MILLING AMARANTH WITH TANGENTIAL ABRASIVE DEHULLING DEVICE

by

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DEDICATION

This work is dedicated to:

My Parents who realized the importance of my education and provided funds so that I could easily obtain my goal of an advanced degree.

Patt Johnson who instilled in me the spark of wanting to learn all I could about the natural world around me.

My friends in the Grain Science Department who encouraged and inspired me during my time at K-State.

God who has given me the gift of curiosity and motivation to learn of and discover the wonders and complexities of His creation.

INTRODUCTION AND LITERATURE REVIEW

HISTORY OF AMARANTH

As early as 5000 B. C., the genus Amaranthus was a wild plant used for food by the Ocampo indians of Mexico. By 1500 A. D., the plant had been domesticated and was grown by the Aztec civilization. Following the Spanish invasion of Mexico in 1519 (Cole, 1979), the growth of amaranth was banned because of its use as a tribute in religious ceremonies. Cortez threatened to punish anyone growing amaranth by cutting off their hands. It proved to be an effective measure and amaranth was never again grown in large quantities.

Family farmers of Mexico have been growing amaranth in small quantities for over 300 years. By the late 19th century, grain amaranth had been introduced to Northern India and Western Nepal (Jain et al, 1980). In the early 1970's, amaranth grain was "rediscovered" by a medical doctor who realized its nutritional benefits in malnourished children. The doctor persuaded Rodale Press to investigate its nutritional properties and agronomic characteristics. Today, Rodale Press has the world's largest collection of amaranth germ plasm. Many midwestern farmers grow small fields to meet the demands of health food companies utilizing the whole grain in pancake mixes, granola, graham crackers, cookies and bread. Most recently a major food

company, General Foods, has expressed an interest in processing amaranth (Stocker, 1987).

PRODUCTION OF AMARANTH

Amaranth is known to most North Americans as "pigweed". This weedy species of amaranth (Amaranthus retroflexus) is quite resilient, occurring anywhere from an urban backyard to a farmer's sorghum field.

Amaranth utilizes the C_4 carbon-fixation pathway which reduces its water requirement (El-Sharkway et al, 1968). Amaranth is very tolerant to arid conditions and poor soils (Pal and Khoshoo, 1974). Maturity for most grain amaranth is four to five months (Feine et al, 1979). Typical yields of amaranth range from 900 kg/ha to 1,900 kg/ha. Amaranth compares favorably in yield with most cereal crops such as wheat, rye and oats which yield about 1,800 kg/ha (Crabbe and Lawson, 1981). Amaranth is superior in grain yield compared to millet and sorghum under drought conditions (Saunders, 1984).

Weed control is a problem because domesticated amaranth is in direct competition with wild amaranth. Thus, use of herbicides is impossible and weeds must be eliminated by hand. Insects include leaf chewing and sucking insects, but none do major damage in the United States (Harwood, 1980). A comprehensive survey of pests on the crop has not been done.

NUTRITIONAL CHARACTERISTICS OF AMARANTH

Amaranth contains 16-19% protein on a dry basis. It contains an unusually high amount of lysine which differentiates it from cereal grains. By combining amaranth and maize, it is possible to make a nutritionally complete protein (Kauffman and Wagoner Haas, 1984). Amaranth contains more dietary fiber than wheat, corn, rice or soybeans. It has no cholesterol and is low in saturated fats (Stiebritz et al, 1985).

Processing amaranth by wet cooking, drum drying (Bressani, 1984) and extrusion (Mendoza and Bressani, 1987) increases digestibility. The process of milling is advantageous because indigestible glucide material, which hinders digestion, is eliminated (Goussault and Adrian, 1976). However, some protein is lost if the bran/germ fraction is discarded. Thus, the advantage of increased digestibility is offset by the loss of nutrients. Protein-rich fractions of amaranth obtained by abrasive milling, are good enriching agents for baby food (Sanchez-Marroquin, 1984).

MORPHOLOGY OF AMARANTH

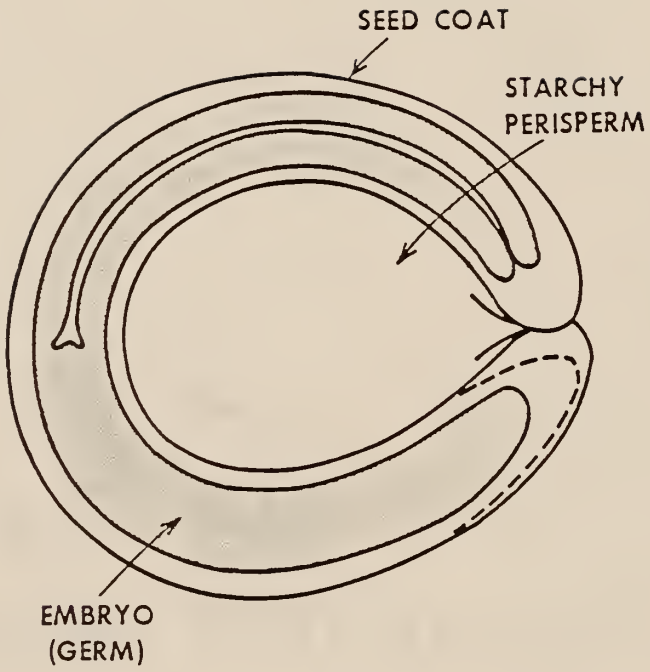
Amaranth grain is lenticular and very small, averaging one millimeter in diameter (Saunders and Becker, 1984). Each grain consists of three major components: seed coat, germ, and perisperm. The germ (embryo) surrounds the entire

perisperm much like the sugar beet (Saunders and Becker, 1984; Irving et al, 1981)(Fig. 1). The seed coat attaches directly to the perisperm with no cell layers between the two, except in the region of the embryo where the seed coat is attached to the endosperm (Irving et al, 1981). The maturing amaranth embryo utilizes endosperm for energy reserves and thus only a single layer of endosperm remains in the mature seed (Esau, 1965). The perisperm is derived from diploid cells and consists of polyhedral parenchyma cells. Unlike cereal grains, there is no aleurone cell layer. The perisperm is a storage tissue and contains highly compacted starch granules with little to no protein matrix holding them together (Irving et al, 1981).

DRY MILLING

The primary goal in the dry milling of cereals is to separate the bran and germ from the endosperm. Roller milling does this most efficiently with wheat. Efficiency of the milling process depends greatly on the structural organization of the kernel. Grains such as sorghum and millet roller mill with reduced efficiency. In the case of millet and sorghum, the pericarp is less tough than that of wheat and pulverizes during roller milling. Bran and endosperm mix and it becomes nearly impossible to separate the two by sifting because of the fineness of the pulverized bran (Perten, 1977).

Figure 1. Morphology of amaranth grain (reprinted from Irving et al, 1980).


SEED COAT
STARCHY
PERISPERM
EMBRYO
(GERM)

Abrasive milling is another type of dry milling process. Instead of rolls opening the kernel and scraping the endosperm from the bran, the outside portion (bran) is abraded from the kernel. Following bran removal, the endosperm portion is often ground into a flour (deMan et al, 1972). This process is best suited for round grains because of the ease of reaching all parts of the grain.

ABRASION MILLS

Abrasion mills, most often called "pearlers", have an abrasive cone set inside a wire screen. The cone rotates inside the screen, causing grains to rub against each other and against both cone and screen. Efficiency of this process is judged by the extent to which endosperm (resulting from kernel breakage) is mixed with bran (Eggum et al, 1982).

Some physical characteristics of the grain structure influencing milling efficiency include hardness of the endosperm, adhesiveness of the hull, size of the grain, and shape (Munck, 1982).

DEVELOPMENT OF LABORATORY ABRASIVE MILLS

Breeders interested in grains destined to be processed by abrasion want to control some of the characteristics of grain structure mentioned above. To test the results of their efforts, breeders require a mill that can handle small samples sizes (as little as five grams), has good

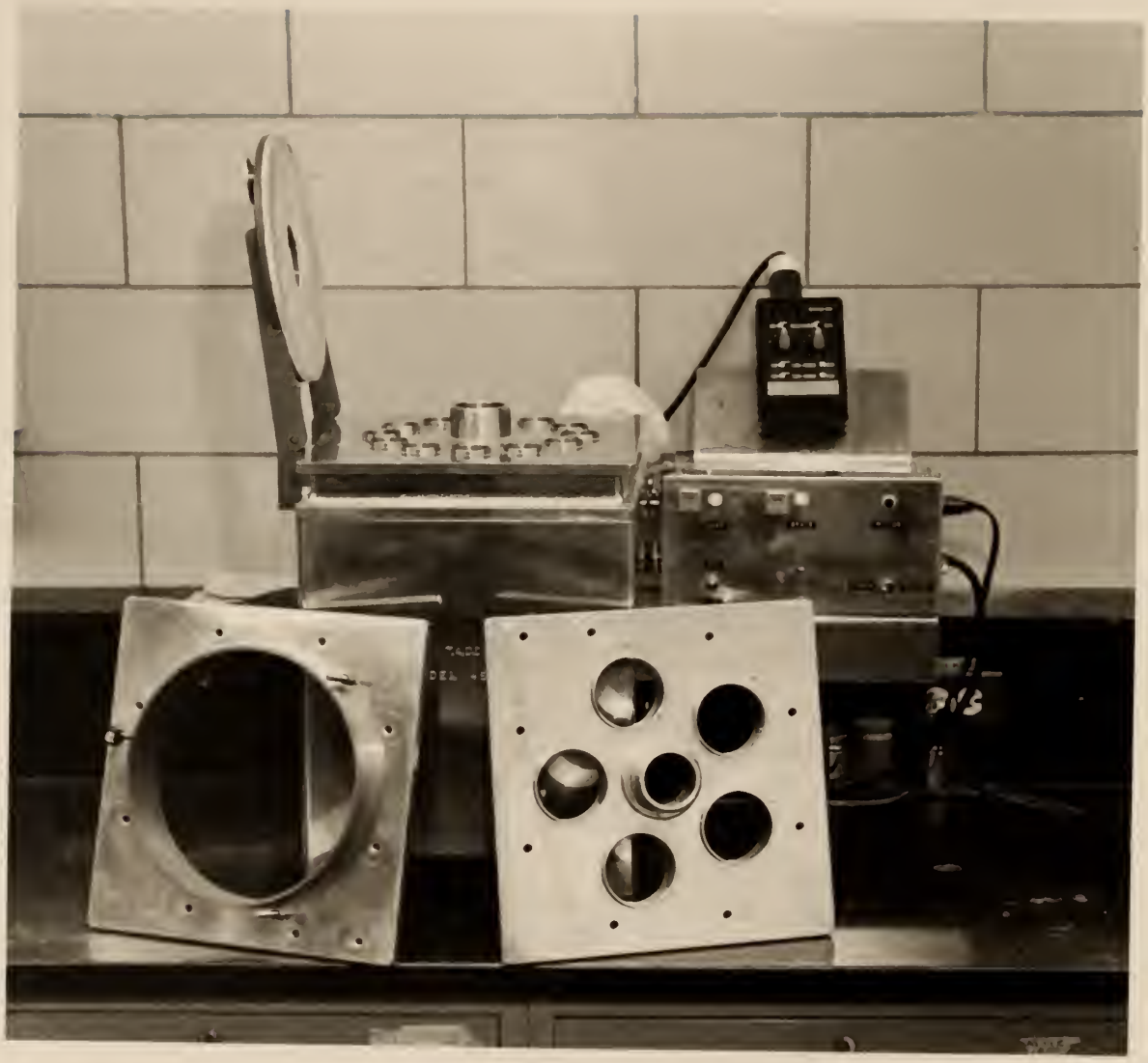
reproducibility, processes multiple samples, and can collect material removed from the grain with high efficiency. Most laboratory mills that have been developed meet only a few of these requirements.

Weinecke and Montgomery (1965) utilized a brush-type mill that produced both tearing and an abrasive action. However, this mill required a minimum sample size of one pound. Normand et al (1965) developed a mill which used tangential abrasion to carefully control removal of successive layers of bran. Although the mill only used a 25 gram sample, recovery of the bran and germ was inconvenient (Shepherd, 1979). The Buhler experimental mill has also been used (Stringfellow and Peplinski, 1966) but it could not separate the germ and required five pounds of sample. Rooney and Sullins (1969) devised a method for milling 100 to 200 gram samples of sorghum with a modified Strong-Scott Barley Pearler. They decreased the sample size the mill required, but processed only one sample at a time. Shepherd (1982) modified a UDY cyclone mill and decreased the sample size required to 5 - 25 grams. However, it too could only process one sample at a time.

TANGENTIAL ABRASIVE DEHULLING DEVICE

Development of the Tangential Abrasive Dehulling Device (TADD) (Fig. 2) met the needs of breeders. It has a wide range of sample sizes, multi-sample processing capabilities,

Figure 2. The tangential abrasive dehulling device plus accompanying 1, 5 and 12 cup plate types.



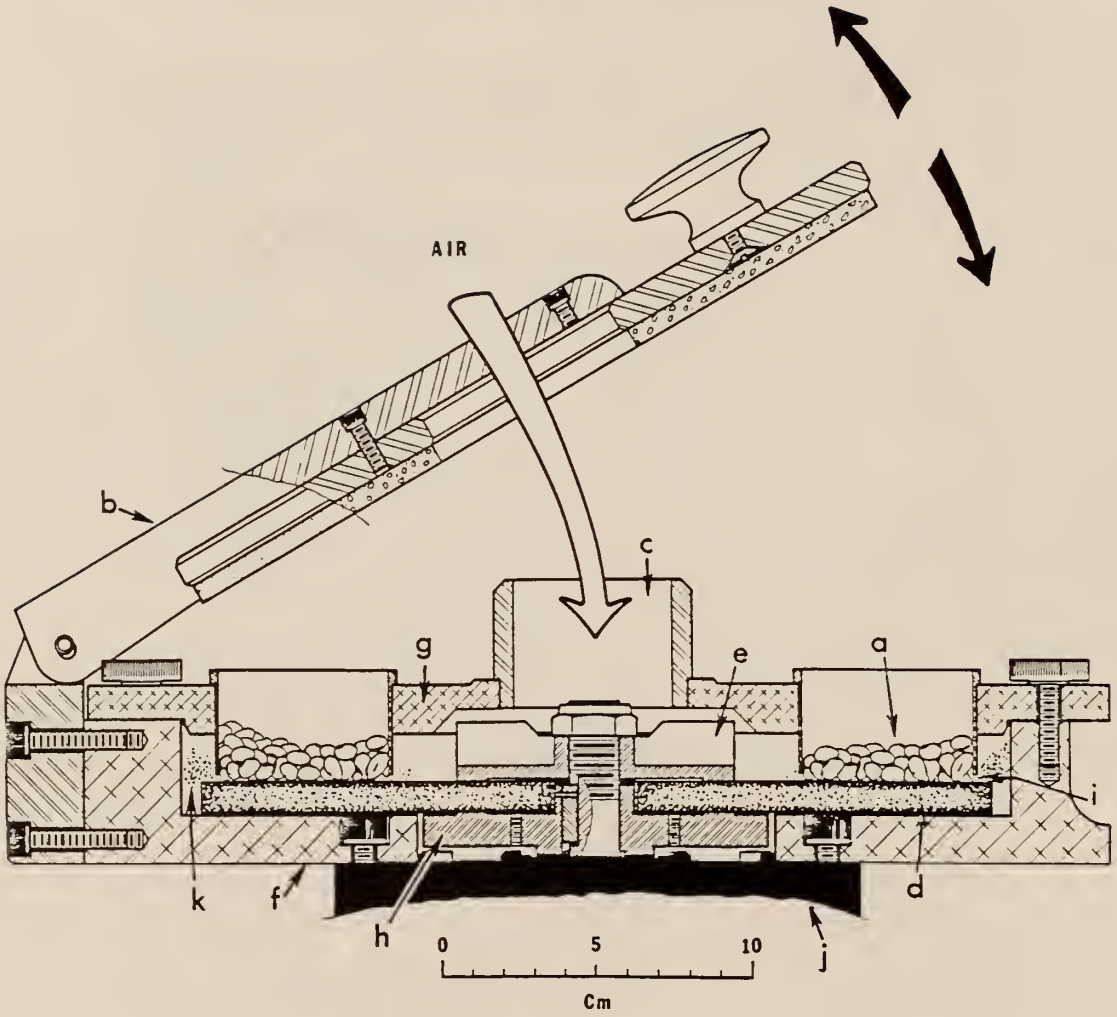
excellent reproducibility (coefficient of variation ranges from one to four percent), and high efficiency in separation and collection of the bran fraction. The TADD has been used on a variety of cereals, legumes and oilseeds (Reichert et al, 1986).

The TADD is based on the same principle, tangential abrasion, as the mill Normand and coworkers (1965) developed. Hogan et al (1964) first developed the concept of tangential abrasion and found that if rice was exposed to a rapidly moving abrasive surface, the outer layers of the kernel would be successively removed without the breakage of the kernels that normally occurs with other abrasive mills. Combined rotational and translational motion, along with the static pressure of a column of grain allows individual kernels to be cyclically subjected to the abrasive action of a disk and exposed to the action of the rubbing of surrounding grains. Normand et al (1965) used a tangential abrasion mill to remove successive peripheral layers from wheat, barley, sorghum and rice and studied protein distribution of resulting fractions. These milling fractions were found to contain 2.5X the amount of protein in the entire kernel. Barber (1972) utilized tangential abrasion to study constituent distribution patterns within the rice kernel. Barber concluded the mill could not remove concentric layers in a rigorous fashion, but milling was homogenous, easily controllable and reproducible. Shepherd

(1979) later observed that the tangential abrasive mills were relatively slow (only 2-5% fines could be removed in 30 minutes to an hour) and difficult to operate. The principle of tangential abrasion is used by large-scale mills such as the Satake Grain testing mill used by Rooney et al (1972), the Decomatic dehuller described by Reichert (1982), and vertical-type dehullers (Reichert, 1982).

The TADD contains a horizontally mounted abrasive disk which rotates below bottomless sample cups mounted in a steel plate (Fig. 3). This geometry allows rapid and reproducible processing of multiple samples. In 1981, Oomah and coworkers designed the prototype of the TADD. As much as 40% of the kernel could be removed in seven minutes, with coefficients of variation ranging from one to four percent, depending on the abrasive disk utilized (Oomah et al, 1981). Reichert and coworkers (1986) improved Oomah's design by including different sample plates which have 1, 5, or 12 sample cups, stone abrasives and aluminum plates with interchangeable adhesive sanding disks, bran collection via air movement generated by a fan attached to the rotating disk, an adjustable electronic timer, an electromagnetic brake controlled manually and by the timer, and degree of milling control, adjustable by changing the gap between the bottomless sample cups and the abrasive disk.

Figure 3. Cross-section of the TADD illustrating: a. grain in the sample cup, b. hinged lid, c. air inlet port, d. abrasive disk, e. fan, f. base, g. eight-sample cup plate, h. driving disk, i. gap between bottom of sample cup and abrasive disk, j. brake and k. bran (reprinted from Reichert et al, 1986).


AIR
b
c
g
e
a
i
k
f
h
d
j
0
5
10
Cm

AMARANTH AND THE TADD

Betschart et al (1981) made several unsuccessful attempts to mill amaranth on roller mills. Sanchez-Marroquin et al (1985) found the yield of flour produced with a Brabender roller mill was only 26%, which is extremely low when compared to the average 72% flour produced from wheat. This illustrates amaranth's structural unsuitability for roller milling.

Abrasive milling of amaranth was found to be successful by Betschart et al (1981) who used a modified Strong-Scott Barley Pearler in which the wire screen was replaced with a 16 gage stainless steel sheet. Because of the structural suitability of amaranth to tangential abrasion and the fact that varietal development of amaranth is in the beginning stages, the TADD meets the processing needs of amaranth and the needs of amaranth breeders.

MATERIALS AND METHODS

MATERIALS

Grain Samples. A. cruentus was obtained from Jack Horst, Edgar, Nebraska. A. hypochondriacus was obtained from Post Rock Natural Grains, Luray, Kansas. Neither sample required cleaning (see Appendix I). Moisture contents of the A. cruentus and A. hypochondriacus were 10.8% and 9.8%, respectively.

TADD Components. The TADD was manufactured as model 4E-115 by Venables Machine Works Ltd., Saskatoon, Saskatchewan, Canada (Fig. 2). The machined aluminum disk, to which an abrasive cloth was fixed, was 10 in. in diameter and 9/32 in. thick with a 1-in. diameter arbor. The heavy-duty, adhesive-backed, abrasive cloths (Shur-Stick disks) were manufactured by Merit Abrasive Products Inc., Compton, California and purchased from B.C. MacDonald and Company, Kansas City, Kansas. Stone disks A-46 L5VBE, A-36 L5VBE and A-24 L5VBE were manufactured by Norton Canada Inc., Hamilton, Ontario, Canada. The bran collection port consisted of a 5 pound seed bag obtained from Garst Seed Company, Garden City, Kansas.

Additional Milling Equipment. The UDY cyclone sample mill was manufactured by the UDY Corporation in Fort Collins, Colorado.

Organic Solvents. Reagent-grade ethanol, acetone and toluene were obtained from Fisher Scientific Company, Fairlawn, New Jersey.

Dyes. Methylene blue and eosin-Y were obtained from Fisher Scientific Company, Fairlawn, New Jersey.

Scanning Electron Microscopy. The ETEC U-1 Autoscan scanning electron microscope utilized was located at the Kansas State University agricultural experiment station, Manhattan, Kansas.

METHODS

TADD Operation. Grains were abraded by a rotating, horizontally mounted stone or abrasive cloth mounted on an aluminum plate. The abrasive disk was driven by a shaft from the motor (Fig. 2). The fan, which secures the abrasive disk to the driving disk and circulates air, was screwed directly onto the motor shaft when the 5 or 12 cup plate was used. When the 1 cup plate was used, a cup, whose purpose was to keep seeds from entering the shaft area during milling, was placed on the motor shaft and secured with washers and a screw. Reichert et al (1986) used the fan to tighten down the cup onto the abrasive surface. During milling, direction of abrasive disk rotation tightened the fan. The fan could not be removed by a rubber hammer normally used to loosen it because of the fan's

location inside of the cup. Washers which only sat around the shaft, instead of screwing onto it, eased disassembly.

The gap between the bottomless cups and the abrasive was the size restraint on material escaping (bran fraction) the cup during milling (Fig. 2). Shims were placed under the driving disk to vary the gap size. A hinged lid covered the 12 and 5 cup plates. A separate lid was used with the 1 cup plate.

Milling time was controlled by an electronic timer. An electromagnetic brake stopped the TADD when time expired. The aspirating device, described by Oomah et al (1981) was used to remove the abraded grain from the sample cups. Bran was collected in the bran collection port.

Gap Size Adjustment. Shims used ranged in thickness from 0.001 in. to 0.062 in. Shims were added to the driving disk until the abrasive disk touched the bottom of the sample cup(s). At this point, manual movement of the abrasive disk was not possible and total shim thickness was reduced by 0.001 in. increments until abrasive disk movement occurred without the "ticking" noise that indicated abrasion of sample cup(s). A few amaranth seeds were placed in one cup and the abrasive disk was manually rotated to determine: (1) if seeds escaped, (2) if seeds remained with "ticking" or (3) if seeds remained in the cup without "ticking". If the seeds escaped, the gap was too large and total shim thickness was increased in 0.001 in. increments until (3)

occurred. If the seeds remained in the cup with "ticking", total shim thickness was decreased in 0.001 in. increments until (3) occurred. The occurrence of (3) indicated the ideal gap was attained. This was confirmed by running all sample cups with the specified sample amount. If the gap was too large, the bran collection port contained whole amaranth seeds. Total shim thickness then had to be increased in 0.001 in. increments. Gap size was readjusted each time an abrasive or plate type was changed.

To provide a close fit between the sample cups and the horizontally mounted abrasive, the cups in the 12 cup plate were ground *in situ* using an 120 grit abrasive fixed to the aluminum disk. Because the machined aluminum disk thickness did not match the 4E-115's specifications exactly, two cardboard disks were fitted to the top of the driving disk so the fan would tighten down completely onto the disk.

Sample Size Determination. To determine the sample size, all of the machine and operating variables other than sample weight were fixed: abrasive, 180 grit; plate, 12 cup; and time, 2 minutes. Speed was constant at 1,750 rpm. Reichert et al (1986) utilized 5 grams of quinoa in the 12 cup plate of the TADD. Since the size of quinoa (2 mm) (Simmonds, 1965) is similar to amaranth, five grams of amaranth was used as a starting point. Sample size was varied in increments of five grams up to 15 grams. The

coefficient of variation increased as sample size increased. Five grams was chosen as the optimum sample size.

Sample size for other plates were calculated on the basis of equivalent on a seed weight:abrasive area ratio. The sample size was determined as follows:

Seed weight:abrasive area ratio for 12 cup plate:

5 grams amaranth/10.5 cm^2 abrasive area = 0.48g/cm^2

therefore, to maintain the same ratio, the sample size for 5 cup plate was:

(0.48 g/cm^2) X 36.6 cm^2 = 17 g amaranth

where 36.6 cm^2 is the abrasive area available in each cup of the 5 cup plate.

Sample Size for the 1 cup plate:

(0.48 g/cm^2) X 396 cm^2 = 190 g amaranth

Abrasive Disks. Only aluminum disks with adhering abrasive cloths finer than 50 grit could be used with the 5 and 12 cup plates due to loss of whole grain. Scanning electron microscope pictures were taken of the 50, 120 and 180 grits to understand this phenomenon. Only stone A-24 could be used with amaranth on the 1 cup plate.

Milling Curve: 12 Cup Plate. Each cup mounted in the TADD plate was numbered. Five grams of amaranth was weighed into each of twelve numbered plastic sample cups. The weight of the plastic cup and plastic cup-plus-amaranth was recorded. The Shur-Stik disk was placed on the aluminum

plate. Contents of each numbered plastic cup were poured into the corresponding numbered cup in the steel plate.

The mill was run for 1.0 minute and the aspirating device was used to collect milled amaranth from each sample cup. The sample cup was then weighed and this value was designated as "total weight after milling". Milling loss was calculated by subtracting the total weight after milling from the initial amaranth-plus-plastic cup weight. Milling loss as a percentage was calculated by dividing the milling loss by the amaranth weight and multiplying by 100. Because the milled kernels (pearls) were collected at each stage for microscopic analysis, new samples were milled for increasing time periods. Thus, the two minute milled fractions consisted of the first-plus-second fraction of the grain removed. This process was continued up to nine minutes. Three trials per time period were run. Percent milling loss was averaged over cups and trials.

Milling Curve: 5 and 1 Cup Plates. Milling curves for the 5 and 1 cup plates were incremental, i.e., the seed was milled for one minute, weighed to obtain milling loss and then placed back into the TADD for further milling. This procedure was repeated for another eight, one minute time periods resulting in an incremental milling curve. Cumulative milling loss percentage per time period for the 5 and 1 cup plates was calculated by adding each successive fraction milling loss percentage. A variable number of

trials per time period were run (depending on bran yield) and milling loss percentage was averaged over cups and trials.

Proximate Analysis. Whole seed samples, as well as pearls, were ground with a UDY cyclone sample mill equipped with a 1.0 mm screen and analyzed for moisture (AACC method 44-32), nitrogen (AACC method 46-13), ash (AACC method 08-01), crude fiber (AACC method 32-10) and crude fat (AACC method 30-10). The same analyses were done on the seed coat/embryo fractions and incrementally removed fractions. All protein values were expressed as crude protein (N X 6.25). Protein, ash, fat and fiber were determined in duplicate and expressed as a mean of the duplicates on a moisture free basis.

Determination of Component Distribution. Cumulative ash, fiber, protein and fat curves were used to establish distribution patterns of components in each amaranth species. Data from the 1 cup plate incremental milling curves and proximate analysis of incrementally removed fractions were used to construct cumulative component curves.

Component contents were directly compared over time. Component contents were compared at the same milling loss % between grits of the two amaranth species. When comparisons of component contents were made between plates at the same milling loss %, the 1 cup data had to be changed to a

cumulative form in order to be directly compared with the 12 cup plate data.

Scanning Electron Microscopy. Random samples of pearls and bran milled in the 12 cup plate, and a small portion of each abrasive were mounted on aluminum stubs and vacuum coated with gold palladium prior to examination.

Tests of Physical Properties. One thousand kernels of amaranth were hand-counted and weighed. This was repeated three times for each species of amaranth and the results expressed as grams.

Uniformity of size was determined by establishing a particle size distribution for each amaranth species using a Ro-Tap Testing Sieve Shaker with sieve numbers 16, 18, 20, and 25. Fifty grams of each amaranth species was sifted for 3 minutes four times. Results were expressed as a mean particle size distribution for each species.

Toluene displacement was used to determine the true density of each amaranth species. A graduated cylinder was filled with 20 ml of toluene. Twenty grams of amaranth was added to the graduated cylinder and the resulting volume of toluene was recorded. True density of each amaranth species was calculated:

Vol. displaced = vol. plus grain - initial vol. toluene

True density = initial weight of grain/volume displaced

This procedure was repeated four times for each amaranth species.

Measurements of angle of repose were repeated three times for each amaranth species. Angle of repose was determined using the method of Appel (1985).

Test weight was determined with an Ohaus Bulk Density Meter. Four trials were run for each species. Bulk density was calculated by dividing the test weight (lb/bu) by 1.25 lb/ft^3.

Cleaning of Abrasive Grit. Acetone was applied to half of a used abrasive mounted on an aluminum stub that had been previously coated with gold palladium. Acetone was gently brushed across the abrasive to remove remaining seed coat/embryo fractions on the grit. Acetone was also applied to an unused abrasive in order to determine if the solvent damaged the abrasive.

Cooking Amaranth. Thirty grams of pearls, abraded using the 120 grit abrasive and in the 12 cup plate, were cooked for 15 minutes in 235 ml of deionized, distilled water.

Staining of Amaranth. A staining method to differentiate between perisperm and the seed coat/embryo fraction was adapted from the work of Scheuring and Rooney (1979). A 70% ethanol solution with 0.25% methylene blue and 0.75% eosin-Y was allowed to equilibrate for 24 hours. Two grams of milled amaranth was immersed for 1 minute in solvent (70% ethanol), 1 minute in dye, 1 minute in each of three 70% ethanol rinses, and 1 minute in deionized, distilled water. After staining, the grain was allowed to

air dry on absorbent paper. Stained, milled amaranth was examined with a light microscope at 30X.

Statistical Analysis. One-, two-, and three-way factorial experiments involving combinations of species, plates and abrasives were used to examine different milling conditions. Because sample sizes were not equal, the general linear model procedure of SAS (SAS Institute, 1982) was used to perform analysis of variance. A t-test was used to determine significant differences between amaranth species' thousand kernel weight, true density, angle of repose and test weight.

RESULTS AND DISCUSSION

Comparison of Milling Curves Between Abrasives

Cumulative milling curve data for two amaranth species were obtained using both 120 and 180 grit abrasives with the 12, 1 and 5 cup plates. Incremental milling curve data were collected for both species on the 5 and 1 cup plates. SEM was used to examine a random sample of pearls and removed fractions at each milling time for the 12 cup plate.

The 120 grit abrasive removed significantly more material on a cumulative basis than the 180 grit abrasive with all plate types (Fig. 4). The 120 grit abrasive knocked out chunks of material whereas the 180 grit gradually abraded the surface of the amaranth seed.

When both species of amaranth were milled using the fine abrasive (180 grit), A. cruentus had a significantly larger milling loss than A. hypochondriacus (Fig. 4). Final milling loss (9 min.) for A. cruentus was about 27%. Betschart et al (1981) found by hand dissecting A. cruentus that the seed coat/embryo fraction constituted 26.3% of the total seed. Thus, very little perisperm milling probably occurred. Differences in species' milling curves was primarily due to differences in seed coat/embryo characteristics. (The effect of the 180 grit abrasive's ability to distinguish milling differences in the perisperm was not tested and should be further studied.)

Figure 4. Cumulative milling curves for 2 species of amaranth using the 1, 5 and 12 cup plates with the 120 and 180 grit abrasives.

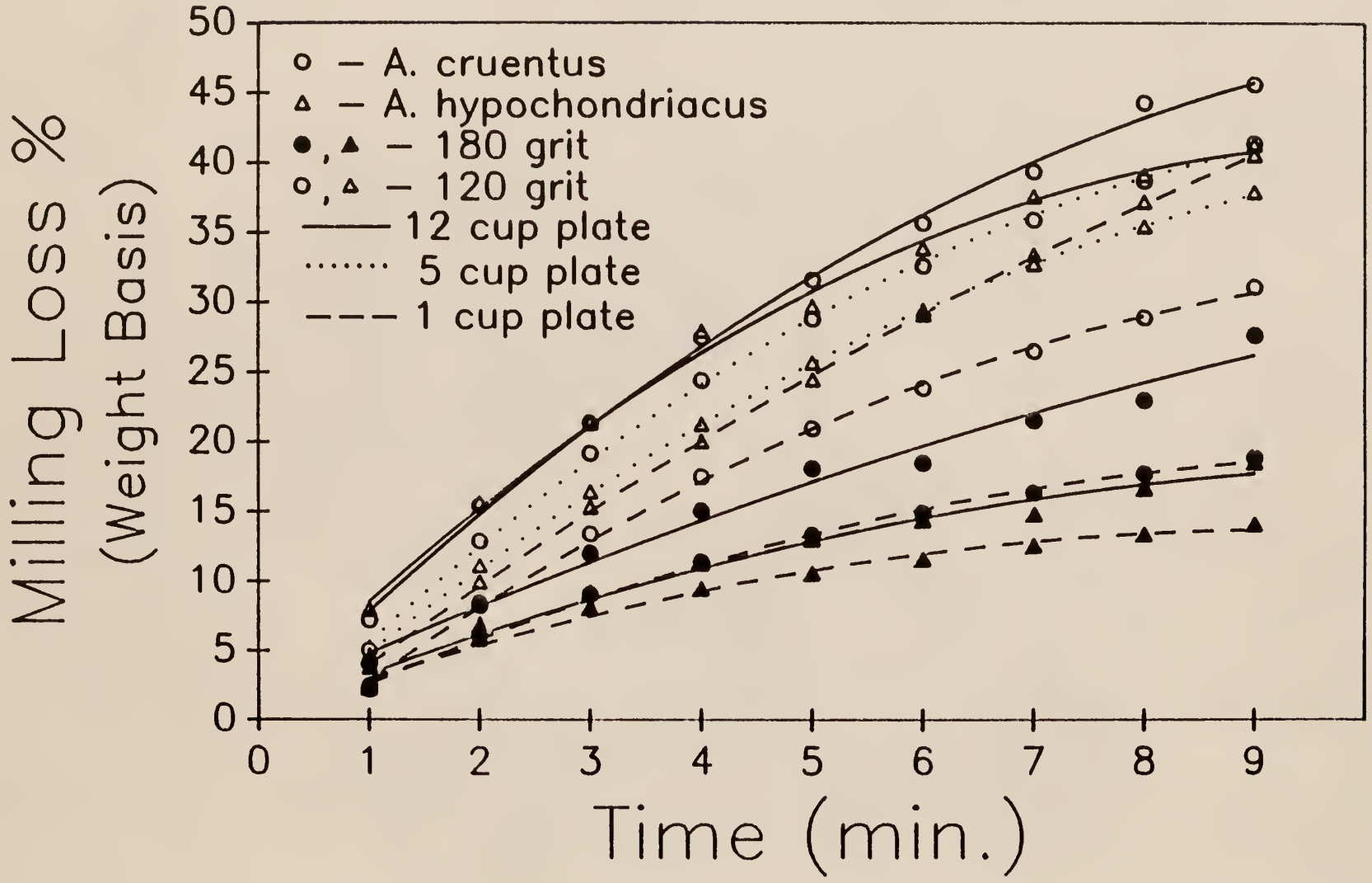

Milling Loss %
(Weight Basis)
50
45
40
35
30
25
20
15
10
5
0
0
1
2
3
4
5
6
7
8
9
Time (min.)
○ – A. cruentus
△ – A. hypochondriacus
●, ▲ – 180 grit
○, △ – 120 grit
12 cup plate
5 cup plate
1 cup plate

Figure 4 (Appendix II, Tables 1-3) indicates that the two species of amaranth have similar milling characteristics up to 5 minutes of milling using the coarse abrasive (120 grit) and 12 cup plate. With the chunk-removing effect, the coarse abrasive was not sensitive enough to detect differences between seed coat/embryo milling characteristics of the two species. After 5 minutes of milling, A. cruentus had a larger cumulative milling loss percentage than A. hypochondriacus. Milling loss for both species was over 30% after 5 minutes. Thus, because differences in the curves occur after the time the seed coat/embryo should have been removed, milling differences between species after 5 minutes might be due to differences in perisperm characteristics.

When the 5 cup plate and 120 grit abrasive were used to mill both species, A. cruentus had a larger cumulative milling loss percentage than A. hypochondriacus for all time periods (Fig. 4). Use of the 5 cup plate and 120 grit abrasive allowed differentiation of milling characteristics between the amaranth species' seed coat/embryo fraction. Once perisperm milling began, the two species' milling curves were not significantly different until after 40% of the grain was removed.

Incremental milling curves for both species on both grits using the 5 or 1 cup plate followed the same trend with peak milling loss occurring at 2 minutes (Appendix II, Table 4).

SEM indicated amaranth species' seed appearance differed in the extent of the definition of ridges of the embryo (Figs. 5a,b). A. hypochondriacus had a smoother continuous ridge whereas A. cruentus had multiple discontinuous ridges. Thus, A. hypochondriacus appeared plumper and smoother than A. cruentus.

The seed coat of the pearls peeled away during the first minute of milling of A. hypochondriacus with the fine abrasive (Fig. 5c). Seed coat and embryo of A. cruentus were removed by the 180 grit abrasive with accompanying gouging of the seed coat/perisperm. The fraction removed from A. cruentus showed material attached to flakes of seed coat. This material was not observed in equivalent fractions of A. hypochondriacus (Figs. 5d,e). Given that the seed coat is attached directly to the embryo (Betschart et al, 1981), the adhering material is probably embryo tissue.

After 2 minutes of milling, both species fractured at the embryo/perisperm interface. The embryo had begun to pull away from the perisperm of A. cruentus. A. hypochondriacus had less embryo removed than did A. cruentus after 4 minutes of milling. However, fracture lines extended into the perisperm of A. cruentus, whereas they were absent from A. hypochondriacus. The same trends continued for the 6 and 7 minute pearls but were more exaggerated (Figs. 6a,b). Some of the A. cruentus seeds

Figure 5a. Intact A. hypochondriacus (60X).

Figure 5b. Intact A. cruentus (60X).

Figure 5c. A. hypochondriacus milled 1 minute (180 grit, 12 cup plate)(200X).

Figure 5d. A. cruentus 1 minute bran (180 grit, 12 cup plate)(30X).

Figure 5e. A. hypochondriacus 1 minute bran (180 grit, 12 cup plate)(30X).


A


B


C


D

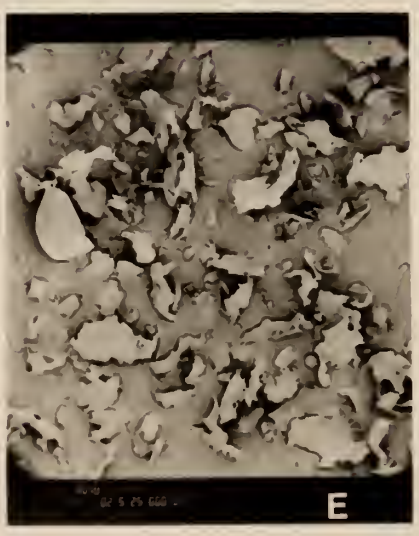
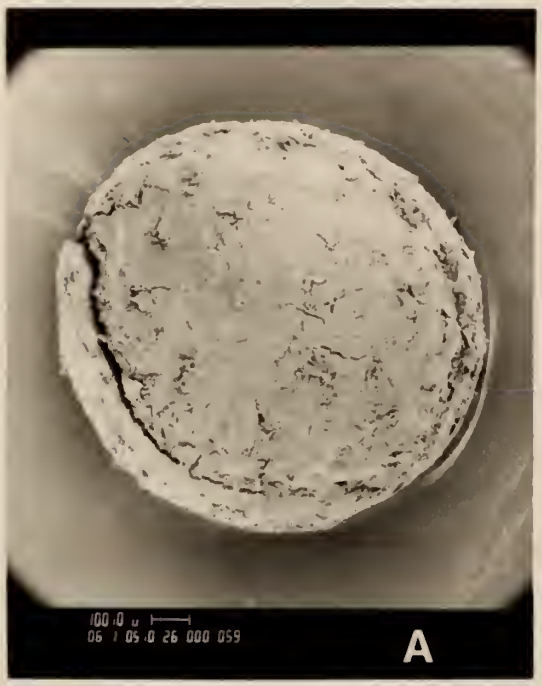

E

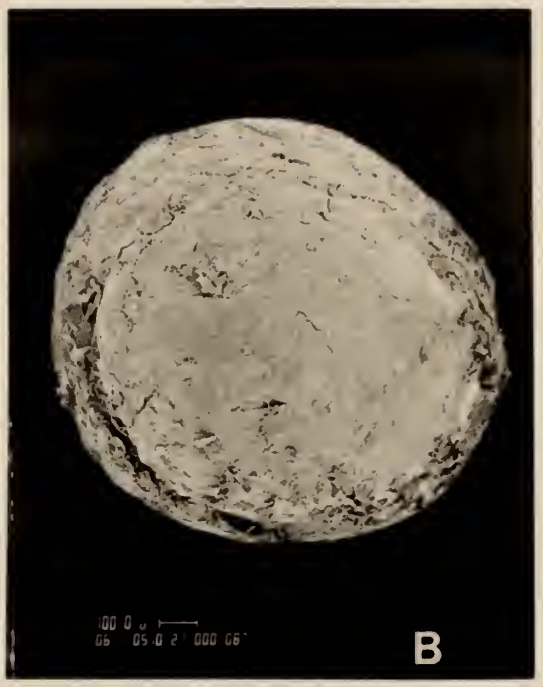
Figure 6a. A. cruentus milled 6 minutes (180 grit, 12 cup plate)(60X).

Figure 6b. A. hypochondriacus milled 6 minutes (180 grit, 12 cup plate)(60X).

Figure 6c. A. cruentus milled 9 minutes (180 grit, 12 cup plate)(60X).

Figure 6d. A. hypochondriacus milled 9 minutes (180 grit, 12 cup plate)(60X).


A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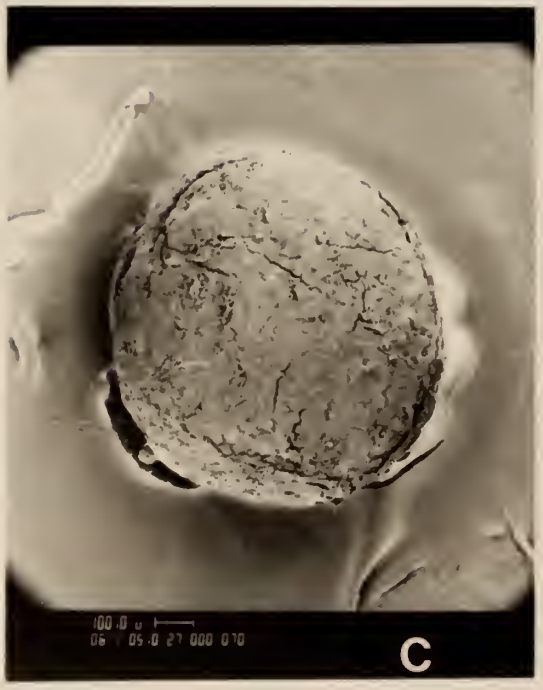
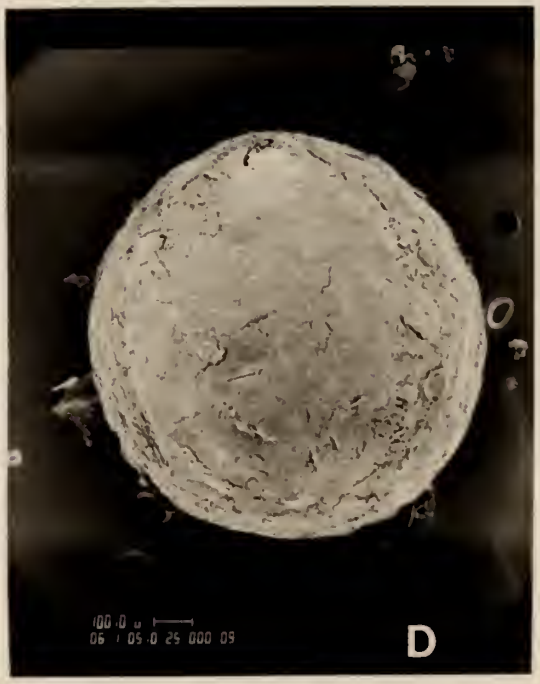

C


D

milled 8 minutes had lost entire embryo portions and the pearls had a characteristic concave area remaining. A. hypochondriacus continued to fracture between the embryo and perisperm without loss of embryo from the perisperm. A. cruentus pearls showed variable attrition at 9 minutes (Figs. 6c,d). Embryo loss was erratic.

Amaranth milled with the coarse abrasive for 1 minute resulted in very little of the seed coat being left on the embryo of A. hypochondriacus seeds. There was quite a bit of seed coat left on the embryo of equivalent A. cruentus pearls (Figs. 7a,b). After 3 minutes of milling, A. cruentus lacked the remnant ridge tissue still present on A. hypochondriacus. After four minutes of milling, the embryo of both species' pulled away from the perisperm. After 5 minutes of milling, both species had large chunks of perisperm removed from the pearl (Figs. 7c,d) with portions of embryo removed. This same appearance persisted in 6-9 minute pearls along with fractures in the perisperm (Figs. 7e,f). SEM supports the conclusion that milling differences between species after 5 minutes on the 120 grit in the 12 cup plate are most likely due to the ease with which chunks of perisperm are removed from the grain.

SEM pictures were taken from the top view of each abrasive (Figures 8a-c). The 180 grit abrasive was a continuous matrix of smaller abrasive particles whereas the 120 grit abrasive particles were larger and more sparse in

Figure 7a. A. cruentus milled 1 minute (120 grit, 12 cup plate)(60X).

Figure 7b. A. hypochondriacus milled 1 minute (120 grit, 12 cup plate)(60X).

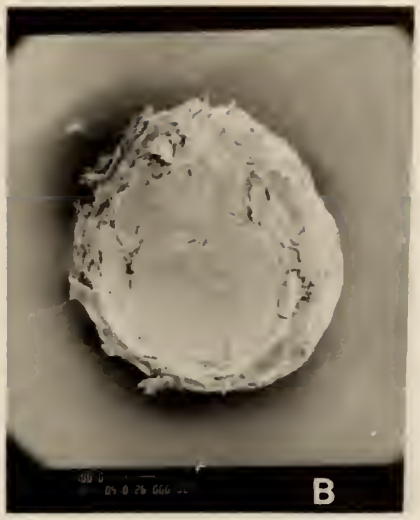
Figure 7c. A. cruentus milled 5 minutes (120 grit, 12 cup plate)(60X).

Figure 7d. A. hypochondriacus milled 5 minutes (120 grit, 12 cup plate)(60X).

Figure 7e. A. cruentus milled 9 minutes (120 grit, 12 cup plate)(60X).

Figure 7f. A. hypochondriacus milled 9 minutes (120 grit, 12 cup plate)(60X).


A


B


C


D


E

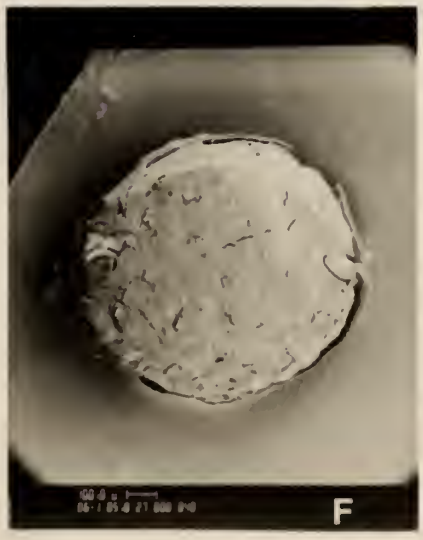
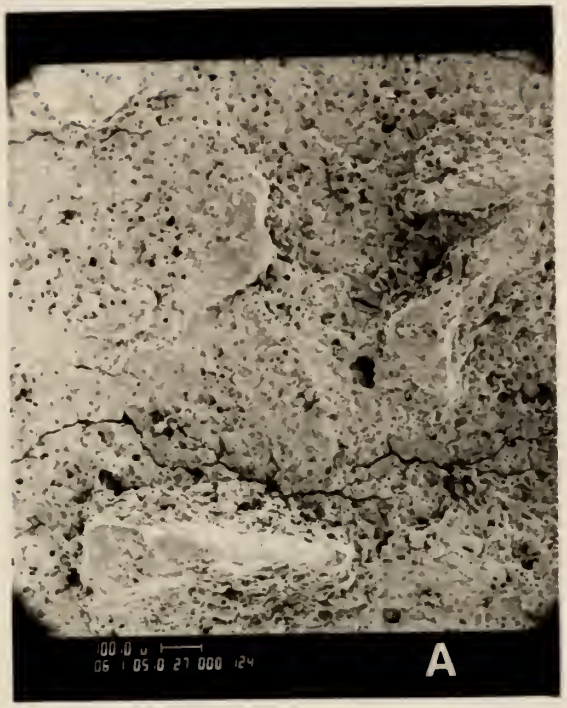
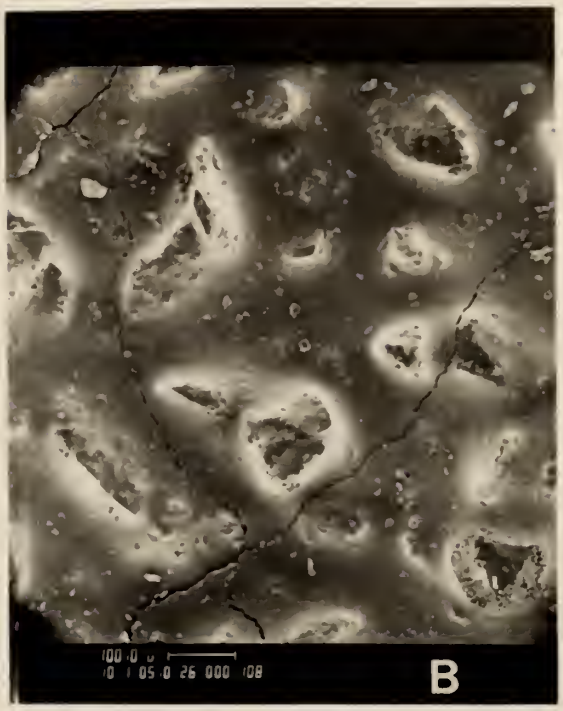

F

Figure 8a. Top view, 50 grit (60X).

Figure 8b. Top view, 120 grit (100X).

Figure 8c. Top view, 180 grit (100X).


A


B


C

their placement. Abrasive particles, in general, were irregular in shape and their height increased with decreasing grit number.

Pit size in A-46 and A-36 stones allowed amaranth to settle in and escape intact underneath cups and out of the mill. The same phenomenon occurred with abrasives more coarse than the 120 grit, except amaranth settled in between abrasive particles. SEM shows the dimensions of the 50 grit abrasive (Fig. 8a) would allow amaranth seeds (Figs. 5a,b) to fit in between abrasive particles.

Plate designs other than the 1 cup plate were not suitable for use with the stone A-24 because amaranth seeds escaped from the mill intact via pits in the stone surface. Translational motion (that which drives the grain in a radial direction across the cup and directly into a cup wall) accompanying the 5 and 12 cup plates carried entrapped amaranth seeds underneath and outside of the cups, exposing the seeds to open areas underneath the steel plate where they could escape. In the 1 cup plate, no translational motion occurred because of its geometrical design. Thus, trapped amaranth seeds were never carried underneath and outside of the cup.

Cumulative milling curves of A. cruentus were examined when milled on the 180 grit, 120 grit and stone abrasives using the 1 cup plate. Only the seed coat/embryo fraction was removed by all three abrasives. The 120 grit abrasive

removed more material than the 180 grit abrasive and stone (Appendix II, Table 13). The 180 grit abrasive removed more material than the stone when the outer edge of A. cruentus embryo was milled. Farther into the embryo, the stone had a faster rate of milling than the 180 grit abrasive. This probably occurred because the relatively jagged surface of the 180 grit was more adept at catching and removing the wrinkled surface of the A. cruentus seed coat than the pits in the stone were.

Methods for Determining Embryo Presence in Milled Amaranth

Because embryo loss was found to be erratic in the 12 cup plate, methods to determine presence of embryo on milled grain were investigated.

Two dye systems utilized by Scheuring and Rooney (1979) stained sorghum germ, pericarp, and endosperm a blue, green and pink, respectively. This method was adapted to determine embryo presence on milled amaranth. Unmilled amaranth did not stain. In sorghum, this phenomenon was due to a waxy layer on the outside of the seed preventing entry of the dye (Shepherd, 1981). This appears to also occur with amaranth. Further evidence of a hydrophobic exterior on amaranth was found when it was placed in various liquids. In water, seeds clumped together and tended to float. In toluene or any other hydrophobic solvent, amaranth neither

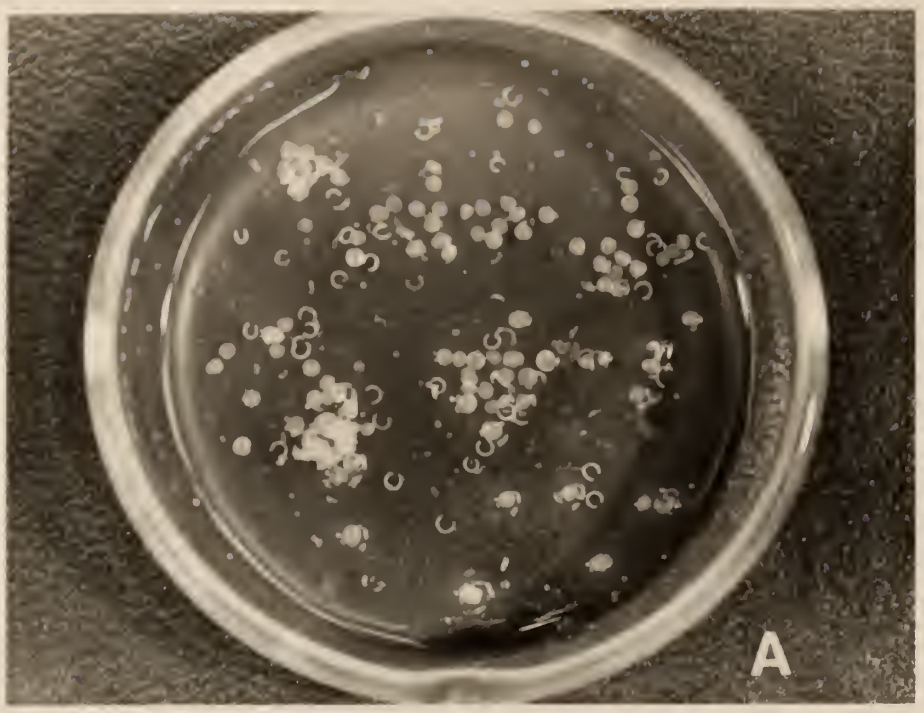
floated nor clumped. The presence of such a hydrophobic surface has not been documented previously.

After one minute of milling, the embryo of some seeds stained blue-green and the inner spherical portion remained unstained. After six minutes, the blue-green embryo was still attached to some seeds, but not to others. At eight minutes, the blue-green portion was completely gone on the seeds examined. The perisperm of amaranth did not stain pink as did the endosperm of sorghum. This method did an excellent job of indicating presence of embryo.

When A. cruentus was milled on the TADD with the 120 grit and 12 cup plate to 45% milling loss and boiled in water, white "horseshoe-shaped" objects broke loose from the amaranth (Fig. 9a). Evidently, the perisperm "popped" the embryo or remaining embryo off due to starch swelling during cooking. The presence of the embryo on seeds milled to 45% milling loss was not expected because Betschart et al (1981) claimed that all the embryo was removed from the amaranth seed when cumulative milling loss reached 27%. SEM of an isolated intact embryo showed it to be of the same shape as the released white horseshoe-shaped objects (Fig. 9b). Boiling stained milled amaranth released blue-green horseshoe-shaped objects. Concluding the white horseshoe-shaped objects were embryos, the cooking test would allow a very quick and relatively inexpensive method of determining embryo presence on a large number of milled seeds.

Figure 9a. Cooked 9 minute milled amaranth pearls with horseshoe-shaped embryos freed from starchy perisperm.

Figure 9b. Intact embryo, A. cruentus (60X).


A


100.0 µ
B

Comparison of Milling Curves Between Plate Types

Differences in cumulative milling curves of A. cruentus and A. hypochondriacus between the 12, 5 and 1 cup plates with the 120 grit abrasive were investigated.

Because of the geometrical placement of cups in the steel plate, the abrasive area decreased as the number of cups in the plate decreased. Even though seed weight to abrasive area was initially made the same for each plate, theoretical available abrasive area (this figure was based on amount of abrasive area exposed in each cup) increased because seeds were exposed to different forces within each geometrical arrangement of cups or a cup. Because of the 1 cup plate design, it lacked translational motion occurring in the 5 and 12 cup plates and had only rotational motion. Thus, centrifugal force drove the grain to the cup wall where it traveled uniformly around the edges of the cup without being broken up. This was evidenced by a path along the outside edge of the cup which was 1.7 cm in width (Fig. 10a). Theoretical abrasive area for the 1 cup plate was initially 396 cm^2, however, the area being used was approximately 105 cm^2. The wear pattern on the abrasive used with the 5 cup plate indicated less abrasive area being used than was theoretically possible (Fig. 10b). Circulation of the seeds within cups of the 12 and 5 cup plates differed. The area of abrasion in the 5 cup plate was reduced because the flow of grain was to one side of the

Figure 10a. Path worn on the outside edge of stone A-24 and 180 grit with use of the 1 cup plate.

Figure 10b. Path worn on the outside edge of the 120 grit with use of the 5 cup plate.

A

B

cup with half of the surface area rarely being exposed to a complete layer of grain.

Because the seed weight:abrasive area ratio became larger as the number of cups decreased, milling loss would be expected to decrease. When A. cruentus was milled on the coarse abrasive, the 12 cup plate had the highest rate of milling while the 1 cup plate had the lowest. The 5 cup plate milling rate fell in between the other two milling curves (Fig. 4).

Plate effect on milling loss of A. hypochondriacus was unlike that of A. cruentus. Decreased abrasive area did not lower the milling rate for the 1 cup plate. A. hypochondriacus had a faster milling rate than A. cruentus on only the 1 cup plate using the coarse abrasive (Fig. 4). Effect of amount of abrasive area to seed weight was found to be dependent on specie type.

SEM of a whole kernel of each species indicated the surface characteristics of A. hypochondriacus were smooth compared to the relatively wrinkled surface of A. cruentus (Figs. 5a,b). The physical properties of the two species were investigated to examine whether surface characteristics were significantly different. The test weight (converted to bulk density) of A. hypochondriacus was greater than that of A. cruentus (Table 1). Test weight is dependent upon shape, density and uniformity of kernel size (Hlynka and Bushuk, 1959). Uniformity of kernel size is determined by particle

Table 1. Comparison of results of physical properties for two species of amaranth.

PHYSICAL PROPERTIES (Avg. Values)	SPECIES	
	A. cruentus	*A. hypochondriacus*
THOUSAND KERNEL WT. (grams)	0.84	0.82
BULK DENSITY (lbs/ft^3)	49.79	50.98
TRUE DENSITY (g/cm^3)	1.33	1.35
ANGLE OF REPOSE (degrees)	23.25	16.14
PARTICLE SIZE DIST.		
1.00mm > % > 0.85mm	69.06	37.20
0.85mm > % > 0.71mm	30.94	62.80

size distribution. Particle size distributions of the two species were approximately the reverse of one another. A. hypochondriacus had a higher proportion of smaller seeds while A. cruentus had a lower proportion. Because true density was not significantly different between the two species and particle size distribution differed, A. cruentus, having the majority of larger seeds, should have had a larger thousand kernel weight. Because thousand kernel weight did not differ significantly between the two species, the smooth A. hypochondriacus probably slipped through the square openings of the larger sieve easier than the relatively wrinkled A. cruentus. Angle of repose data indicated A. cruentus had a larger angle of repose than A. hypochondriacus. Thus, the flow of A. cruentus was probably less because of the wrinkled surface characteristics.

A kernel with a smooth surface could probably move more easily within the mass of grain packed against the 1 cup plate wall because it would encounter less resistance than a kernel with a relatively wrinkled surface. The tangential velocity of A. hypochondriacus should have been greater than that of A. cruentus. The effect of less abrasive area to seed weight on the 1 cup plate may have decreased because the faster-moving, smoother A. hypochondriacus seeds were in more contact with the abrasive area than the slower-moving wrinkled seeds of A. cruentus. Thus, milling rate was faster for the smoother seed, A. hypochondriacus.

A. cruentus and A. hypochondriacus were milled with the 12 and 1 cup plates to establish cumulative milling curves using the fine abrasive. The 12 cup plate removed more material per time period than the 1 cup plate for both species (Fig. 4). Inconsistency of plate effects disappeared when A. hypochondriacus was milled on the 180 grit abrasive. A. cruentus had a faster milling rate than A. hypochondriacus on the 1 cup plate. This may have occurred because increased contact of the smoother seed with the fine abrasive did not have a significant effect on milling loss that the chunk-removing action had.

Cleaning of Abrasives

The life of "Shur-Stik" disks ranged from 4.5 to 9 hours depending on the ratio of seed weight to abrasive area. The life of the abrasive ended when the milling loss of a given amount of seed had been reduced by greater than 5% from the milling loss obtained when the abrasive was first used. Abrasive particles of worn grits were clogged with fragments of amaranth (Fig. 11a).

To determine whether the abrasives were being worn and/or simply clogged, acetone was used as cleaning solvent. The solvent did not change the abrasive particles themselves (Fig. 11b,c). When acetone-cleaned, worn abrasives were compared to uncleaned controls, it was evident that the solvent removed material clogging the grit (Fig. 11d). The

Figure 11a. Side view of worn 120 grit abrasive (100X).

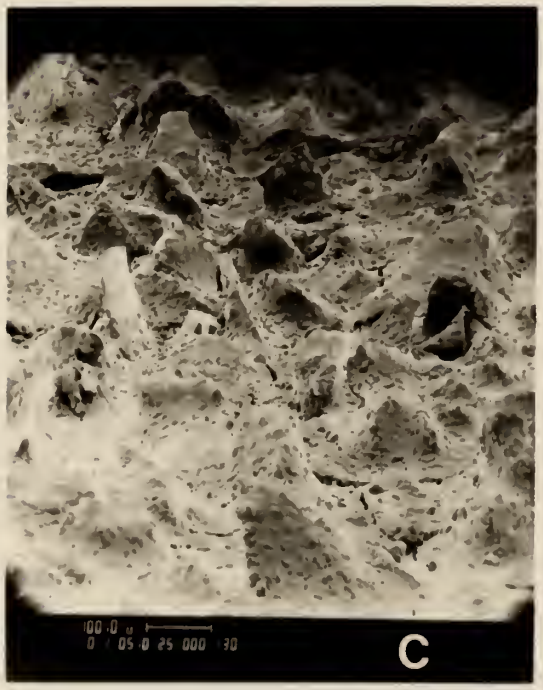
Figure 11b. Side view of unworn 120 grit abrasive (100X).

Figure 11c. Side view of unworn 120 grit abrasive cleaned with acetone (100X).

Figure 11d. Side view of worn 120 grit abrasive cleaned with acetone (100X)


A


B


C


D

180 grit abrasive particles became more smooth, but it was not evident that they were broken with use. Some of the 120 grit abrasive particles were broken and those which were not broken became smoother (Fig. 11d).

To increase the life of the 180 grit abrasive, it may be possible to clean it with a solvent such as acetone. When a worn grit was cleaned with acetone, it removed 17% more material than before it was cleaned. However, immersing the disk in a cleaning solvent would damage the adhesive backing. The use of high pressure air, a more inexpensive and less time-consuming option, was used to clean grits by blowing the fragments of amaranth away.

Distribution of Components

The slopes of the component (fat, ash, fiber and protein) curves for the pearled grain milled on the 120 grit and 12 cup plate were both negative and steep from 0 - 4 minutes, but began to flatten once milling time exceeded five minutes (Appendix II, Tables 5-8). Proximate analysis of the pearls indicated a progressive loss of protein, fat, fiber, and ash. The rapid decrease reflects the removal of the embryo. As embryo was removed, the slope of the curve flattened, reflecting removal of the carbohydrate-rich perisperm.

The component curves for the removed fractions are the reverse of the pearl component curves. After the majority

of the embryo was removed, protein, fat, and ash content of successive fractions decreased to a level consistent with perisperm content (Appendix II, Tables 9-12).

When comparing component values at each time period, fat, ash, fiber and protein contents of fractions from the 120 grit abrasive differed from those of the 180 grit (Figs. 12,13 and Appendix II, Tables 14-17). This occurred because milling rate was different at each time period and thus different portions of the seed were being removed. However, when comparing component contents at the same milling rates, fat, fiber, ash and protein contents were approximately the same independent of cup or grit used (Figs. 14,15 and Appendix II, Tables 14-20).

The majority of fat, protein and ash had been removed from A. cruentus by 40% milling loss. Fat, protein and ash increased from the outside in within the parameters of the 40% milling loss. The distribution of fiber was much different from fat, ash and protein. A large portion of the fiber (30%) was concentrated in the outer 10-15% of both species and increased very little thereafter. There was little difference in the component contents of the removed fractions of A. hypochondriacus and A. cruentus. Some of the removed fractions (Appendix II, Tables 9-12) had as much as 40% protein and 12% fiber. Such fractions would be excellent enriching agents.

Figure 12. Component distributions over time for both species of amaranth milled on the 120 grit.

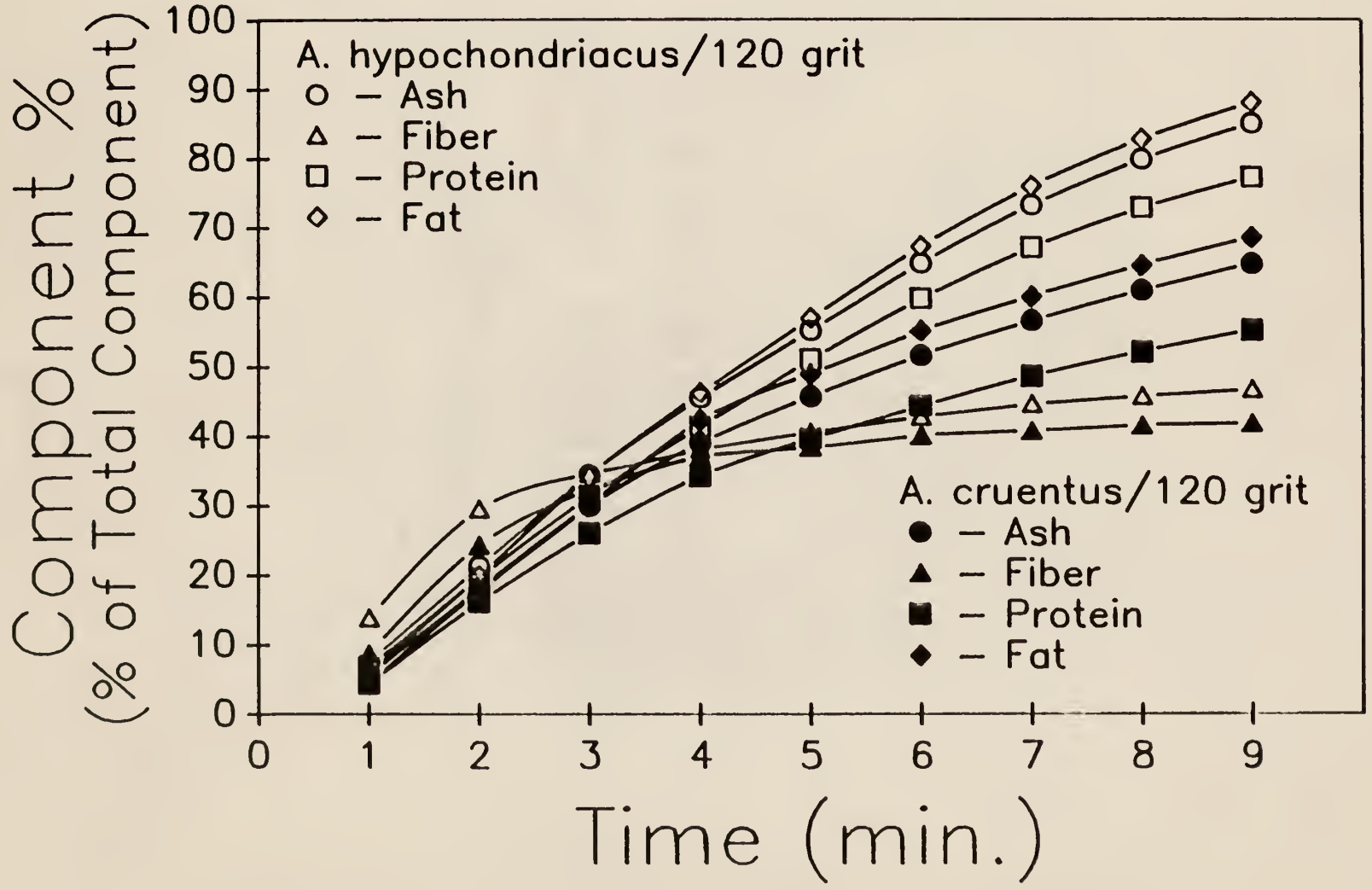

Component %
(% of Total Component)
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
Time (min.)
A. hypochondriacus/120 grit
○ – Ash
△ – Fiber
□ – Protein
◇ – Fat
A. cruentus/120 grit
● – Ash
▲ – Fiber
■ – Protein
◆ – Fat

Figure 13. Component distributions over time for both species of amaranth milled on the 180 grit.

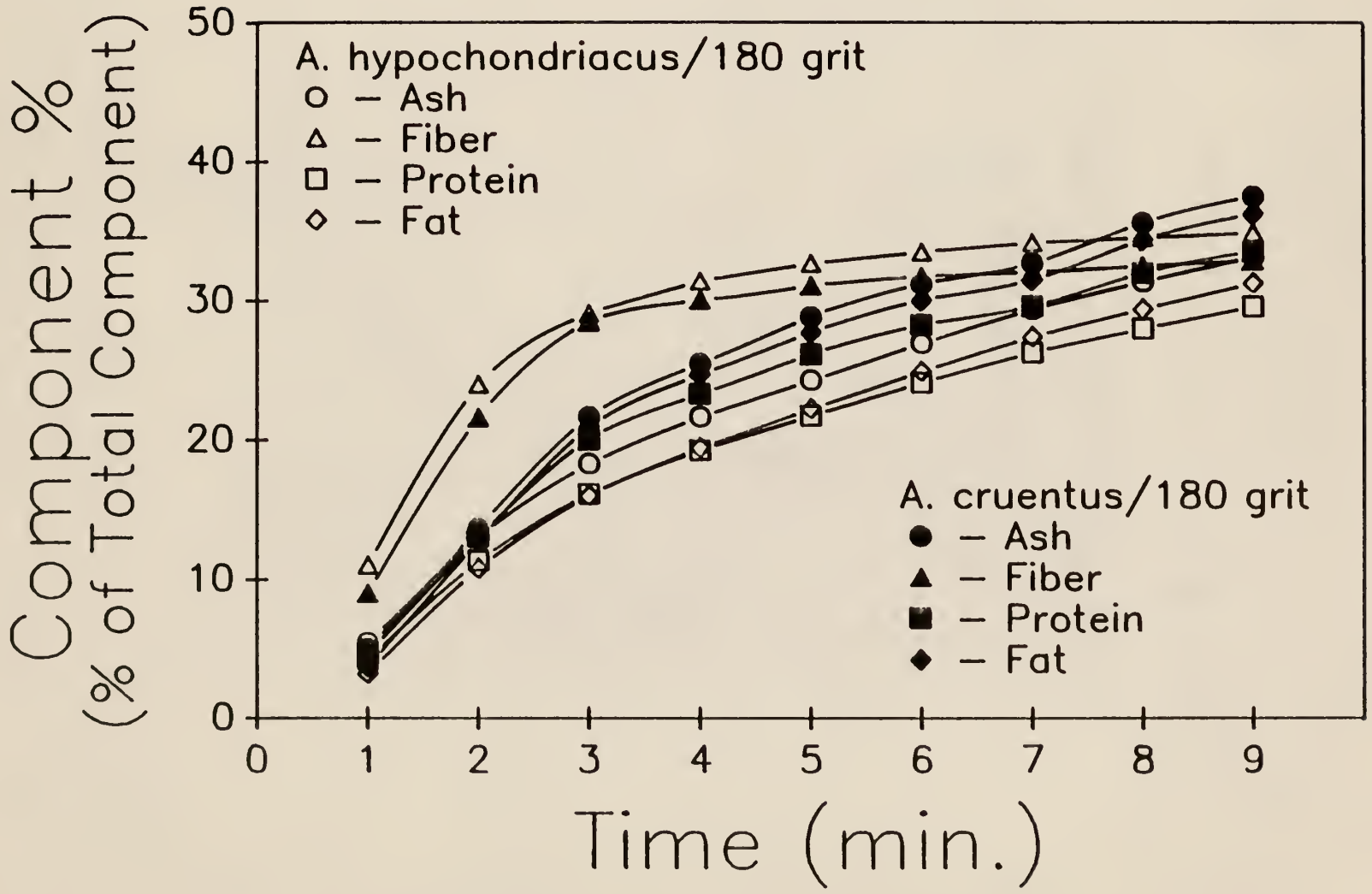

A. hypochondriacus/180 grit
○ – Ash
△ – Fiber
□ – Protein
◇ – Fat
A. cruentus/180 grit
● – Ash
▲ – Fiber
■ – Protein
◆ – Fat
Component %
(% of Total Component)
0
10
20
30
40
50
0
1
2
3
4
5
6
7
8
9
Time (min.)

Figure 14. Component distributions versus milling loss for both species of amaranth milled on the 120 grit abrasive.

A. cruentus	A. hypochondriacus
Total ash = 2.72%	Total ash = 3.08%
Total fiber = 4.19%	Total fiber = 4.73%
Total protein = 15.35%	Total protein = 16.83%
Total fat = 7.97%	Total fat = 7.03%

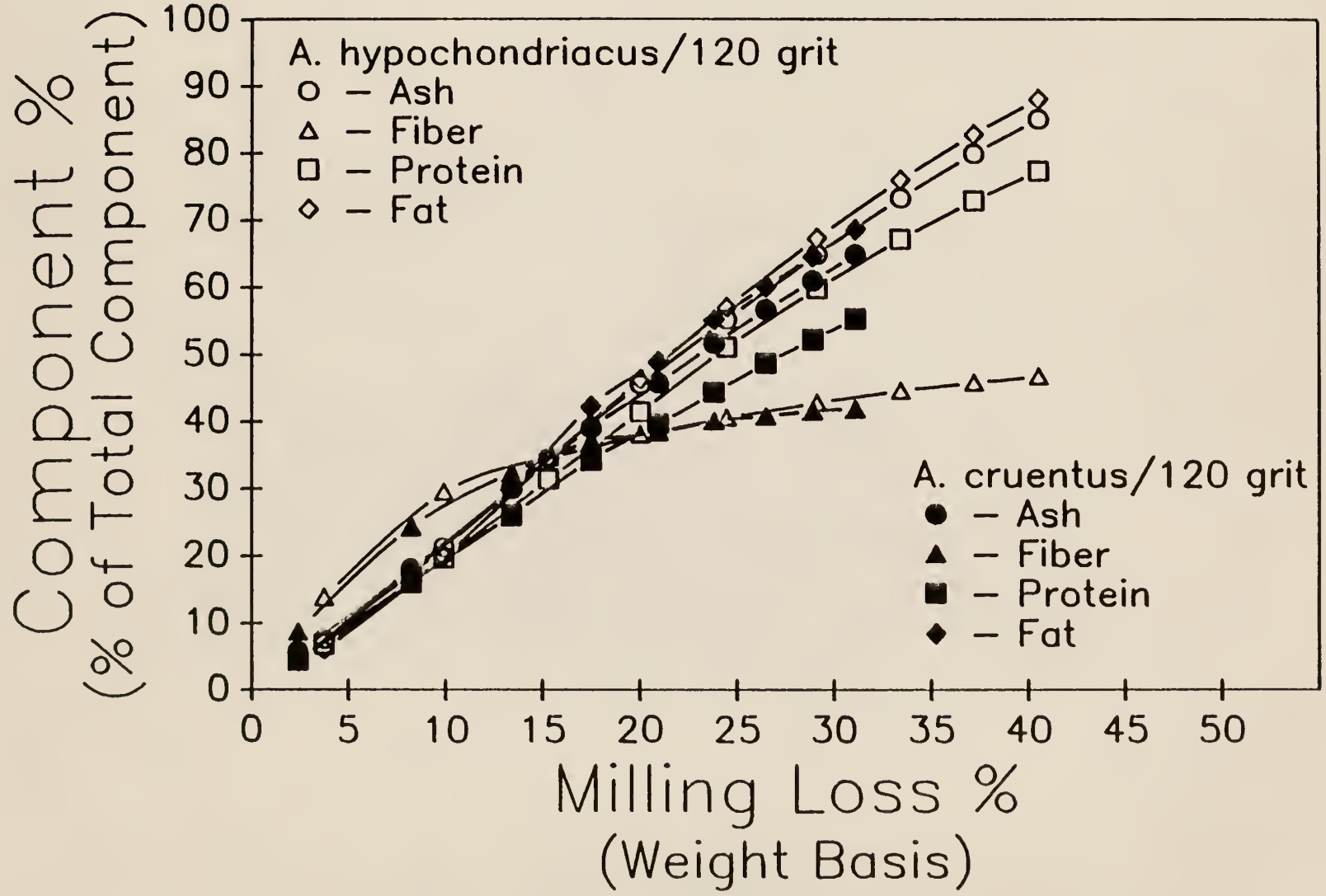
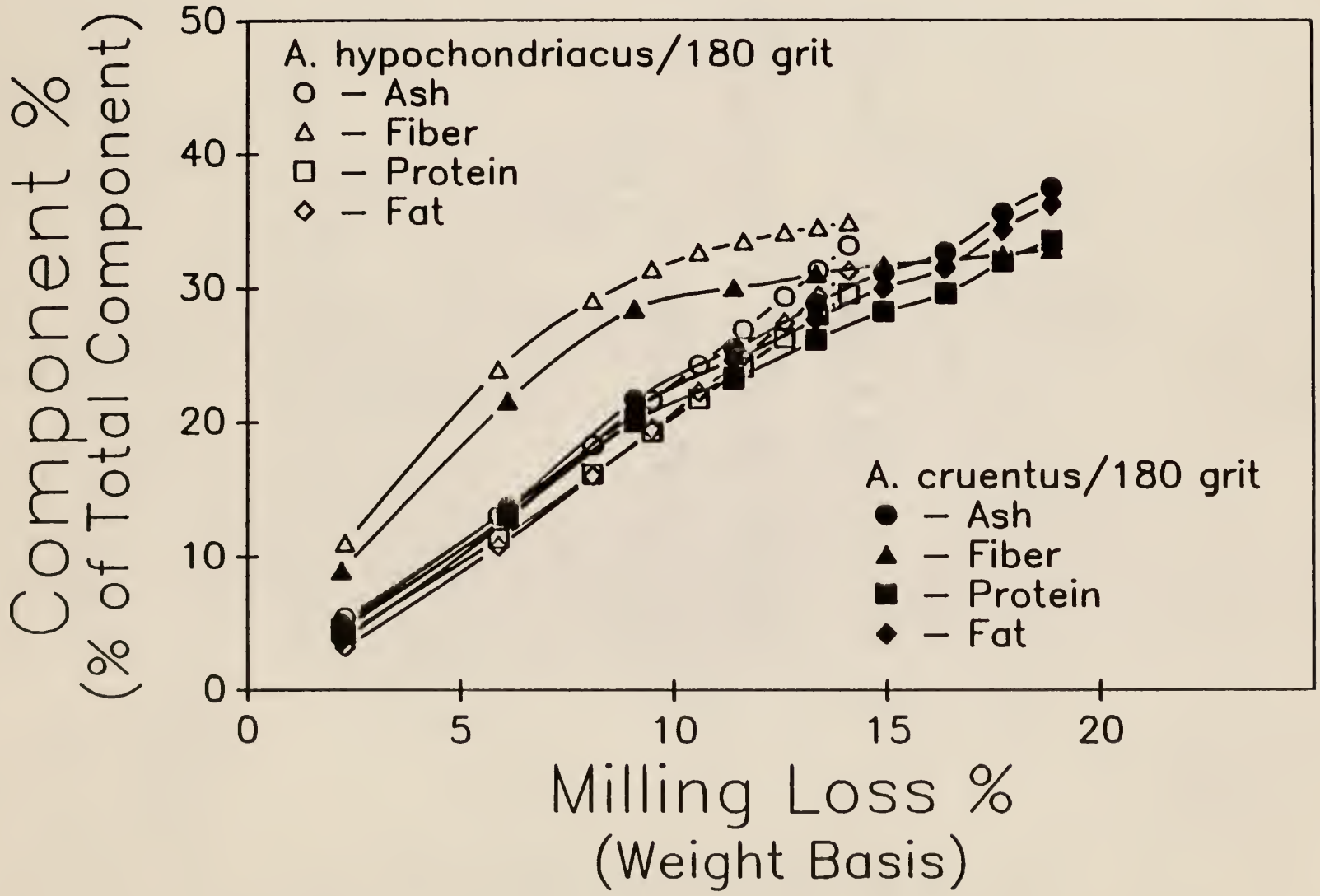

Component %
(% of Total Component)
100
90
80
70
60
50
40
30
20
10
0
A. hypochondriacus/120 grit
○ – Ash
△ – Fiber
□ – Protein
◇ – Fat
A. cruentus/120 grit
● – Ash
▲ – Fiber
■ – Protein
◆ – Fat
0
5
10
15
20
25
30
35
40
45
50
Milling Loss %
(Weight Basis)

Figure 15. Component distributions versus milling loss for both species of amaranth using the 180 grit abrasive.

A. cruentus	A. hypochondriacus
Total ash = 2.72%	Total ash = 3.08%
Total fiber = 4.19%	Total fiber = 4.73%
Total protein = 15.35%	Total protein = 16.83%
Total fat = 7.97%	Total fat = 7.03%


Component %
(% of Total Component)
50
40
30
20
10
0
0
5
10
15
20
Milling Loss %
(Weight Basis)
A. hypochondriacus/180 grit
○ – Ash
△ – Fiber
□ – Protein
◇ – Fat
A. cruentus/180 grit
● – Ash
▲ – Fiber
■ – Protein
◆ – Fat

Scanning Electron Microscopy of Amaranth Starch Granules

Scanning electron microscopy of milled amaranth was done to further investigate the morphology of starch granules and organization of the granules within the perisperm.

SEM revealed uniformly distributed, tightly packed, one micron starch granules. Shape of the starch granules were rounded for A. cruentus (Fig. 16a) and angular for A. hypochondriacus (Fig. 16b). Amaranth starch has been reported as polygonal (Irving et al, 1981; Tomita et al, 1981; Saunders and Becker, 1984; Stone and Lorenz, 1984; Yanez et al, 1986) and rounded (Stone and Lorenz, 1984 and Sugimoto et al, 1981). Variation in starch granule shape may have been due to changing amylose content. Starch granules of maize were found to have a greater amylose content as the shape of the granule became more rounded (Greenwood, 1976). This may occur in amaranth as well, however, the amylose and amylopectin percentages of two species were not determined in this study.

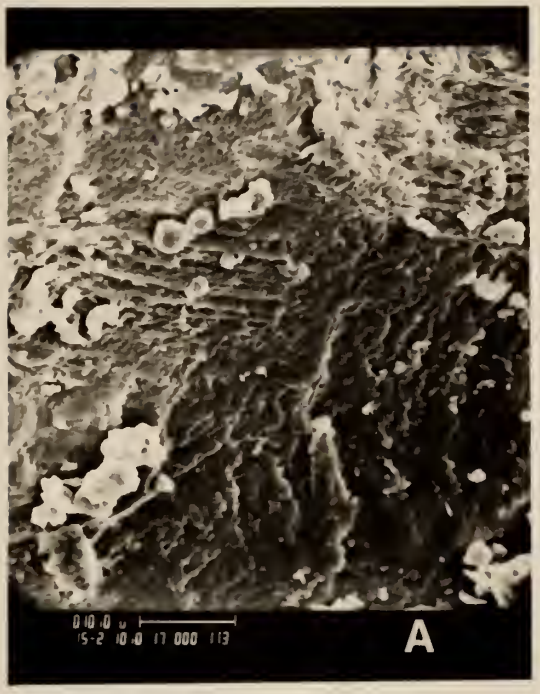
Irving et al (1981) concluded there was little to no protein matrix around starch granules, however, evidence in this study indicated otherwise. The surface of amaranth flour particles had a wave-like surface with multiple holes (Figs. 16a,b). This resembled the surface of hard pearl millet (Fig. 16c). In hard cereal grains, a protein matrix wets the surface of the starch granules and the protein-starch bond is very strong. When the starch granules are

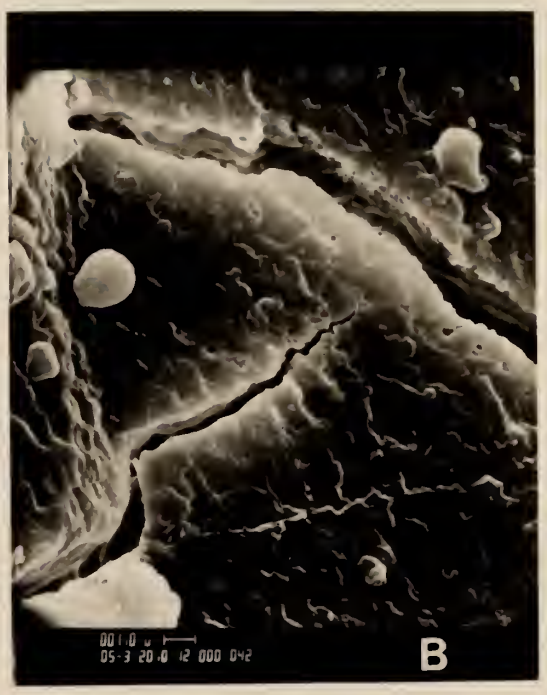
Figure 16a. A. cruentus flour particle surface.

Figure 16b. A. hypochondriacus flour particle surface.

Figure 16d. Contents of an endosperm cell of hard pearl millet (photo provided by Dr. Carl Hoseney).

Figure 16e. Unbroken starch granules of A. hypochondriacus with one broken granule exposing the hilum.


A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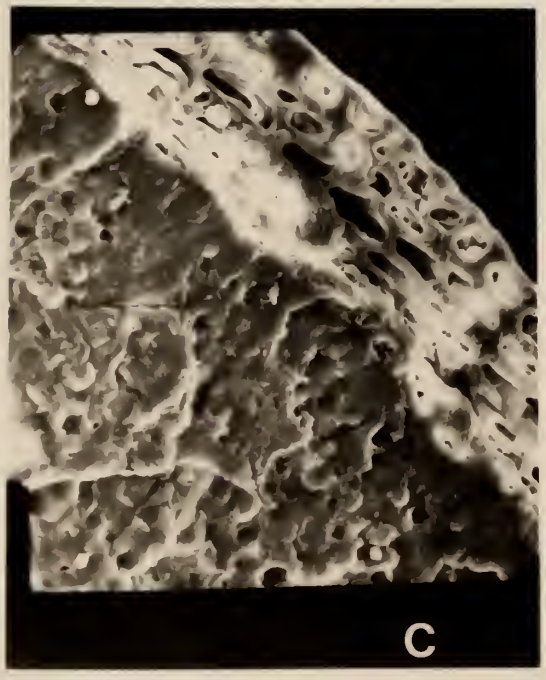
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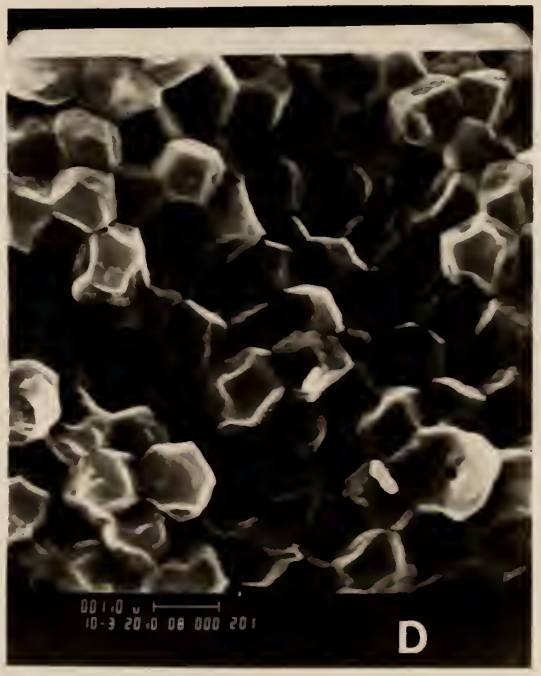
D

subjected to a force, the granules break (Fig. 16d), rather than the protein-starch bonds. Thus, the surface of the amaranth flour particle consisted of broken starch granules with exposed hila. Further evidence can be seen in the protein distribution curves of both species (Fig. 14). At 40% milling loss (and probably well into the perisperm), there is still 30% of the protein left. Because of the wetting phenomenon, the protein matrix may be so tightly adhered to amaranth starch that it is not visually obvious. Staining or extraction techniques should be used to further determine presence of a protein matrix.

Evaluation of TADD Performance

The TADD processes samples rapidly compared to the Strong-Scott Barley Pearler. Using the 120 grit and 12 cup plate on the TADD, it took 16 minutes (Fig. 4) to remove the same fraction Betschart et al (1981) removed in 25 minutes with the Strong-Scott Barely Pearler (plus added sifting not needed with the TADD).

Because of the small number of removable pieces on the TADD, the mill was extremely easy to completely clean of any residue left by the milled grain. However, quantification of the bran was difficult because not all of the bran went directly to the bran collection port. Bran remained around the cups, under the disk and around the shaft.

Gap size adjustment was a very time-consuming process with amaranth. It was not unusual to spend four or more hours finding the correct gap size. Changing the abrasive or aluminum plate to which the abrasive was attached altered shims needed. Very small changes in the size of the grit or plate would effect gap size, and use of the same combinations of shims was mandatory. The 0.015 in. shim did not give the same adjustment in gap size as using the 0.010 in. and 0.005 in. shims together because of imprecise machining of shims.

Rusting of the 1 cup plate and hinged lid of the TADD occurred because these parts were made of galvanized steel instead of stainless steel. The presence of rust did not directly affect this study, but any food contact surface should be stainless steel and it is undesirable to have parts of the mill deteriorate.

The cups in the 12 cup plate were not machined evenly and thus the gap size was different in each cup. This problem was remedied by using a stone to grind them down as evenly as possible. However, the remaining unevenness still hampered gap size determination.

Use of the cup around the shaft for the 1 cup plate was an excellent method to prevent seeds from entering the shaft area. However, the cup also prevented air circulation which facilitated bran movement into the bran collection port.

Another problem with the 1 cup plate was the lack of abrasive area available to seeds. One way of eliminating this problem would be to completely fill the cup. However, milling efficiency would most likely decrease if the grain was not given enough time to fully circulate within the cup. A better solution would be to include a device in the cup which would disrupt the flow pattern of the grain along the wall of the cup.

All of the problems associated with the TADD could be eliminated by design changes. Further work should be conducted in this area.

CONCLUSIONS

In general, SEM of amaranth milled on the 180 grit indicated A. hypochondriacus seed coat peeled away from the perisperm during the first minute of milling whereas A. cruentus had chunks of embryo removed with seed coat. Using the 120 grit, chunks of seed coat/embryo were removed for both species. After 2 minutes of milling, fracture lines occurred between the perisperm and embryo for both species on both grits. By five minutes, perisperm fractured and embryo began to pull away. With continued milling, the 180 grit sanded the surface of the seed while the 120 grit removed chunks of perisperm. A. cruentus had a larger cumulative milling loss than A. hypochondriacus on both the fine and coarse abrasives.

Stone surfaces with pits larger than the amaranth seeds and abrasive grit types more coarse than 120 grit could not be used to mill amaranth. Stone A-24 could be used with the 1 cup plate because it had suitable pit size, and rotational motion of the abrasive in the 1 cup plate prevented seeds from being pushed underneath the cup intact. Independent of plate type or species, the 120 grit abrasive removed more material than the 180 grit abrasive and stone. Because the stone had a longer abrasive life and about the same milling rate as the 180 grit, further investigation of its use should be conducted.

Removal of intact embryo from both species was erratic. Three methods determined presence of the embryo on milled amaranth: (1) staining the embryo, (2) examining seeds with SEM, and (3) cooking milled grain to release the embryo (if present) from the perisperm. Staining and SEM were limited in effectiveness because sample size consisted of a few seeds. The cooking test was quick, relatively inexpensive, and allowed examination of a large sample of milled amaranth.

Because of the geometrical placement of cups in the steel plates, translational motion decreased as the number of cups decreased and abrasive area subsequently decreased. For the 5 and 12 cup plates, A. cruentus milled faster than A. hypochondriacus. However, the reverse occurred in the 1 cup plate. A. cruentus milling rate decreased as abrasive area decreased, while A. hypochondriacus milling rate remained about the same between the 5 and 1 cup plates. A. cruentus may have encountered more resistance to movement within the grain mass in the 1 cup plate than A. hypochondriacus because of its relatively wrinkled surface. Increased tangential velocity of A. hypochondriacus may have allowed seeds to be in more contact with abrasive area available. Thus, the effect of decreased abrasive area did not decrease milling loss. Inconsistency of plate effects disappeared when the fine grit was used with the 1 cup plate.

Shur-Stik abrasive grits had a short abrasive life depending upon the ratio of seed weight to abrasive area. With extended use, broken abrasive particles were observed on the coarse grit where the finer grit had worn abrasive particles. Cleaning grits with acetone extended the life of the abrasive, but damaged the adhesive backing. Blowing away fragments of amaranth with high pressure air was inexpensive and less time-consuming, although not as effective as a cleaning solvent.

The majority of fat, fiber, ash and protein were concentrated in the seed coat/embryo portion of both amaranth species. Fat, ash and fiber contents were different between species and grits at the same time periods because different portions of the seeds were being removed. Component contents were nearly identical at the same milling rate, independent of cup or grit used. For both species of amaranth, fat, protein and ash contents increased from the outside in within the first 40% of the seed removed. Thirty percent of the fiber was concentrated in the outer 10-15% of both species and increased very little up to 40% milling loss. Removed fractions, even with perisperm dilution, had high concentrations of protein.

Clumping behavior in water and the inability of dye to penetrate the intact seed indicated presence of a hydrophobic exterior.

Amaranth is physically hard and amaranth flour particle surfaces resemble hard cereal grain flour particle surfaces. Approximately 30% of the protein is left in the perisperm fraction. Collectively this data indicates the presence of protein matrix around starch granules.

Time consuming gap-size adjustment for very small grain, rusting of galvanized steel on the TADD, quantification of removed fractions, uneven machining of cups, and decreased abrasive area in the 5 and 1 cup plates were some of the disadvantages of using the TADD mill. Advantages of the TADD mill included flexibility in sample size, rapid processing, multi-sample capability, reproducibility, and removal of high protein fractions. The TADD 4E-115 used in this study was one of the first commercial models available. Thus, most of the problems encountered with the TADD in this study could be easily solved with a few modifications of the design of the mill.

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APPENDIX I

CLEANING OF AMARANTH

Introduction

Some samples of amaranth received contained a large amount of black A. retroflexus (wild amaranth) (Fig. 1). Various machines, including a North Dakota Seed Blower, a Tylar Ro-Tap, a purifier and an aspirator failed to separate the wild seed from domesticated amaranth.

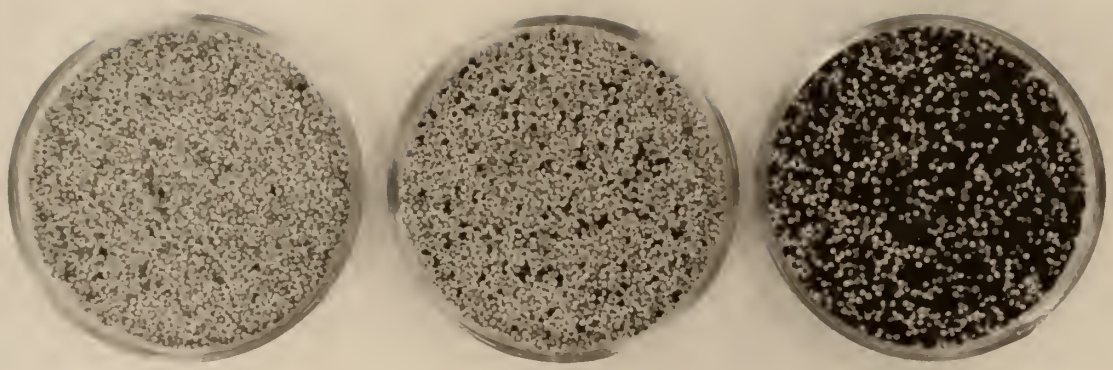
Materials and Methods

An experimental laboratory sifter was manufactured by Great Western Manufacturing Company, Inc., Leavenworth, Kansas. A Kice Mini-Aspirator was manufactured in Wichita, Kansas by Kice Metal Products Company, Inc. Miag NorthAmerica, Inc. manufactured the Miag Laboratory Purifier in Minneapolis, MN. Seedburo Equipment Company manufactured the North Dakota Seed Blower in Chicago, Illinois.

The separation of wild amaranth from domesticated amaranth was attempted using a purifier, aspirator, sieve shaker, and seed blower.

Screens used in the experimental lab sifter included 16TT, 18SS, 20W, 24GG, and 24TT. Twenty-five grams of uncleaned amaranth was poured over the 16TT screen. The overs on the 16TT and 18SS were removed and dumped as trash. The sifter was run 30 seconds. Overs of the 20W, 24GG, and

Figure 1. Increasing A. retroflexus content from left to right.



24TT were combined and resifted for 15 seconds. The overs of the 20W, 24GG and 24TT screens following resifting were considered cleaned amaranth.

Results and Discussion

None of the grain cleaning equipment separated the black wild seeds from the domesticated pale seeds. Evidently, the physical properties of the two grains were very similar.

Yield after sifting averaged around 24.5 grams. The experimental lab sifter was very effective, but extremely slow. A gravity table was also effective in cleaning the amaranth, and larger quantities could be cleaned. However, like the sifting method, it was slow because of the need to resift.

Much of the A. retroflexus contamination in domesticated amaranth can be eliminated if the producer weeds fields during early crop growth. As of yet, no quality standards have been developed. Until these regulations become available, clean amaranth grain can be obtained by carefully choosing a grower who is eliminating the growth of wild amaranth early in production.

APPENDIX II

Table 1. Milling curves for *A. hypochondriacus* using the 120 grit with the 12, 5 and 1 cup plates.

TIME (min.)	CUMULATIVE % MILLING LOSS ± STANDARD ERROR OF MEAN		
	PLATE TYPE		
	12 CUP	5 CUP	1 CUP
0	0.00	0.00	0.00
1	7.93±0.13	4.62±0.12	3.74±0.10
2	15.64±0.21	11.09±0.18	9.91±0.16
3	21.33±0.24	16.41±0.21	15.31±0.19
4	27.92±0.29	21.25±0.25	20.02±0.23
5	29.67±0.34	25.65±0.29	24.46±0.26
6	33.85±0.36	29.44±0.32	29.12±0.28
7	37.59±0.42	32.73±0.37	33.43±0.33
8	39.10±0.42	35.44±0.36	37.20±0.32
9	41.29±0.49	37.91±0.43	40.54±0.38

Table 2. Milling curves for *A. cruentus* using the 120 grit with the 12, 5, and 1 cup plates.

TIME (min.)	CUMULATIVE % MILLING LOSS ± STANDARD ERROR OF MEAN		
	PLATE TYPE		
	12 CUP	5 CUP	1 CUP
0	0.00	0.00	0.00
1	7.17±0.13	5.02±0.12	2.41±0.09
2	15.45±0.21	12.89±0.18	8.24±0.14
3	21.36±0.24	19.19±0.21	13.40±0.16
4	27.47±0.29	24.41±0.25	17.50±0.19
5	31.60±0.34	28.81±0.29	20.95±0.22
6	35.68±0.36	32.61±0.32	23.83±0.24
7	39.37±0.42	35.91±0.37	26.50±0.28
8	44.27±0.42	38.72±0.36	28.90±0.27
9	45.62±0.49	41.43±0.43	31.11±0.32

Table 3. Milling curves for both species of amaranth using the 1 and 12 cup plates with the 180 grit abrasive. (*Species 1 = A. cruentus and *Species 2 = A. hypochondriacus)

	PLATE TYPE			
	12 CUP		1 CUP	
*SPECIES	1	2	1	2
TIME (min.)	CUMULATIVE % MILLING LOSS ± STANDARD ERROR OF MEAN			
0	0.00	0.00	0.00	0.00
1	4.05±0.04	2.45±0.12	2.21±0.05	2.29±0.05
2	8.41±0.13	6.87±0.22	6.11±0.08	5.89±0.08
3	12.01±0.17	11.32±0.29	9.08±0.11	8.10±0.11
4	15.07±0.21	13.03±0.36	11.41±0.13	9.49±0.13
5	18.12±0.24	14.40±0.42	13.34±0.16	10.59±0.16
6	18.49±0.24	14.40±0.42	14.93±0.16	11.63±0.16
7	21.54±0.30	14.80±0.52	16.37±0.20	12.60±0.20
8	22.99±0.31	16.68±0.53	17.72±0.20	13.39±0.20
9	27.64±0.35	18.55±0.61	18.87±0.23	14.11±0.23

Table 4. Incremental milling curves for 2 species of amaranth using the 1 cup plate and 2 abrasives. (*Species 1 = A. cruentus and *Species 2 = A. hypochondriacus)

	ABRASIVE			
	120		180	
SPECIES *	1	2	1	2
TIME (min.)	INCREMENTAL % MILLING LOSS ± STANDARD ERROR OF MEAN			
0	0.00	0.00	0.00	0.00
1	2.41±0.06	3.74±0.05	2.21±0.05	2.29±0.05
2	5.83±0.04	6.17±0.05	3.90±0.04	3.60±0.04
3	5.16±0.06	5.40±0.07	2.97±0.06	2.21±0.06
4	4.10±0.04	4.71±0.04	2.33±0.04	1.39±0.04
5	3.45±0.05	4.44±0.05	1.93±0.05	1.10±0.05
6	2.88±0.02	4.66±0.02	1.59±0.02	1.04±0.02
7	2.67±0.02	4.31±0.02	1.44±0.02	0.97±0.02
8	2.40±0.02	3.77±0.03	1.35±0.02	0.79±0.02
9	2.21±0.03	3.34±0.04	1.15±0.03	0.72±0.03

Table 5. Ash curves for pearl fractions of 2 species of amaranth milled on the 120 grit with the 12 cup plate.

	AVERAGE ASH % (D.B.) ± STANDARD ERROR OF MEAN	
TIME (min.)	A. hypochondriacus	A. cruentus
0	3.08±0.04	2.72±0.04
1	2.89±0.03	2.46±0.03
2	2.31±0.04	2.30±0.04
3	1.83±0.01	2.02±0.01
4	1.36±0.03	1.68±0.03
5	1.16±0.04	1.48±0.04
6	0.97±0.03	1.27±0.03
7	0.80±0.08	1.18±0.08
8	0.69±0.01	0.77±0.01
9	0.58±0.01	0.72±0.01

Table 6. Crude fat curves for pearl fractions of 2 species of amaranth milled on the 120 grit abrasive with the 12 cup plate.

	AVERAGE CRUDE FAT % (D.B.) ± STANDARD ERROR OF MEAN	
TIME (min.)	*A. hypochondriacus*	*A. cruentus*
0	7.03±0.17	7.97±0.17
1	6.13±0.20	7.24±0.20
2	4.94±0.20	5.66±0.20
3	4.00±0.34	4.71±0.34
4	2.77±0.02	3.61±0.02
5	2.56±0.12	2.98±0.12
6	1.95±0.12	2.24±0.12
7	1.73±0.09	2.69±0.09
8	1.21±0.08	1.47±0.08
9	0.88±0.06	1.49±0.06

Table 7. Crude fiber curves for pearl fractions of 2 species of amaranth milled on the 120 grit abrasive with the 12 cup plate.

	AVERAGE CRUDE FIBER % (D.B.) ± STANDARD ERROR OF MEAN	
TIME (min.)	*A. hypochondriacus*	*A. cruentus*
0	4.73±0.05	4.19±0.05
1	3.50±0.13	3.00±0.13
2	2.10±0.09	2.88±0.09
3	1.97±0.11	1.65±0.11
4	1.58±0.08	1.64±0.08
5	1.26±0.06	1.40±0.06
6	1.13±0.02	1.31±0.02
7	0.85±0.09	1.42±0.09
8	0.83±0.09	0.97±0.09
9	0.73±0.04	0.91±0.04

Table 8. Protein curves for pearl fractions of 2 species of amaranth milled on the 120 grit abrasive with the 12 cup plate.

TIME (min.)	AVERAGE PROTEIN % (D.B.) ± STANDARD ERROR OF MEAN	
	A. hypochondriacus	A. cruentus
0	16.83±0.27	15.35±0.27
1	16.03±0.52	14.79±0.52
2	14.89±0.95	12.66±0.95
3	11.38±0.17	11.31±0.17
4	9.09±0.00	9.19±0.00
5	7.95±0.12	7.81±0.12
6	6.23±0.02	7.06±0.02
7	6.11±0.05	6.31±0.05
8	5.20±0.13	5.32±0.13
9	4.73±0.10	4.91±0.10

Table 9. Ash curves for the removed fractions of 2 species of amaranth milled on the 120 grit abrasive with the 12 cup plate.

TIME (min.)	AVERAGE ASH % (D.B.) ± STANDARD ERROR OF MEAN	
	A. hypochondriacus	*A. cruentus*
1	7.21±0.11	6.40±0.11
2	7.51±0.05	6.42±0.05
3	7.70±0.21	6.22±0.21
4	7.46±0.07	6.58±0.07
5	7.34±0.07	6.43±0.07
6	7.25±0.02	6.01±0.02
7	6.75±0.06	5.82±0.06
8	7.03±0.07	5.91±0.07
9	6.44±0.03	5.81±0.03

Table 10. Crude fat curves for the removed fractions of 2 species of amaranth milled on the 120 grit abrasive with the 12 cup plate.

TIME (min.)	AVERAGE CRUDE FAT % (D.B.) ± STANDARD ERROR OF MEAN	
	A. hypochondriacus	*A. cruentus*
1	13.65±0.13	17.19±0.13
2	17.56±0.55	18.69±0.55
3	17.18±0.25	19.18±0.25
4	18.02±0.21	18.69±0.21
5	15.95±0.16	18.52±0.16
6	16.67±0.06	17.99±0.06
7	14.23±0.15	16.99±0.15
8	14.57±0.27	15.82±0.27
9	14.15±0.60	15.90±0.60

Table 11. Crude fiber curves for removed fractions for 2 species of amaranth milled on the 120 grit abrasive with the 12 cup plate.

TIME (min.)	AVERAGE CRUDE FIBER % (D.B.) ± STANDARD ERROR OF MEAN	
	A. hypochondriacus	*A. cruentus*
1	18.28±0.35	15.72±0.35
2	14.31±0.12	11.13±0.12
3	12.37±0.31	10.73±0.31
4	9.80±0.19	8.78±0.19
5	9.10±0.36	8.63±0.36
6	8.88±0.17	8.74±0.17
7	8.38±0.12	8.06±0.12
8	8.66±0.39	7.77±0.39
9	8.43±0.10	7.30±0.10

Table 12. Protein curves for the removed fractions of 2 species of amaranth milled on the 120 grit abrasive with the 12 cup plate.

	AVERAGE PROTEIN % (D.B.) ± STANDARD ERROR OF MEAN	
TIME (min.)	*A. hypochondriacus*	*A. cruentus*
1	36.40±0.64	33.79±0.64
2	38.46±0.40	33.92±0.40
3	40.67±0.20	34.00±0.20
4	39.99±0.34	32.50±0.34
5	39.11±0.44	31.61±0.44
6	39.21±0.50	31.38±0.50
7	38.29±0.11	29.91±0.11
8	35.04±0.71	28.99±0.71
9	35.64±0.60	29.57±0.60

Table 13. Cumulative milling loss for *A. cruentus* on 3 types of abrasives using the 1 cup plate.

	CUMULATIVE % MILLING LOSS ± STANDARD ERROR OF MEAN		
	ABRASIVE		
TIME (min)	120 GRIT	180 GRIT	STONE
0	0.00	0.00	0.00
1	2.41±0.02	2.21±0.02	1.20±0.04
2	8.24±0.07	6.11±0.07	4.60±0.10
3	13.40±0.12	9.08±0.12	8.40±0.19
4	17.50±0.14	11.41±0.14	11.50±0.22
5	20.95±0.16	13.34±0.16	14.00±0.25
6	23.83±0.17	14.93±0.17	16.00±0.26
7	26.50±0.18	16.37±0.18	18.00±0.33
8	28.90±0.19	17.72±0.19	19.80±0.36
9	31.11±0.21	18.87±0.21	21.90±0.39

Table 14. Cumulative component curves for A. hypochondriacus using the 1 cup plate and 180 grit abrasive.

TIME (min.) (% removed)	% OF TOTAL COMPONENT Ash	Fiber	Protein	Fat
1 (2.29)	5.47	11.00	4.22	3.22
2 (5.89)	13.05	23.97	11.33	10.77
3 (8.10)	18.29	29.08	16.13	16.01
4 (9.49)	21.65	31.39	19.26	19.45
5 (10.59)	24.28	32.67	21.72	22.23
6 (11.63)	26.93	33.50	24.09	24.90
7 (12.60)	29.37	34.15	26.26	27.39
8 (13.39)	31.36	34.52	29.98	29.39
9 (14.11)	33.17	34.89	29.58	31.27

Table 15. Cumulative component curves for A. hypochondriacus using the 1 cup plate and 120 grit abrasive.

TIME (min.) (% removed)	% OF TOTAL COMPONENT Ash	Fiber	Protein	Fat
1 (3.74)	7.61	13.81	6.81	6.03
2 (9.91)	21.27	29.48	19.63	19.91
3 (15.31)	34.55	34.61	31.39	34.39
4 (20.02)	45.53	38.08	41.41	46.26
5 (24.46)	55.21	50.57	51.04	56.99
6 (29.12)	64.88	42.77	59.77	67.30
7 (33.43)	73.29	44.57	67.14	76.00
8 (37.20)	79.91	45.74	72.88	82.84
9 (40.54)	85.09	46.73	77.32	88.12

Table 16. Cumulative component curves for A. cruentus using the 1 cup plate and the 120 grit abrasive.

TIME (min.) (% removed)	% OF TOTAL COMPONENT Ash	Fiber	Protein	Fat
1 (2.41)	5.73	8.77	4.48	4.39
2 (8.24)	18.14	24.37	16.13	17.82
3 (13.40)	30.00	32.35	26.08	30.09
4 (17.50)	39.08	37.07	34.33	42.37
5 (20.95)	45.78	38.44	39.68	49.04
6 (23.83)	51.65	40.13	44.36	55.18
7 (26.50)	56.67	40.82	48.68	60.15
8 (28.90)	60.98	41.56	52.22	64.66
9 (31.11)	64.90	41.85	55.33	68.66

Table 17. Cumulative component curves for A. cruentus using the 1 cup plate and 180 grit abrasive.

TIME (min.) (% removed)	% OF TOTAL COMPONENT Ash	Fiber	Protein	Fat
1 (2.21)	5.01	9.01	4.65	3.77
2 (6.11)	13.70	21.64	13.03	12.81
3 (9.08)	21.69	28.50	20.08	20.95
4 (11.41)	25.50	30.02	23.30	24.69
5 (13.34)	28.86	31.08	26.17	27.74
6 (14.93)	31.22	31.75	28.26	30.05
7 (16.37)	32.72	32.07	29.62	31.52
8 (17.72)	35.63	32.51	32.02	34.41
9 (18.87)	37.53	32.89	33.58	36.29

Table 18. Comparison of A. cruentus component contents at 13.40% removal for the 120 grit and 13.34% removal for the 180 grit using the 1 cup plate.

	COMPONENT %	
COMPONENT	120 grit	180 grit
Ash	30.00	28.86
Fat	30.09	27.74
Fiber	32.35	31.08
Protein	26.08	26.17

Table 19. Comparison of A. hypochondriacus component contents at 9.91% removal for the 120 grit and 9.41% removal for the 180 grit using the 1 cup plate.

	COMPONENT %	
COMPONENT	120 grit	180 grit
Ash	21.27	21.65
Fat	19.91	19.45
Fiber	29.48	31.39
Protein	19.63	19.26

Table 20. Comparison of A. cruentus component contents at 31.60% removal on the 12 cup plate and 31.11% removal on the 1 cup plate using the 120 grit abrasive.

	COMPONENT %	
COMPONENT	12 cup	1 cup
Ash	6.43	6.50
Fat	18.52	19.16
Fiber	8.64	6.46
Protein	31.44	31.30

APPENDIX III

SENSORY EVALUATION OF AMARANTH AS A SUBSTITUTE IN CREAM OF WHEAT

Introduction and Literature Review

Over ten years ago, the National Academy of Science identified amaranth grain as a promising, under-utilized food source and concluded it should receive more study (NAS, 1975). Rodale Research Center has been identifying appropriate varieties of amaranth for specific food uses. It has conducted many sensory evaluations of potential amaranth food products. Rodale researchers found whole amaranth grain can be utilized as a hot breakfast cereal. Their research has been limited by the fact that there is no standard industrial processing technique for amaranth.

Betschart and coworkers (1981) found conventional mills do not effectively fractionate amaranth. The Strong-Scott barley pearler allows fractionation of the amaranth into a bran-germ fraction and a pearl consisting mostly of waxy starch. Abrasive milling has been shown to be a promising processing technique. Most recently, an experimental mill known as TADD has been used to abrasively mill amaranth. This mill is advantageous in that it allows: (1) multiple samples per batch, (2) controlled fractionation, (3) different abrasive surfaces, and (4) bulk milling. Whereas the Strong-Scott barley pearler takes 25 minutes to attain a starchy pearl, the TADD takes only 7-9 minutes.

No work in new product development or sensory evaluation has been done with abrasively milled amaranth. Visual and textural characteristics of cooked milled amaranth are similar to "Cream of Wheat", whereas cooked whole amaranth visual properties are less appealing and it has been described as "greasy" (Stiebritz et al, 1985). Cooked milled amaranth has about the same particle size and bland taste as "Cream of Wheat". It became obvious that milled amaranth could be substituted into "Cream of Wheat". When combined with whole wheat, the resulting protein approximates the FAO/WHO recommended composition for optimum human nutrition (Stiebritz et al, 1985). The nutrition of the substituted "Cream of Wheat" product would increase tremendously through additional fiber and lysine.

Whole amaranth has 8% crude fat, 4.2% crude fiber, 16.5% protein and 2.5% ash. Three minute milled amaranth, using the 12 cup plate and 120 grit abrasive on the TADD, has approximately 23% of the kernel removed. It has 4.3% fat, 1.7% crude fiber, 8.8% protein and 1.8% ash. Nine minute milled amaranth has about 45% of the kernel removed. It has 1.7% crude fat, 1% crude fiber, 3% protein and 0.6% ash.

Materials and Methods

Amaranth. *Amaranthus cruentus* was obtained from Jack Horst, Edgar, Nebraska.

TADD Components. The TADD 4E-115 was manufactured by Venables Machine Works Limited, Saskatoon, Saskatchewan, Canada. The machined aluminum disk to which the 120 grit abrasive cloth was fixed, is 10 in. in diameter and 9/32 in. thick with a 1 in. diameter arbor. The 120 grit Shur-Stik abrasive disks were manufactured by Merit Abrasive Products, Inc., Compton, California and purchased from B.C. MacDonald and Company, Kansas City, Kansas.

"Cream of Wheat". Regular, long-cooking "Cream of Wheat" was manufactured by Nabisco Brands, Inc. and purchased locally.

Sensory Analysis Test Equipment. Materials required for testing included: 16 metal spoons, 500 ml graduated cylinder, warming plate, 2 double boilers, 24 custard dishes with accompanying watch glasses, 1 in. diameter ice cream scoop, red masking lights, distilled water, and 24 duo-trio test questionnaires.

Milling of Amaranth. A. cruentus was milled for 3 and 9 minutes using the 12 cup plate and 120 grit abrasive.

Sample Preparation. The reference was prepared by adding 84.4 g of "Cream of Wheat" to 450 ml of warm, distilled water in the double boiler. This was heated and constantly stirred. The 3 min. milled amaranth-"Cream of Wheat" sample and 9 min. milled amaranth-"Cream of Wheat" sample were prepared in the same manner. Samples were cooked until they were visually estimated to have the same

viscosity. The milled amaranth substituted product consisted of 24 g milled amaranth and 60.4 g "Cream of Wheat" (28% substitution level). Custard dishes were labeled with a random 3-digit code and placed on a warming plate. Equal portions were placed into each dish using an ice cream scoop.

Test Procedure. Panelists were given "Cream of Wheat" as a reference and two more samples to compare to the reference. One of these samples was "Cream of Wheat" and the other was a milled amaranth substituted product. They were to identify which sample was different from the reference and indicate the degree of difference on a four point scale. Panelists also had a "Comments" section available to write any further observations. Panelists were familiar with sensory evaluation techniques, but no screening tests were done with the product.

Two duo-trio tests were conducted per testing session. One test presented the 3 min. milled amaranth substituted product to be differentiated, while another test presented the 9 min. milled amaranth substituted product. Order of presentation of tests was random and balanced. All sessions were conducted under red masking lights because 3 min milled amaranth is clearly visible in the mixture and this was not to be the basis for differentiation.

Statistical Analysis. Because of limited resources, only 4 panelists were utilized. During the last quarter of

the 1986 spring semester at Kansas State University, three trials were run: two were run on Tuesday and Thursday of the same week and the other was run the week before on Thursday at 1:30 p.m. Because of the lack of a sufficient number of independent samples, a two-sample, one tail test was done on combined trials (n=12). Trials were evaluated separately but not with statistical analysis.

Results and Discussion

All panelists detected the correct sample (the sample which was different from the reference) in the duo-trio test utilizing 3 min. milled amaranth substituted product (Table 1). The difference was described as: gritty; nutty; grainy; large grain present; harder grain; better, richer taste; bitter; and thicker. The grain may have been "hard" because of cooking time difference between wheat and amaranth. The last descriptor, "thicker", illustrates the importance of controlling viscosity.

This test revealed the classic error involved in using duo-trio tests: examining a difference that is too large. Screening tests would alleviate this problem.

Although statistical analysis could not be used to analyze the results for the 3 min. milled amaranth substituted product, it was obvious that all four panelists chose the correct sample every time. The degree of difference was judged six times as being "much", five times

Table 1. Duo-trio test results of 3 min. milled amaranth substituted product.

		# choosing degree of difference			
Test Day	# correct	Slight	Moderate	Much	Extreme
1	4	0	3	1	0
2	4	0	1	2	0
3	4	0	1	3	0
TOTAL:	12	0	5	6	0

as being "moderate", and once as "extreme" (Table 1). With the use of more panelists, this seems to indicate a statistical difference could be found.

Eight out of twelve panelists detected the correct sample in the duo-trio test utilizing 9 min. milled amaranth substituted product (Table 2). No significant difference was indicated between "Cream of Wheat" and the 9 min. milled amaranth substituted product.

In the first replication, only one panelist detected the correct sample. In the second and third replications, four and three panelists, respectively, chose the correct sample. The results of the first and second replications were very inconsistent. This could be due to : (1) replications not occurring in the same week, (2) increased sensitivity to "graininess" of amaranth present, and (3) viscosity differences between the reference and substituted product were larger in the second repetition than the first. Also, three out of four panelists were inconsistent in judging the degree of difference in the same week. This did not occur for the 3 min. milled amaranth substituted product (Table 3). The degree of difference was judged seven times as being "moderate" and once as being "much" (Table 2). It would be unwise to place any confidence in the results obtained for this section of the study.

Selection of panel members could not be controlled in this particular study. Difference testing is complicated by

Table 2. Duo-trio test results of 9 min. milled amaranth substituted product.

		# choosing degree of difference			
Test Day	# correct	Slight	Moderate	Much	Extreme
1	1	0	1	0	0
2	4	0	3	1	0
3	3	0	3	0	0
TOTAL:	8	0	7	1	0

Table 3. "Degree of Difference" answer patterns.

	1 2 3	1 2 3	1 2 3	1 2 3
Panelist:	1	2	3	4
PRODUCT				
3 min.	Mod Ex Mod	Mod Mch Mch	Mod Mod Mod	Mch Mod Mod
9 min.	Slt Mod Mod	Mod Mch Slt	Mod Mch Mod	Slt Mod Mch

varying thresholds and thus actual differences may be overlooked (Baker, 1954). This problem was evident in this study. Looking at the panelists' "Comments" section, one panelist could always detect a difference in the 9 min. milled amaranth substituted product. This panelist was sensitive to incompletely cooked amaranth and viscosity differences. However, another panelist only detected the correct sample once and attributed the difference to a "wheatier" taste. Hence, it is obvious that the threshold of one panelist to viscosity differences and incompletely cooked amaranth is much lower than the other panelist's. Thus, it may be possible this study overlooked differences that actually existed, but did not show up due to threshold differences between panelists.

Dawson et al (1963) also found that texture, appearance, and color of a sample must be carefully controlled. Appearance and color differences were masked by red lighting in this study. However, two major problems with this study centered around texture of the product: (1) viscosity differences between the samples, and (2) undercooked amaranth grain. Some remedies to the latter problem are to: (1) crack the milled amaranth into smaller particles (increasing surface area and perhaps decreasing cooking time), (2) find a cook time in which amaranth grain is tender, cook amaranth until 10 minutes are left of that cook

time and then add "Cream of Wheat", and (3) pregelatinize the amaranth before combining it with "Cream of Wheat".

Viscosity of the samples is a more complex problem. Viscosity differences between "Cream of Wheat" and the milled amaranth substituted product are probably due to the fact that amaranth's large amylopectin:amylose ratio dilutes the setting effect of the wheat's higher amylose content. Viscosity differences may be noticed at a 28% level but not at other levels. Varying levels of milled amaranth and using a Brookfield viscometer to measure viscosity differences could be used to further explore this area. Eventually, it might be advantageous to relate visocometer values to panelists' judgements.

Different viscosities of the substituted products from trial to trial indicated the cooking procedure was not well standardized. The simplest solution would be to cook the product until it reached a predetermined value by monitoring it with a viscometer.

More panelists and replications are needed if results are to be subjected to correct statistical analysis. Otherwise, this type of study would be a very good screening tests for panelist thresholds and determination of substitution levels.

APPENDIX IV

MILLING SORGHUM WITH THE TADD

Introduction

A preliminary study was conducted on the TADD utilizing sorghum in order to familiarize the experimenter with the operation of the mill and factors affecting the mill's performance. Sorghum was chosen because the TADD mill was developed to simulate the abrasive action produced in commercial sorghum dehullers (Reichert et al, 1982).

The objectives of the study were as follows:

(1) Examine whether sample cups in the 12 cup plate could be used as replicate samples by comparing the difference between cups versus the difference between trials.

(2) Examine the effect of size-grading sorghum into "large" and "small" kernels on the milling curves obtained.

(3) Examine effect of stone type on milling loss of sorghum size-graded as "small" by analyzing milling curves and pictures of the milled product.

(4) Examine whether measurements made by the Dapple ImagePlus system could be substituted for weight loss measurements as a tool for tracing milling loss.

Literature Review

VARIATION IN TADD PERFORMANCE.

Oomah et al (1981) claim the TADD has multi-sample capabilities. This means each cup could be used as a

replicate because the difference in performance between cups is negligible. Oomah et al (1981) found the coefficient of variation for an 8 cup plate to be from one to two percent between cups. The difference in values for coefficient of variation between cup numbers other than eight and between trials, i.e, running the eight cups three or more times, were not investigated by Oomah et al (1981).

SIZE-GRADING OF SORGHUM

Wills and Ali (1982) were the first investigators to report the effect of grain size on the milling curves obtained from a laboratory pearler. Samples were size-graded into three different class sizes: < 4.00mm,< 3.35mm, < 2.80mm. They found the milling yield generally decreased as the grain size decreased for a Kett Electric Pearler. They concluded size-grading sorghum would be wise to prevent undermilling of smaller grains and overmilling of larger ones and to improve the uniformity of cooking (Wills and Ali, 1983).

EFFECT OF ABRASIVE DISK ON MILLING LOSS

Oomah et al (1981) examined the comparison of using two types of resinoid disks versus the action of the Strong-Scott barley pearler on the milling loss of barley. They found that the coarser grit removed more material than the finer grit and that the coarse grit action paralleled that of the Strong-Scott barley pearler. However, sample size of barley in the TADD was 15 grams less than that in the

Strong-Scott barley pearler (25 grams) and thus may have affected the results, given a smaller sample size dehulls faster than a larger one.

VISUAL IMAGING

Computerized visual imaging has recently been used to distinguish among varieties of cereal grains to determine the uniformity of kernel size and shape (Lai et al, 1986). Computerized visual imaging instrumentation is expensive at the moment, but given the strong possibility of future rapid automation, the cost could decrease tremendously over the next decade. Because of the promising future of this type of instrumentation, utilization of visual imaging was an attractive option for examination of milling loss.

Materials and Methods

Sorghum. Sorghum was obtained from the Kansas State University pilot feed mill, Manhattan, Kansas. It consisted of both yellow- and red-bran sorghum.

TADD. The TADD 4E-115 was manufactured by Venables Machine Works Limited, Saskatoon, Saskatchewan, Canada. The stones supplied with the mill included grindstones A-46 L5VBE, A-36 L5VBE and A-24 L5VBE manufactured by Norton Canada Inc., Hamilton, Ontario, Canada.

Visual Imaging System. The Dapple ImagePlus system was obtained from Dapple Systems, Inc., Sunnyvale, CA. A Weiss

dissecting microscope utilized with the visual imaging system was manufactured in Germany.

Size-grading of sorghum. A 100 gram sample of sorghum was sifted for 3 minutes on a Tylar Ro-Tap Sieve Shaker according to the method of Wills and Ali (1982). Sorghum less than 4.00 mm but greater than 3.35 mm was referred to as "large" and that less than 3.35 mm but greater than 2.80 mm was noted as "small".

TADD Operation and Milling Curve Determinations. The TADD was assembled by adding a .015 inch shim to the bottom of the driving disk to give a .010 inch gap between the 12 cup sample plate and the stone. Each sample cup mounted in the steel plate of the TADD was numbered. Each plastic cup was numbered and weighed. All twelve sample cups were filled with 10 $\pm$ .05 grams of "small" sorghum ("small" sorghum was used because its yield upon size-grading was much larger than "large" sorghum). Optimum sample size had already been determined by Oomah et al (1981). The sorghum was then milled for time intervals of 1, 2, 4, 6, 8, 10, and 12 minutes. After each time interval was over, an aspirating device was used to collect the milled sorghum from each sample cup into a numbered plastic cup. The cup was then weighed and this was designated as the "total weight after". Milling loss was calculated by subtracting the total weight after milling from the initial sorghum weight plus cup weight. Milling loss % was calculated by

dividing the mill loss by the initial sorghum weight and multiplying by 100. The milled grain was added back to the numbered sample cups and milled for another time interval. "Total weight after" was recorded and mill loss and milling loss % were calculated as stated above. Milling loss % was plotted against time and milling curves resulted.

The same procedure was followed to compare differences in the milling curves between different stones and sizes of sorghum (statistical analysis for differences was not done). However, for the latter experiment, grain was milled for time intervals of 1, 2, 4, and 6 minutes to prevent contamination of brokens into the sample.

A repeated measures design was conducted to compare the difference between cups of the 12 cup plate versus the difference between trials. Using the same sample size of sorghum as stated above, six alternating cups of the 12 cup plate were used and three trials were conducted for 1, 3, and 6 minutes. Milling loss % was calculated and a split-plot ANOVA was used to determine if significant differences existed between cups or trials.

Operation of the Dapple ImagePlus System. The visual imaging system was set up by attaching the video camera to a dissecting microscope. The lighting scheme utilized consisted of back-lighting underneath the microscope stage. The computer was turned on and calibration of the instrument was accomplished by setting 0.3 cm to equal a constant

amount of pixels. "Small" sorghum (the number of kernels was varied for experimental purposes) was placed on the microscope stage and an image was accessed. A grey scale image was obtained and turned into a binary image the computer could measure. If the image lacked definition in some areas due to lack of contrast, the operator was allowed to modify the image by adding to or taking away pixels. After modification, the area of the kernels was measured. When the number of kernels to be measured exceeded 10, the microscope was no longer utilized. Back-lighting was provided by a light box (usually used to view slides or trace drawings on). A template was constructed to allow rapid placement of the kernels in the viewing field. To determine the sensitivity of the instrument, large sorghum kernels were milled for 2, 4, 6, and 8 minutes. One cup was randomly chosen out of the 12 used in the milling process and was measured by using 30 whole kernels per viewing field.

Results and Discussion

Variation in TADD Performance. Statistical analysis revealed that there was no significant difference at the 0.01% level between milling loss of alternating cups on the 12 cup plate or between three trials. This attests to the fact that the TADD is very reproducible and truly has multi-sample capabilities.

Size-grading Effects. The kernels rated as "small" had greater milling loss than the "large" kernels (Figure 1, Table 1). This result was opposite of what Wills and Ali (1983) found. Given that the same weight of both kernels were put into the TADD cups, one would expect the large sized grain to have fewer kernels per cup than the smaller grain. Thus it may be assumed that for the TADD mill, the smaller seeds have more surface area to be exposed to the stone and milling loss increases with increased exposure to the abrasive. This evidently does not hold true for the Kett Electric Pearler. This is probably due to the difference in milling action between the pearler and the TADD.

Effect of Different Abrasive Disks. As expected, increasing the coarseness of the stone increased the milling loss. Also, as milling time increased, the milling loss rate difference between the stones increased (Figure 2, Table 2). This is probably due to the brokens that occur past six minutes. The brokens become small enough to slip underneath the gap and are then regarded as "bran". Thus the milling loss weight increases because of the broken soft endosperm. This is a good example of the dilution of the bran that can be encountered when soft seeds are milled in the TADD.

Figure 1. Comparison of milling curves over time between size-graded sorghum using the 12 cup plate, stone A-24 and a ten gram sample size.

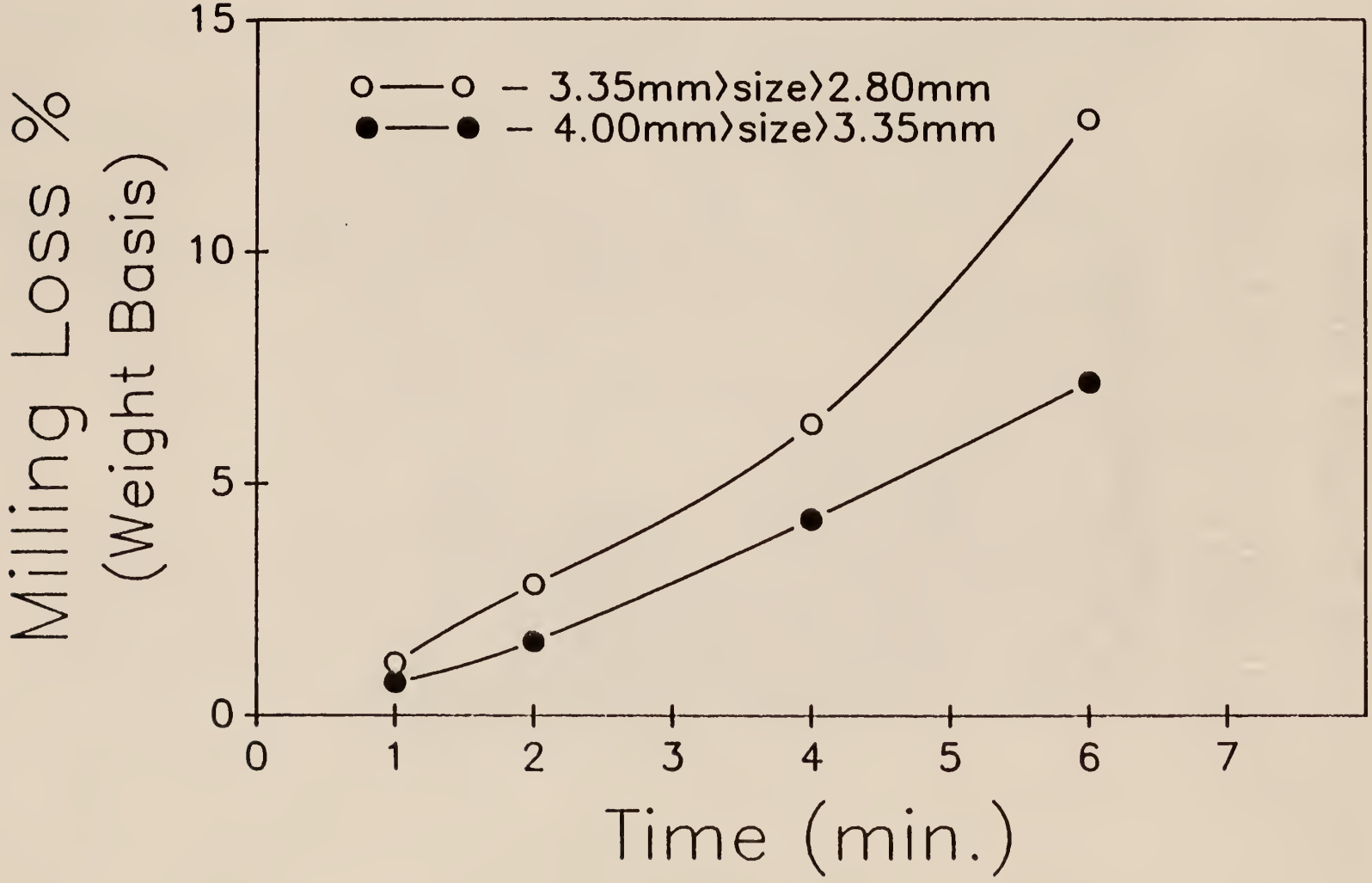

Milling Loss %
(Weight Basis)
15
10
5
0
o—o – 3.35mm>size>2.80mm
●—● – 4.00mm>size>3.35mm
0
1
2
3
4
5
6
7
Time (min.)

Table 1. Data for Figure 1.

	CUMULATIVE AVERAGE MILLING LOSS %	
	TYPE OF SIZE GRADED SORGHUM	
TIME (min.)	SMALL	LARGE
0	0.00	0.00
1	1.15	0.73
2	2.84	1.62
4	6.28	4.24
6	12.85	7.19

Figure 2. Effect of three different stones on the milling curves of a 10 gram sample size of "small" sorghum.

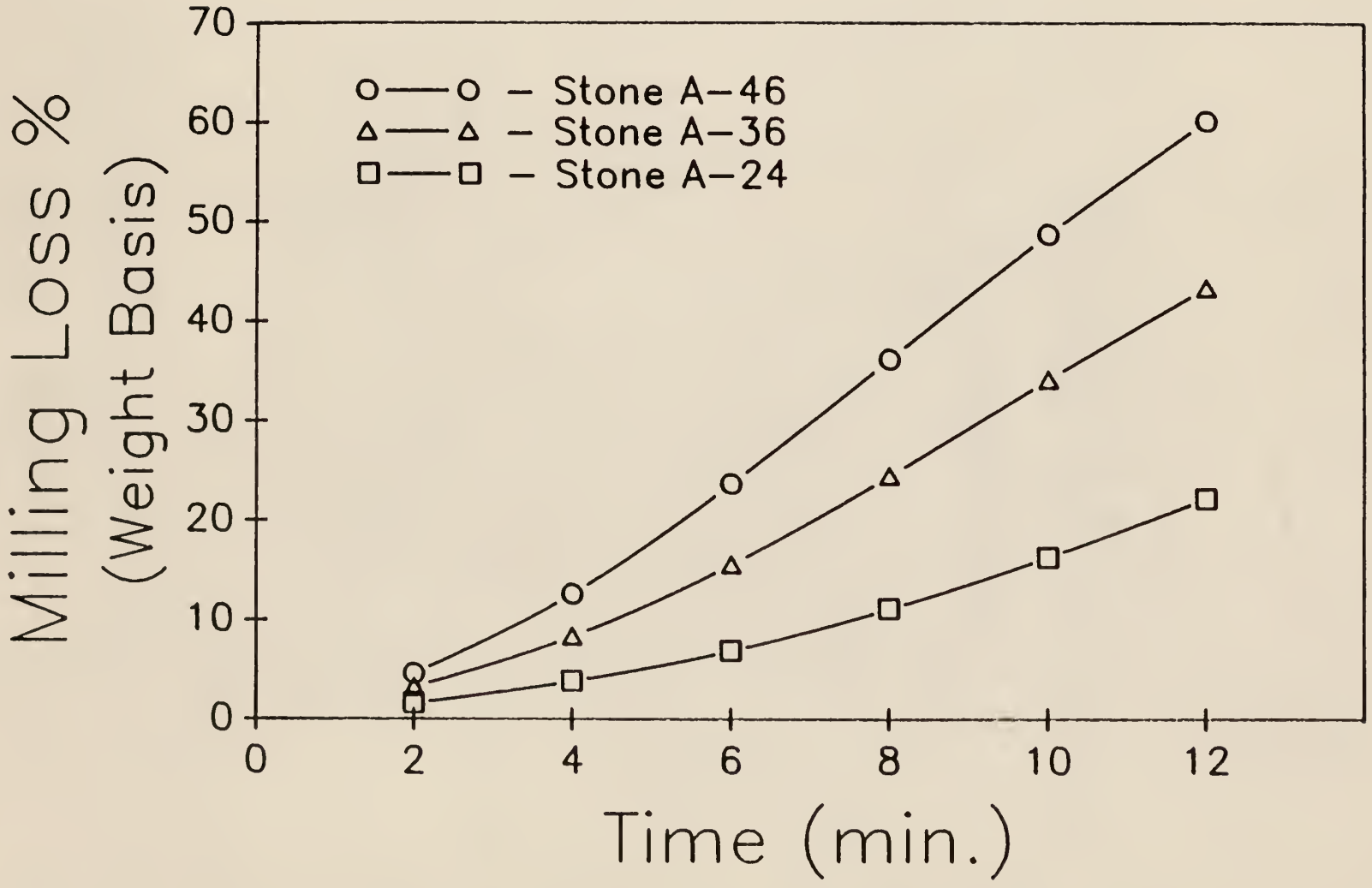

Milling Loss %
(Weight Basis)
70
60
50
40
30
20
10
0
0
2
4
6
8
10
12
Time (min.)
o—o – Stone A–46
Δ—Δ – Stone A–36
□—□ – Stone A–24

Table 2. Data for Figure 2.

	CUMULATIVE AVERAGE MILLING LOSS %		
	TYPE OF STONE ABRASIVE		
TIME (min.)	A-46	A-36	A-24
0	0.00	0.00	0.00
2	4.62	3.25	1.64
4	12.60	8.33	3.85
6	23.66	15.54	6.90
8	36.16	24.44	11.10
10	48.74	34.15	16.30
12	60.19	43.39	22.20

Image Analysis of Milled Grains. The average area (square centimeters) per time interval generally decreased as the incremental milling loss (this is the milling loss per time interval) increased for the first four minutes of milling (Table 2). However, upon increasing the time intervals to 6, 8, and 10 minutes, the average area remained the same (Table 2). This was probably due to the fact that the amount of brokens remaining inside the cup increased dramatically after four minutes and they could not be distinguished from small whole milled kernels. At first, two kernels per viewing field were measured using the microscope. However, this proved to be too time consuming. It took 16 hours to process one representative sample (10 grams). Instead, the magnification of the field was decreased. This decreased the time of analysis, but sacrificed sensitivity. Although it was up to the operator to adjust the image as seen fit (manually adding or taking away pixels), the variability of this procedure did not seem to affect the end results. Using image analysis to trace milling loss seems promising but is not worth the time involved, even for research purposes. Using a computer with more memory and faster speed would help the process a great deal. Further work is being done in this area at Kansas State University.

CONCLUSIONS

The TADD has been found to be a very reproducible, multi-sample milling device for small amounts of grains. The size of seed has an effect on the milling loss: the smaller the kernel, the higher the milling loss. This is a function of the amount of surface area exposed to the abrasive. Increasing coarseness of the abrasive will increase the milling loss of the grain. When softer sorghum is milled in the TADD past six minutes, the number of brokens dramatically increases and begins to dilute the bran fraction. Use of the Dapple ImagePlus system was found to be a potential way of tracing milling loss as long as there were no brokens. However, because of the type of computer utilized, it was not economical time-wise. With future work in this area, further examination of the use of visual imaging as a tool for tracing milling loss could be invaluable.

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MILLING AMARANTH WITH THE TANGENTIAL ABRASIVE DEHULLING DEVICE

by

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The TADD was utilized to remove fractions from Amaranthus cruentus and Amaranthus hypochondriacus. Use of different abrasives was limited by abrasive particle size of grits. The coarse abrasive removed more material than the fine abrasive because of chunk-removing action. The fine abrasive and stone generated approximately the same milling curves. SEM indicated fracture lines in the perisperm and between embryo and perisperm with embryo eventually pulling away. Loss of embryo was erratic. A cooking test estimated embryo presence after milling.

A. cruentus had a faster milling rate than A. hypochondriacus except in the 1 cup plate. A. cruentus milling loss decreased as the number of cups in the plate decreased because geometrical placement of cups in the plates decreased translational motion of the abrasive. This resulted in less abrasive area available than was theoretically possible. A. hypochondriacus milling rate did not decrease on the 1 cup plate. The smooth surface characteristics of A. hypochondriacus probably increased its tangential velocity and it may have had more contact with the abrasive than the slower-moving A. cruentus with relatively wrinkled surface area.

Proximate analysis indicated fat, ash and protein contents increased from the outside in the first 40% of both species. Thirty percent of the total fiber was located in the outer 10-15% of both species. Flour particle surface, protein curves and knowing amaranth was physically hard

indicated a protein matrix. Because the protein matrix was not visible with SEM, it may have tightly wetted the surface of the starch granules.

Design improvements of the TADD are still needed.