is a cubic measurement, and the test was designed to test linear spread.

The AWRC values of the barley flour were higher than the soft wheat flour AWRC values. The AWRC means of the barley flour varied from Compana's 103.7% to Washonupana's 138.75%. The AWRC means of soft wheat flour varied from 40% to 60% (Yamazaki, 1953). The multiple regrinds of the barley milling process may have reduced enough of the hulls and aleurone cells to pass through the 183N sieve to become flour. The ash values were high enough to indicate that some hulls and aleurone cells were in the flour. The multiple regrindings may

have caused more starch damage in the barley flour than was present in the soft wheat flours of Yamazaki. Yamazaki (1955) reported that ball milled prime starch had an AWRC value of 430% and that Hydroxyethyl cellulose had an AWRC value of 1030%.

Taste Panel

The taste panel was not able to differentiate between the four barley cultivars and the two temper treatments in either the sugar cookies or the biscuits. The panelists graded the soft wheat controls significantly better than the barley cookies or biscuits. The barley cookies were rated acceptable and the biscuits were rated slightly lower than acceptable by the panelists.

The best explanation for the failure of the taste panel to differentiate between the barley cultivars was that the taste panelists were too few in number to differentiate between the minute differences in the flavor, texture, color, overall appearance, and overall palatability of the barley flours. The biscuits and cookies may have lost some of their unique flavor characteristics by being frozen four months prior to the taste panel testing. If the cookies and biscuits had been tasted the morning after the bake, the panelists may have been able to differentiate between the barley cultivars.

CONCLUSION, SUMMARY AND RECOMMENDATIONS

This thesis deals with the answers to five principal questions:

1. Can barley be experimentally milled using an Allis roller mill?
2. Where is the lysine found in the milling fractions?
3. Is it possible to develop a test that will predict, or indicate, the baking quality of barley flour?
4. Will the cookie or biscuit bake be sensitive to the differences among the barley cultivars?
5. Can acceptable cookies and/or biscuits be baked using barley flour?

The answer to question one was yes, it was possible to distinguish between cultivars using the Allis experimental roller mill. In addition, the milling test was able to differentiate between dry and tempered milling treatments, and yielded milling fractions that were different in protein and ash content. In all cultivars the dry milling treatment had higher flour extractions and flour ash than the tempered milling treatment. In both milling treatments, Hiproly had the highest flour yield, followed by Compana, Hiproly Normal and Washonupana. Regardless of the milling treatment and cultivar, the ash decreased through the fractions from the highest, hulls, to the coarse shorts, fine shorts, red dog, and flour, the lowest. The protein decreased through the fractions from the highest, fine shorts, to the red dog,

flour, coarse shorts, and hulls. This relationship held regardless of the temper treatment for Compana, Hiproly Normal, and Hiproly. In Washonupana, the protein increased from the hulls to the flour in both temper treatments. The flour protein of Hiproly Normal, Washonupana, and Compana was essentially equal to the whole grain protein. In Hiproly, the whole grain protein was higher than its flour protein.

The answer to question two was that the highest lysine when calculated as a percentage of protein was located in the hulls followed by the coarse shorts, fine shorts, red dog, and flour for Hiproly Normal, Compana, and Washonupana. Hiproly has the highest lysine in the fine shorts followed by the coarse shorts, hulls, flour, and red dog. The whole barley lysine was essentially the same as the flour lysine in Compana, Hiproly Normal, and Washonupana. The lysine in the flour of Hiproly was lower than the lysine in its whole grain.

The correlation of the ratio of % lysine to % protein and % protein was -0.623 ($p < .001$). When the Hiproly lysine data were taken out of the correlations, the correlation coefficient increased to -0.91 ($p < .001$). This negative relationship between protein and lysine means that as the protein increases, the percentage of lysine in that protein decreases. In Hiproly there was no significant correlation between % lysine/% protein and % protein. The amount of lysine appeared to be independent of its protein content.

The biscuit and cookie bake tests had high F values for cultivar and significant F values for the temper treatments. The cookie bake F value for cultivar was 79.5 (df = 3,32; $p < .001$). The biscuit bake F value for cultivar was 10.0 (df = 3,32; $p < .01$). The higher F value of the cookie bake indicates that the cookie bake was more sensitive to cultivar differences than the biscuit bake test. The cookie bake was able to differentiate among Hiproly, Compana, and Washonupana in cookie quality as determined by cookie spread. The cookie bake test was not able to differentiate between Hiproly Normal and Compana. The biscuit bake was able to indicate that biscuits from Hiproly were significantly ($p < .01$) smaller in specific volume than the other three cultivars. Washonupana, Compana, and Hiproly Normal were not significantly different in biscuit specific volume when averaged over all cultivars and replications. Tempered barley flour had a significantly ($p < .05$) greater biscuit specific volume and cookie spread when taken across all cultivars and replications. From among the cultivars and temper treatments used in this study, tempered Compana barley flour had the best over all biscuit and cookie baking performance.

The answer to the question can the alkaline water retention capacity test (AWRC) be used to indicate the baking quality of barley flour depended on the flour used and whether cookies or biscuits were baked. The AWRC test was not able to predict cookie quality in all cases.

The overall correlation of AWRC versus cookie spread was -0.76 ($p < .01$). AWRC was able to correctly predict the cookie spreads of Hiproly Normal, Compana and Washonupana but could not predict the cookie spread of Hiproly. There was no significant correlation between AWRC and biscuit specific volume. Therefore, AWRC was not able to predict biscuit specific volume.

The answer to question five was that the consumer taste panel rated barley flour cookies as acceptable, and the barley flour biscuits as not acceptable. The panel rated the soft wheat pastry flour cookies and biscuits as superior to barley flour biscuits and cookies. The panelists indicated a need for considerable improvement in the barley flour cookies and biscuits in color, flavor and texture.

The milling, baking, AWRC, lysine and consumer taste panel tests indicated that Compana had the best quality followed by Hiproly Normal, Hiproly and Washonupana.

The difference in the barley cultivars' response to the AWRC, cookie, biscuit, protein, lysine, ash, milling and taste probably represent the differences in the genetic make-up of the four barley cultivars. Each of the barley cultivars differed from the others by one or more genes. Hiproly possessed the high lysine gene which Hiproly Normal did not. Compana had the hulled gene whereas Hiproly, among many other genetic differences, possessed the hullless gene. Washonupana differs from Compana in at least three important traits:

it has waxy starch, short awns, and no hulls. Washonupana and Hiproly have many genetic differences, among them are the possession of the waxy starch gene by Washonupana and the lack of the high lysine gene by Washonupana.

Summary

The milling, baking, tempering, alkaline water retention, lysine in the milling fractions, and the consumer reaction to barley flour cookies and biscuits were studied in four barley cultivars, Hiproly, Hiproly Normal, Compana, and Washonupana.

The milling test using an Allis experimental roller mill had significant cultivar and temper treatment main effects. Hiproly yielded the highest amount of flour followed by Compana, Hiproly Normal, and Washonupana. The dry milled barley yielded more flour than tempered barley.

The cookie and biscuit bake was influenced by cultivar and temper treatment. Hiproly Normal and Compana had similar cookie spreads and were significantly ($p < .05$) larger than either Washonupana's or Hiproly's cookie spreads. Washonupana had a significantly larger ($p < .05$) cookie spread than Hiproly. In the biscuit bake, the specific volumes of Compana, Hiproly Normal, and Washonupana were similar. The biscuit specific volume of Hiproly was significantly ($p < .05$) smaller than the other three cultivars. For both the biscuit and the cookie bake tests, the tempered barley flour

significantly ($p < .05$) increased the biscuit specific volumes and the cookie spreads. Tempered Compana flour yielded the best cookies and biscuits when taken over both baking tests.

The AWRC was not always able to predict cookie spread. The overall correlation was -0.77 ($p < .01$). It was able to predict the cookie spread of Hiproly Normal, Compana, and Washonupana but not Hiproly. There was no significant correlation between AWRC and biscuit specific volume.

The protein and lysine varied from one sieve fraction to other sieve fractions. In Compana, Hiproly, and Hiproly Normal, the greatest protein concentration was found in the fine shorts followed by the red dog, flour, coarse shorts, and hulls. In Washonupana, the protein increased from the hulls to the flour. The lysine when calculated as a percentage of protein decreased from the hulls to the endosperms for Washonupana, Compana, and Hiproly Normal. In Hiproly, the highest lysine was located in the fine shorts followed by coarse shorts, hulls, flour, and red dog. The milling fraction lysine distribution of Hiproly was different than the milling fraction lysine distribution of Hiproly Normal, Compana, and Washonupana. The barley flour cookies were rated acceptable but the barley flour biscuits were not rated acceptable by the consumer taste panel.

Recommendations

The results of this thesis are valid for only the four cultivars grown at the Bozeman Agricultural Research farm during the 1975 year. Further research should be done to see if these tests could be used universally for barley flour.

A determination needs to be made to see if the flour from an Allis Experimental Mill will give the same results as the flour from a Buhler Experimental Mill. A study should be made of the water-solubles, starch, protein, and starch tailings fractions of the barley flour to determine which fraction, or fractions, prevent barley flour from producing cookies the equivalent of soft wheat flour. Another question which needs answering is why barley flour has a much higher alkaline water retention capacity than soft wheat flour. When barley cultivars have been identified that give the best baking response, then a trained taste panel should be used to test the acceptability of these cultivars in baked food products. An last, but perhaps the most important, a nutritional study should be conducted to identify the most nutritious barley flour.

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APPENDIX

GLOSSARY OF TERMS

- Grit gauze - a cotton thread dipped repeatedly in a wax, or resin, and woven to make a sieve cloth,
- Wire - metal threads woven together to make sieving material,
- Nitex - nylon thread woven together to make sieving material,
- Endosperm - starch center of the kernel excluding the hulls, bran, and germ,
- Roller Mill - the process of gradual grinding of grain through a series of steel rolls,
- Mill - grind,
- Air Classifying - the process of using air to separate flour according to particle size and weight,
- Red Dog - tailings, in this study, is the overs of the 183 nitex sieve,
- Temper - the addition of water to grain to change its moisture level and milling characteristics,
- Shorts - by-product of milling that includes germ, fine bran, and some flour,
- Aleurone - amorphorous protein layer immediately under the bran; separates the endosperm from bran coat,
- Extraction - the amount of endosperm separated from the bran kernel,
- Thousand Kernel Weight - the weight in grams of one thousand kernels of grain,
- Absorption - the amount of water necessary to obtain an optimum consistency,

- Hulls - the outer covering of a seed,
- Pericarp - ripened and variously modified walls of a plant ovary.

TASTE PANEL SCORE SHEET

CODE _____ TASTER'S NAME _____

Below are listed several characteristics to be evaluated.
Rate each numerically on the following scale.

- 5 -- excellent (great as is, no improvement needed)
- 4 -- very good (pretty good, but not of rave quality)
- 3 -- acceptable (OK, but could stand improvement)
- 2 -- barely acceptable (edible, if nothing better is around)
- 1 -- unacceptable (forget it, probably not worth working on)

In addition, briefly describe, or characterize, your reaction to the quality being tested.
Use one or two words, for example: under texture -- grainy, smooth, lumpy, crunchy, crisp.

Sample Number	CHARACTERISTICS				
	Texture	Flavor	Color	Overall Appearance	Overall Palatability
	Rat- Reaction ing	Rat- Reaction ing	Rat- Reaction ing	Rat- Reaction ing	Rat- Reaction ing

