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 in Home Economics
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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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Date 1-9-78

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TO BARLEY

by

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ABSTRACT

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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 fiberous 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 hordein 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.

Zaehringer (1956) studied the interaction of starch, gluten, amylodextrins, 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 amylodextrins produced smaller and darker biscuits than soft wheat amylodextrins.

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 acceptibility, 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 tastes 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 1XT2 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).