EVALUATION OF NEW VARIETIES OF SORGHUM GRAIN FOR WET-MILLING

by

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INTRODUCTION AND REVIEW OF LITERATURE

Sorghum is a crop of world-wide importance. The sorghum family has a history dating back to ancient civilizations in Africa and Asia. The grain sorghums, which are of most economical importance, are known by different local names. Karper and Quinby (1) reported the local names of edible sorghum grains of Africa and Asia as: dura, Kafir, milo, shallu, Koaliang, feterita and hegari; these authors also attributed the name sorghum to height of the plant, from the Latin word "Surgo" which means "arise." Watson (2) reported the local names of sorghum grain as: "milo maize," "Kafir corn," and "gyp corn" in the United States of America and "jowar" in India.

In the United States of America sorghum grain has been considered as feed grain although in most of Africa, Asia and part of Latin America it is the staple food, as has been reported by Karper and Quinby (1) and Rooney and Clark (3).

Before 1942 corn had been processed industrially for many years to obtain starch, corn oil and numerous by-products. As a result the corn wet-milling industry was well established so that optimum methods had been developed for this type of corn processing. This was not true for sorghum grain, since very little work had been done on the recovery of starch and other products from this raw material. The diversity of uses of starch and its products according to their properties widened the field for more sources to come into the picture. The low price of sorghum and its ability to thrive at low moisture and produce grain and forage under conditions that cause other crops to fail pushed sorghum grain into the race for industry, Zipf et al. (4) reported. Furthermore the starch content ranging from 60 to

70% was a favorable factor.

Sorghum as a raw material for starch production was not considered in the industry until 1942, however, when World War II cut off Java as the source of cassava starch used for tapioca in the United States and waxy sorghum was used as a source of starch by General Foods to make "Minute Dessert" to replace "Minute Tapioca." Corn Products Company in 1949 completed erection of a plant at Corpus Christi, Texas, for wet-milling of sorghum grain, Taylor (5) reported.

Work on starch from sorghum grain was reported as early as 1935 when Kao (6) of China claimed that he prepared technically pure starch from sorghum by removing bran and germ and using air separation. Das Gupta (7) of India used fermentation followed by treatment with 0.8% sodium hydroxide and centrifuging to get a product of 95% purity from jowar, which is a variety of sorghum. Johnston (8) seems to have been the first to use a wet-milling procedure similar to that used in the corn industry, with little modifications. He showed a flow sheet for the proposed design of a pilot plant for processing sorghum grain for starch. He recommended a capacity of 1000 pounds per day for his proposed pilot plant. His results showed yield of starch comparable to that from corn except for the high percentage of protein left in the sorghum starch. Later, Taylor (5) reported that the procedure used for wet-milling of sorghum grain, in the Corpus Christi, Texas, plant of Corn Products Company was similar to that used for the manufacture of corn starch. Watson and Hirata (9) and Watson (10) discussed the wet-milling of corn and sorghum grain. They reported that wet-milling of sorghum grain was more difficult than corn wet-milling. The former gave lower yields of starch containing too much protein unless the wet-milling procedure was modified. Watson et al. (11) and Watson (2) attributed the difficulties of wet-milling of sorghum grain to

the size and shape of kernels, the high percentage of horny or corneous endosperm and the thick outer layer of starchy endosperm (probably part of the horny endosperm) just under the aleurone cell layer.

Wet-Milling

Wet-milling is a long process which starts with steeping, continues with grinding and sieving, followed by centrifugal separation of starch and protein, and ends with drying of the various products.

Steeping has been defined by Watson et al. (12) as "essentially a process of soaking dry grain to soften it for subsequent grinding and starch liberation." The steeping variables seem to be mainly: (1) the grain, (2) water, (3) time, (4) temperature, (5) concentration of lactic acid formed during steeping, (6) concentration of sulfur dioxide used in the steep and (7) pH; some of these factors are interrelated.

Rooney and Clark (3) reported that the sorghum grain kernel measured 4 mm. long by 3.5 mm. wide by 2.5 mm. thick and weighed 8 to 50 mg. with average of 28 mg.

Steeping can be outlined as soaking the grains in water at somewhat higher than ambient temperature with added sulfur dioxide. Water absorption into the sorghum grain is controlled by structural barriers. Sanders (13) reported that the cell wall thickening as well as development of the seed coat slowed down the passage of water through the pericarp. He added that the formation of the hilar layer also affected the supply of moisture to the endosperm and the germ. Watson et al. (11) comparing the wet-milling of corn and sorghum grain correlated the difficulty of wet-milling the sorghum grain kernel with the occurrence of the large proportion of horny endosperm and the layer of dense cells rich in protein at the periphery of the starchy endosperm just inside the aleurone cell layer, which slows down the water penetration

into the kernel. This was confirmed by Watson and Hirata (9).

Wolf et al. (14) and Fan et al. (15) revealed the passage of water into the kernel, during steeping, to take place early through the porous tip cap and then to continue quickly into voids in the pericarp by capillary action. Furthermore they indicated that the diffusion of water into the endosperm and the germ followed the standard diffusivity laws that apply equally to corn and milo. Once the water is in the endosperm or germ it moves rapidly into the areas of crushed cells and intercellular spaces, Baird et al. (16) and Wolf et al. (14) reported. The ratio of water used in steeping to the amount of grain is not constant; different workers reported different ratios used in their experiments. Zipf et al. (4) steeped 4 lb. of grain in 2,800 ml. of distilled water, which is approximately 2:3 (gm. ml.), using 0.2 to 0.25% concentration of SO_2. Watson and Hirata (9) steeped 350 gm. of grains (d.b.) in 1500 ml. which is approximately 1:4, but they used the ratio of 1:5 in one experiment and 1:4 in another. Watson et al. (17)used a water-to-grain ratio of 3.75 ml. per gm. (grains at 12% moisture) and during steeping the water was circulated over the grain. These writers stated that such steeping was similar to commercial practice.

The steeping does not only soften the kernel but also dissolves some of the soluble material in different parts of the kernel. Watson (10) reported that from 6 to 6.5% of the weight of the kernel (dry basis) was removed as solubles during steeping. The temperature, time, amount of lactic acid developed during steeping and sulfur dioxide added to the steep water have been reported as different from experiment to experiment but the amount of solubles removed seemed to be dependent on the temperature. Hightower (18) in his report about a sorghum grain processing plant gave the steeping temperature as 125°F., and the time about 60 hours for proper steeping. He

mentioned the use of SO_2 but he did not indicate any amount. Taylor (5) reported the use of dilute sulfurous acid and steeping for 60 hours in the case of sorghum grain in comparison with 48 hours steeping required for corn. For laboratory methods Zipf et al. (4) steeped sorghum grain in a solution of 0.2 to 0.25% SO_2 in water at 110° to 120°F. for 24 hours or more. Their results showed optimum separation of starch and gluten. These workers showed that it was necessary to increase the pitch of the starch table over that used for wet-milling of corn. Working with artificially dried sorghum grain, they concluded that no serious damage was observed in the wet-milling operations, provided the moisture content of the grain remained above 11 to 13%.

Watson et al. (12) reported that a maximum moisture content of 42 to 45% was reached in the first 8 to 10 hours of steeping, yet they said that the time required for thorough steeping was between 40 and 50 hours. Watson and Hirata (9) in their investigations on different varieties of sorghum grain used a steeping medium composed of 0.5% lactic acid and 1.15% sulfur dioxide adjusted initially to pH 3 with potassium hydroxide. The temperature of steeping they reported ranged from 120° to 122°F., the steeping liquid was circulated by a pump for ten minutes every hour. Under these conditions the pH rose rapidly toward 4, leveling off at 4.2 to 4.3.

Campbell and Jones (19) in their investigations on wheat found that the rate of penetration of water to the cheek center of damped menitoba wheat was increased three-fold by a rise in temperature of 12°C. between 20° and 43.5°C. In this work it was also reported that the periods required for completion of 85% moisture movement at 20°, 31.5° and 43.5°C. were 24, 8 and 2.6 hours respectively. The same workers concluded that the initial warming of damped grain to 43.5°C. for a period of one hour or more greatly shortened the subsequent period at 20°C. required for completion of moisture

distribution. Zipf et al. (4) steeping several lots of sorghum grain for 24 and 71 hours showed that quality and recovery of starch, gluten and germ were not improved by the longer period of steeping. The higher rate of water absorption and releasing of solubles from sorghum kernels than from corn was attributed to the small size of the sorghum grain kernel(9). The same workers also reported that waxy varieties of sorghum grain gave higher yields than non-waxy, of steeping solubles. Watson (10) stated the probability that the steeping temperature of 50° to 60°C. might cause the germ cells to die, lose their semipermiability and become flacid. This would aid in the recovery of the germ later on in the initial milling process. Small organic molecules such as sugars, phytate and amino acids are known to pass through the membranes into the water, during steeping. The same worker reported that these substances add up to 6 to 6.5% of the dry substance of the grain.

Increase of the kernel volume during steeping was reported by Grosh and Milner (20). The same authors indicated that the volume increase of the cereal grains accompanying absorption of water might be due to the continuous formation of cracks during processing. The mathematical expression for this postulation has been given by an equation developed by Fan et al. (21) in 1962 as follows:

$pf\Delta V = \Delta W$ where pf is density of water, ΔV is the total increase in volume, and ΔW is the total increase in weight. The data latter workers obtained indicated that the linear relationship between the weight and the volume increases as indicated above by the equation was clearly shown by all the samples of sorghum, wheat and corn tested. The same workers added that for White Kafir (a sorghum variety) the volume of water initially absorbed by kernels by capillary action was slightly affected by temperature while in corn it was independent of temperature.

Anderson (22) found that during steeping, corn with starch of 75% amylose content exhibited 125% increase in volume over its dry state. This, the same worker reported, to be greater than that of corn of 67% amylose content and twice as much as the increase in volume of ordinary corn but the same as that of corn of 57% amylose content. In 1965 the same author (23) reported an increase in volume of 105% exhibited by Class 8 amylomaize (high amylose corn).

The role of SO_2 in steeping: The use of SO_2 in steeping of corn was known in the past to control the microbial growth. Johnston (8), studying different varieties of sorghum grain, used 1/16 M sulfur dioxide solution as steep water, but he did not show any results to evaluate the use of sulfur dioxide; however he had the same idea as previous workers. Later, Cox et al. (24) who studied the effect of steeping agents by microscopic observations, demonstrated that during steeping with SO_2 over a 24-hour period at 50°C. the protein matrix gradually swelled, became globular and finally dispersed. These workers showed that the protein dispersion was faster as the SO_2 concentration was increased up to 0.4%. They concluded from their findings that other reducing agents could replace sulfur dioxide. Watson and Sanders (25) soaked endosperm sections in a constant bisulfite ion concentration with agitation; the starch granules were rapidly loosened from the protein matrix. The rate of the starch release was increased by increasing the bisulfite ion concentration from 0.02 to 0.05% and by increasing the temperature from 52° to 60°C. But at pH values below 9, SO_2 was found to have no effect on starch release from the endosperm sections. Other acids, including lactic acid, were found to have no effect even if agitation was carried on for 24 hours at 52° to 60°C. This again shows the role of sulfur dioxide in releasing the starch from the protein matrix in the endosperm. Watson (10), dissolving SO_2

in water, reported the formation of a bisulfite ion which he referred to as "the active agent in steeping." He added that the reaction of a bisulfite ion in steeping could be completed within 4 to 6 hours provided there was no factor limiting the diffusion of bisulfite ion into the kernel. The same author suggested that "by reacting with the sulfhydryl radical, bisulfite ion reduces the disulfide bonds that cross-link protein strands."

$$RS - S\dot{R} + S\bar{O}_3 \longrightarrow RSS\bar{O}_3 + \dot{R}\bar{S}$$

He reported that the thiosulfate protein produced was more soluble in water than the original and found the reaction rate was greatest at pH 5.0. Duvick's (26) results suggested that bisulfite might be reacting with glutelin.

The role of lactic acid in steeping: The role of lactic acid in steeping was reported by Cox et al. (24) and Wagoner (27) to be to soften the steeped grain by the absorption of water. The lactic acid is produced by the Lactobacillus Spp. which convert the soluble sugars leached out of the grain during steeping to lactic acid. Watson et al. (12) attributed the growth of the lactic bacteria in the steep to the fact that unlike other microorganisms they thrive at 120° to 125°F. and at pH values in the range of 3.8 to 4.4. Watson and Hirata (28) found that the use of 0.5% lactic acid in a synthetic steeping medium, gave satisfactory results which they claimed to be equivalent to those of commercial steeping. Watson et al. (11) reported the use of lactic acid in the steeping medium but no results were correlated with its use. Watson (10) indicated that the lactic acid produced by the lactic bacteria lowered the pH of the medium and restricted the growth of most of other organisms. The same author reported that the bacterial growth was directly proportional to the sugar concentration after 16 hours from the start of the steep.

Watson et al. (12) reported some criteria for the evaluation of

steeping, including analysis of steep water, milling of steeped grain and microscopic examination of grain after steeping by a technique similar to that reported by Cox et al. (24). The results confirmed the last criterion to be the best.

Steeping is followed by milling which is the process to put the grain into a form where separation of different parts will be as easy as possible and most practical. Johnston (8) divided the process into preliminary grinding to separate germ and hull from endosperm and then fine grinding and screening. He added that warm water at 120° to 130° F. had to be used to facilitate freeing the hulls during grinding. A laboratory method was described by Watson et al. (12) in which use was made of a Waring Blender having blunt blades running at reduced speed for 1½ minutes in the case of sorghum grain and one minute in the case of corn. The same workers also used the number of undegerminated kernels as a measure of steeping quality. Other methods used in industry have been described by Watson (10).

The separation of "gluten," which is 8% Kafirin in the case of sorghum grain (11) was reported to be facilitated by the use of slightly sloping tables as Johnston (8) had earlier described. In this method the latter author showed that the concentration of the hulls in the starch slurry could increase the viscosity and thus deter the settling of the starch. Concentrated slurry and low velocity of flow on the table were needed to obtain maximum starch settling, he added. Watson et al. (12) reported the use of a chanel iron (slightly inclined plane) for separation of starch, after adjusting the mill starch slurry to 8° Baume. Other industrial methods were described by Kerr (29) and Watson (10). In industry, tables have been completely replaced by centrifugers including the hydroclone type. The washed clean starch is dried and goes into many types of industrial uses, either as

it is, or more usually after modification of its physical and chemical properties.

Seed Pigments and Starch Color

One difficulty in wet-milling some varieties of sorghum grain is that the pigments of the nucellar layer penetrate the grain during steeping, resulting in the production of colored starch. The product may be tinged with yellow, pink or purple depending on the variety processed. Zipf et al. (4) added the probability of the colors coming from the bran or the glumes if the grains were not properly cleaned. These workers reported only two varieties of sorghum grain with which they had worked, Martin and Early Hegari, to give fairly white starch.

MacMasters and Hilbert (30) showed that sorghum grain with remnants of the nucellar layer persisting at maturity yielded off-colored starch; they suggested the pearling process prior to steeping to overcome this problem. This process was used by Zipf et al. (4), and their results gave a better product i.e., whiter starch than was obtained from unpearled grain. However, it is questionable if this process will be economical since an appreciable amount of starch is lost during pearling. More work needs to be done on the process. Rooney and Clark (3) reported that because of pigments in the pericarp and subcoat (nucellar layer) of the sorghum grain, some varieties could not be wet-milled successfully, although the kernel might appear to be white. An example of this was given by Watson and Hirata (28) when they found that Hegari variety, which has white pericarp but a pigmented seed coat (under coat), was so brittle that the brown specks were carried over into the finished starch and gave it an unacceptable appearance. For this reason alone Hegari, or any other variety with a pigmented seed coat, is

considered to be unsuitable for wet-milling process. Watson and Hirata (17) correlated the color of the plant with the starch color and found that plants with black color produced pinkish starches while those lacking this pigment produced yellowish starches; furthermore these authors reported that the intensity of color of the starch was affected by the pericarp colors: brown, red, tan and white. Blessin et al. (31) identified some of the pigments as anthocyanogens located mainly in the pericarp and generally absent from the endosperm. These workers reported the presence of these anthocyanogens in yellow milo and red Kafir sorghums but not in white Kafir, waxy and yellow-endosperm varieties. These pigments were isolated by a procedure that was described, based on adsorption by strongly basic ion exchange resins. Montgomery and Van Assen (32), steeping Kafir corn (sorghum grain) in a neutral solution of sodium diethyldithiocarbamate or sodium sulfide, found that the red water-soluble pigment in the grain hulls (probably that in the nucellar tissue) dissolved completely to give a reddish solution.

Some Properties of Sorghum Grain Starches

While it is necessary to know the quantity of starch obtainable from different sources, it certainly must be admitted that its quality can be none the less important. The actual property of the starch is a certain indicator of the way in which it will behave when put to the various uses for which it is intended.

The granules of sorghum starch were reported by Senti (33) to range from 10 to 25 microns in diameter and thus to be identical in size with corn starch granules. His statement was a generalization, based on work reported by MacMasters et al. (34) who indicated that sorghum starch granules were usually slightly larger in size than those of corn starch. Existance of

varietal differences among sorghum starches was pointed by Barham et al. (35) and Rooney and Clark (3).

The starch granule, in general, is composed of two different carbohydrate fractions, namely the linear amylose and the branched amylopectin. Each has a different molecular arrangement although both are made up of glucopyranose units. Meyer (36) used the names alpha and beta amylose to distinguish the two fractions separated on the basis of their solubility characteristics. The name amylopectin was introduced by Maquenne and Roux (37) in 1905. The relative amounts of these two fractions vary with the source of the starch and their relative proportion was reported to influence the viscosity, resistance to amylase action and water absorption. Some confusion has existed through the years about the naming of these two fractions. More than that the existence of amylopectin was doubted for some time. Clarification of the properties of the two fractions came only in 1941 when Schoch (38) made the first true separation. He suggested the names "A-fraction" (amylose) and "B-fraction" (amylopectin) to avoid confusion, but the older names still persist. Kerr et al. (39) reported that in 1926 alpha-amylose was considered the equivalent of amylopectin and later in 1933 the two terms were used synonymously. Bates et al. (40) found that most starches contain two and only two components, differing significantly in their degree of branching. However, a third fraction in the starch granule which is supposed to have properties intermediate between those of amylose and amylopectin, was reported by Banks and Greenwood (41) to comprise 5 to 10% of potato starch. Erlander et al. (42) showed the existence of such a fraction and reported 7% from dent corn.

The distribution of the amylose and amylopectin within the starch granule was rather doubted until finally Ulmann (43) in 1958 concluded that

the elementary components of starch were present in the untreated starch granule only in the form of a mixture. The same author added that it was only during swelling of the granule that a granule sheath was formed and it was created of amylopectin whereas amylose remained partly in the swollen granule and some of it seeped out.

The linear fraction, amylose, consists of some 1,700 glucose units (44) exclusively united through alpha-1, 4-glucosidic bonds and has a relatively low molecular weight (45). Depending on the source and the isolation technique employed, Meyer (46) reported that amylopectin, the branched fraction of starch, is a high-molecular-weight polysaccharide consisting of 10,000 to 1,000,000 glucose units. Hixon and Sprague (47) showed that amylopectin is a highly branched molecule with the longest branches being approximately 25 to 30 glucose units long. Hassid (48) indicated that the branched portion is a mixture of polymers of unbranched chain molecules of varying lengths. The constitution of the branches, was shown by Gibbons and Biossonnas (49) to be such that the free reducing groups of the glucose unit of a branch are linked through the sixth hydroxyl group of a glucose in an adjacent branch (alpha-1, 6-glucosidic linkage), thus forming a ramified structure.

Whistler and Smart (50) reported that the majority of starches possess nearly identical ratios of amylose to amylopectin and the most prevalent composition is 22 to 26% amylose and 78 to 74% amylopectin. Deatherage et al. (51) reported the amylose content of 210 varieties of sorghum grain starches ranged from 21 to 38%. Kite et al. (52) indicated the ratio of the two fractions in ordinary corn, sorghum and wheat starches to be in the ratio of 1 to 3, amylose to amylopectin. Rooney and Clark (3) found a range of 21 to 30% amylose and 70 to 80% amylopectin for ordinary sorghum

grain starches.

Waxy starch: Waxy starch easily recognized by the reddish-brown color it stains with iodine was reported by Meyer (53) in his work on sorghum and rice, and by Nixon and Sprague (50) to be in certain varieties of maize, rice, sorghum, millet and barley. The latter workers said that the name "waxy" was established in the literature on corn and the term "glutinous" in the literature on rice, millet and sorghum but meant the same thing. Waxy starches were reported by Schoch (54) to contain practically no amylose but to be composed almost entirely of amylopectin. However, MacMasters and Hilbert (30) reported that the waxy or glutinous rice, sorghum and corn have apparently been known for over a century in the Orient successfully kept pure for this characteristic because they were grown in isolation. The same writers indicated that glutinous cereals under conditions favoring cross pollination with non-glutinous varieties tend to revert to the non-glutinous type, the glutinous characteristic being recessive. Horan and Heider (55) showed that most of the samples of sorghum starches they analysed possessed 0 to 5% amylose and the rest amylopectin.

Schopmeyer et al. (56) said that waxy sorghum grain is difficult to store and possesses undesirable milling characteristics due to the pigments. Such pigments during wet-milling operations stain the starch and will be difficult to wash out. Horan and Heider (55) observed the difficulty of separating starch from protein when processing waxy sorghum grain but this was not encountered in the case of the non-waxy varieties. Watson and Hirata (9), investigating the wet-milling properties of some sorghum grain varieties, found two varieties with tan pericarp and one variety with white pericarp to give yellow starch. However, Watson (2) reported that waxy sorghum grain starch was marketed under the name "white milo starch" because the grain from

which it was made was white in contrast to the red grain used for the manufacture of regular sorghum starch.

Starch Viscosity

One of the most important specifications for determining the suitability of a starch for various industrial uses is the viscosity of the paste formed when the starch is cooked with water. Such pastes are mixtures of swollen granules, fragments of granules in suspension and molecules leached from granules during cooking, according to Kesler and Bechtel (57). During heating a starch suspension the granules begin to swell and lose their birefringence at a certain temperature which Watson (2) specified for sorghum starches to vary from 67° to 75°C. and for corn from 62° to 72°C. MacMasters et al. (34) reported that heating in water at 70°C. caused both waxy sorghum and corn starches to swell considerably and upon increasing temperature from 80°C. to boiling the starch granule size increased greatly and a change in the appearance took place. Schoch (38) commented that the granules continue to swell, under heating, until they can no longer be distinguished under the microscope (unless stained). Moreover, he added that only then the viscosity commences to rise. Hofstee (58) reported that by heating starch granules in water and stirring, the granules will swell and become more and more fragile in structure until at last they cannot withstand the shearing forces exerted by the stirring and consequently are easily ruptured. This point the same author referred to as the point where the increasing viscosity reverses to a decrease. Otterbacher and Kite (59) working on sorghum starch found that the rate of stirring had a clearly decreasing effect on the viscosity of pastes of milo, hegari and Kafir starches that were used. The same authors indicated that increasing the stirring speed from 300 to 1800 rpm., resulted in a rapid

decrease in starch paste viscosity. Bechtel and Fischer (60), using corn industries and modified Stormer viscometers, found that the starch pastes of corn, wheat, rice and milo showed continuous viscosity decrease during the pasting process with greatest decrease in the first hour. They also found that a fairly constant viscosity value was observed after one hour of cooking at 90° to 92°C. with most of the samples they used.

Concentration of starch, kind of starch, temperature attained by the starch-water system, duration of heating at that temperature and degree of agitation of the system affected the viscosity of a starch paste, as shown by MacMasters and Wolff (61). Kesler and Bechtel (57) added the variety, location of the growth and type of viscometer used, also to have some effect on the viscosity of the starch paste. The same workers also reported that this has led to the development of several instruments which either produce a continuous graph of viscosity changes or permit a series of determinations to be made on the same paste. Among such instruments they mentioned the consistometer of Caeser and recording viscometer of Bauer, designed for very concentrated pastes, the viscometer of Barham et al. (62) and others. Kesler and Bechtel developed the Corn Industries Viscometer.

Gallay (63) working with a capillary type viscometer described the critical concentration of potato and corn starches to be between 0.45 and 1.8% at 25°C. for determination of viscosity by this type of a viscometer. The same author added that above the critical concentration the viscosity is dependent on the rate of shear.

By use of a Stormer viscometer, variable results were obtained for sorghum varieties, according to Kerr (29). For non-waxy varieties Barham et al. (35) reported viscosities ranging from 42 to 211 (stormer units) with the majority ranging from 42 to 96 (all varieties were grown under the same

conditions at Fort Hays, Kansas, Experiment Station except two; namely, Blackhull Kafir, C.l.613 and Schrock, C.l.616). Concentration of the starch suspension used was 3.5% and readings were taken at 90°C. The weight to revolve the cylinder was 150 gm. The same authors reported lower viscosity for waxy Leoti Red Sorgo (a waxy sweet sorghum variety) than for the non-waxy varieties of sorghum grain starches. Horan and Heider (55) using a Stormer viscometer to test 2% suspensions of sorghum grain starches showed the opposite i.e., waxy varieties exhibited higher viscosity than non-waxy; these were confirmed by use of Scott and Brabender viscometers. Kazurs et al. (64) using a Brabender viscometer confirmed the latter results. Bechtel and Fischer (60) showed higher viscosity for milo starch than for corn, wheat and rice starches, using a 5% suspension cooked at 90°C. and then tested by Corn Industries Viscometer. Nixon and Sprague (47) reported that the viscosity of 2% pastes, at 90°C., of waxy varieties of corn, sorghum (variety Leoti), barley and rice starches seemed to be similar except for that of rice which was lower. The same authors correlated the difference in viscosity of rice starch with the samller size of its granules. They added that the reason for the low viscosity of barley starch (lower than expected), was due to the fact that the starch was not pure waxy i.e., it was contaminated. Mitchell and Zillmann (65) reported that fatty acids increase the viscosity of starch and the effect increases as longer chain acids in the homologous series are used. This was reported from work on wheat and corn.

Gel Strength

When the starch paste is allowed to cool, it becomes more viscous and if sufficiently concentrated sets to a gel. MacMasters and Wolff (61) reported that this change is known in industry as "setback." The same workers

added that the waxy starches showed less setback than the ordinary starches and they indicated the relation between the size and the shape of non-waxy starch granules and their gel-forming abilities. Kesler and Bechtel (66) reported that the gel-forming property of starches was responsible for the use of starches in industry for some candies, puddings and other products, and for these uses evaluation of the gel properties of starches is essential to ensure suitability of the product.

The gel strength of starch pastes has been measured by a variety of instruments using different principles which Hixon and Brimhall (67) classified into two: 1. those in which the gel is broken and 2. those in which it is merely deformed by a specified amount. The same workers reported their dissatisfaction with the two types of measurements in use and raised the point that the breaking strength of a gel is not always an indication of its resistance to deformation. Several of the instruments Kerr (29) reported on were the rigidometer, penetrometer, Tarr-Baker jelly tester and similar. The same author added that the results of tests with the blind plunger penetrometer depend on a combination of plastic and elastic effects. Hixon and Brimhall (67) developed a gelometer for measuring elasticity and breaking strength of starch gels, in which suction was used to deform the gel. The same workers reported that their apparatus was suited to starch concentrations of 6.5 to 8.5% and recommended, for lower concentration, the use of the rigidometer described by Brimhall and Hixon (68) because it gives greater differentiation with respect to elasticity.

Knowles and Harris (69) showed no varietal difference in gel strength of wheat starches that were tested and the results also indicated no relationship between gel strength and viscosity but some evidence was found that the environmental conditions during growth and the stage of maturity of

the grain might have an effect on the strength of the starch gel. Woodruff and MacMasters (70) measured relative viscosity and gel strength of starches of different varieties of corn. It was found that viscosity differences were very small compared with differences in gel strength, measured by the Tarr-Baker gelometer; and that the two properties frequently did not fluctuate in the same direction. The same workers gave this as further evidence that viscosity and gel strength measure two different sets of properties of the starch. Brimhall and Hixon (68) came to a similar conclusion and added that the rigidity of the starch gel is dependent upon conditions of the granule membrane. Whittenberger and Nutting (71) working on potato starch gels compared with those of other starches, reported that the gel strength of potato starch increased linearly with concentration between 6 and 11%. Determining the gel strength with the Delaware jelly tester, the same workers reported that commercial waxy corn and waxy sorghum starches formed unmeasurably weak gels but had low transmitance despite their freedom from amylose. Barham et al. (35) worked on sorghum starches which were cooked at 90°C. and cooled to 30°C. The gel strength was highest for Feterita starch followed by pink Kafir and lowest for Schrock, which is a waxy sorghum variety. The same workers said that starches of the other varieties followed the same trend according to their waxy and non-waxy properties. Woodruff and Nicoli (72) reported maximum gel strength for 5% pastes of corn, wheat, rice, potato, arrowroot and cassava starches when cooked at 90°C. or above; gel strength was judged by general appearance and firmness. The same workers also indicated that the addition of 60% sucrose, based on the weight of the starch paste, reduced the mass to a viscous syrup. Bechtel (73) investigating corn starch gels, reported that the breaking strength in gm/cm^2 (determined by use of an embedded - disk gelometer) was higher when cooking temperature was 94°C. than when it was

either 96°C. or 92°C. Brimhall and Hixon (68) measured the rigidity of corn starch gels at different concentrations ranging from 4 to 6%. The results showed continuous increase in the gel rigidity with increasing concentration except for starch from a waxy corn variety which showed no rigidity at any concentration. Sterling (74) associated the hardening of starch gels with increasing age to the property of retrogradation and consequent change in the rheological properties of the starch.

Food Uses of Starch

Starch is used in food as a thickener in fillings such as for pies and sauces, etc., as a dusting agent for bread and rolls and for other purposes but its largest volume use in foods is as the major ingredient in puddings, custards and similar products, Schoch (75) reported. In pies waxy sorghum starch has been reported by Cohee (76)and Ford (77) to give satisfactory flavor and good appearance.

The use of starch in the form of ásidah has not been reported in the literature. Such a form of food is used in the Sudan occasionally served with a spiced sauce made from ground or pounded, dehydrated meat. Such a sauce is similar to the "Chili Without Beans" on the market in the United States.

There are definite plans to erect a wet-milling plant to produce starch from sorghum grain in the Sudan. A large proportion of the starch produced will be sold for domestic use, and much will be employed in making ásidah in the home. For this reason, studies were made on the suitability of the experimentally produced starches for making ásidah, to determine whether varietal differences might be found.

MATERIALS AND METHODS

Thirty-one samples of different sorghum grain varieties (listed in Table 1), were received from Port Hays, Kansas, Experiment Station. Samples ranging in size from 350 to 500 gms., depending on the amount received, were cleaned and then steeped in distilled water with a thymol crystal added to each steep. The grain-to-water ratio was 1 to 2 (gm/ml). Steeping was carried out in a 4000-ml Erlenmeyer flask in a water bath thermostatically controlled at 48°C. The steep water was withdrawn from the bottom at the center of the flask (i.e. the lowest point) and returned through a circulating Cole-Parmer pump to the top of the flask. A wire gauze was tied to the intake end of the glass tube at the bottom to prevent suction of the grains and dirt into the pump. The steeping was completely closed except for a small vent consisting of a glass tube through the rubber stopper that closed the flask. The flask was shaken from time to time for even steeping and to prevent blockage of the intake tube at the bottom of the flask.

After 24 hours steeping, the steep water was decanted, measured with a calibrated measuring cylinder and then discarded. The steeped grains were then weighed and washed with distilled water several times until the discarded water was clear.

Rough grinding, of the steeped grains, in a Waring Blender with distilled water just covering the grains, was carried out for three minutes at low speed (this is considered rough grinding). The roughly ground grains with the starch-protein slurry were seived through 60-mesh nylon bolting cloth. The others (hull, germ and endosperm) were placed back in the blender with distilled water added and blended until the germs and hulls floated up. The floating hulls and germs were screened out, washed and discarded. The rough

Table 1

Sorghum Samples

1966 Hay's Row	Pedigree
3301	Combine Kafir-60 x Shallu, F6
3306	do.
3318	do.
3326	do.
3337	do.
3341	do.
3401	55H4134 x 56H5268, F1
3403	55H4134 x 56H4908, F1
3405	56H4802 x 56H5268, F1
3407	56H4802 x 56H4908, F1
3409	56H6095 x 56H4908, F1
3411	56H6095 x 56H 5268, F1
3413	Pink Kafir-Day x Westland, 55H4134
3415	do. 56H4802
3417	Club-Day x Nebr. Waxy, 55H6095
3419	Combine Kafir x Short Kaura, 56H4908
3421	Dwf. Feterita x Gurno, 56H5268
3423	Club-Day x Nebr. Waxy, 55H6014
3425	Schrock-Cody x Wonder Club, 54H8002
3427	Dwf. White Durra x Leoti-Atlas, 54H8005
3429	Dwf. White Durra x Leoti-Atlas, 54H8006
3431	Combine Kafir x Nebr. Waxy, 55H6085
3433	Ak 110-Cody, N3306C
3439	Colby Selection
3441	Spur Feterita
3442	Combine Bonita
3443	White Durra
3444	Dwf. White Durra
3446	White Kaoliang
3447	Thickrind Kaoliang
—	RS 610

grinding was repeated once more using the same procedure. The endosperm, precipitating at the bottom of the blender, was subjected to further high speed grinding, interrupted by seiving, until only hard fractions of the endosperm remained and no further grinding was expected by this method without damage to the starch granules.

The collected starch slurry with protein, fine fibre, hulls, germs and soluble material was stirred and centrifuged in 250-ml bottles in an International size 2 centrifuge. Because the bottles could not hold all the slurry at the same time, after each centrifuging the supernatent liquid was discarded and more of the starch suspension was added, well stirred to mix well with the starch at the bottom of the bottles, and centrifuged. This was repeated until all the starch formed layers at the bottom of the bottles with a protein layer above the starch in each. The protein layer was then scraped off with a spatula and discarded. The starch was resuspended in distilled water with stirring until no lumps remained and the suspension was centrifuged. The supernatent liquid was discarded and the protein layer was scraped out. This was repeated 6 to 10 times or until no layering occurred and the supernatent liquid was clear.

The thick starch slurry was then transferred from the bottles to an enameled tray and dried for 12 hours under hot air blown from a small electric heater. The air-dry starch was weighed, bottled, labled and then stored at room temperature. Later moisture determination was carried out in the starch samples according to the following procedure:

Moisture determination dishes were washed, oven dried and weighed. A two-gm sample of starch was placed in each dish, weighed and then heated in the oven at 130°C. for one hour with an open lid. The dishes with the samples were cooled and then weighed using an electrical balance. The

difference between the original weight of the sample (2 gms) and the oven-dried weight was the moisture content of the two-gm sample.

Therefore percentage moisture content/gm

$$= 2 - \frac{\text{the oven-dried weight of the sample}}{2} \times 100$$

Color Determination

Starch Color: Starch color was determined visually using a clean white cotton cloth as standard.

Seed Color: The relative seed color of the whole grain was recorded as observed. Peculiar shapes and sizes of some of the whole grains were also recorded.

Presence of Nucellar Layer: Presence or absence of nucellar layer was determined by careful filing of the pericarp until the endosperm appeared. The presence of a dark layer between the pericarp and the endosperm indicated the presence of nucellar layer.

Viscosity Measurements: Five percent (oven-dry basis) starch paste was prepared from each sample by suspending the weighed amount in 10 ml cold water which was then added to the correct amount of water heated to 95°C. The paste was then cooked over an open flame at 95°C. $\pm$ 1 in a 400-ml beaker, with aluminum foil having an opening at the center for stirring and temperature measurement. The cooking was accompanied with continuous mild stirring with a glass rod with which a themometer was held to permit following the temperature continuously. Cooking took 5 minutes to reach 95°C. The cooked paste was immediately transferred to the cup of a Stormer viscometer. This had a water bath around the cup. The water bath temperature was held at 90°C. by means of a small Bunsen burner. The water bath with the cup containing the starch paste and rotatory cylinder were covered by aluminum foil to

reduce evaporation and consequently to prevent skin formation at the top of the paste which would have led to erroneous results. The free weight was immediately released. Its fall rotated the cylinder in the paste. The time for complete revolution of the indicator was recorded in seconds by means of a stop watch. Two measurements were made on each sample as a check. However, only the first reading was recorded for each sample. The free weight that rotated the cylinder of the viscometer weighed 165 gm.

Gel Strength and Asidah Testing: A nine percent (oven-dry basis) starch suspension prepared similarly as for viscosity measurements previously described, was cooked in a 400-ml beaker at 95°C. for 10 minutes over an open flame. The beaker was covered with aluminum foil except for a small opening at the center to allow stirring and temperature readings. The hot starch paste was then poured into 50-ml beakers (6 for each sample). The top of the paste in the beaker was covered with a thin layer of paraffin oil to prevent moisture loss and formation of "skin" at the top of the paste. Each beaker with the paste was placed in the refrigerator for 24 hours at refrigeration temperature. After 24 hours the paraffin layer was poured off and the beaker was inverted to release the gel. The gel came out easily by careful use of the spatula to push the gel away from one side of the beaker to allow air to replace the gel. The gel was turned over and pushed back into the beaker so that the side which was originally at the bottom of the beaker was at the top. The spatula was used to aid removal of air from the beaker so that the gel could replace it. Two samples of starch from each variety of sorghum grain were tested for gel strength by use of a modified precision penetrometer. The modification was in the plunger. The usual plunger was replaced by a flat-ended plunger with a diameter of $\frac{1}{2}$", a thickness of $\frac{1}{4}$" and a weight of 8.061 gm. The plunger was adjusted to just touch the surface of the gel,

then released and closely observed until a scratch on the side of the plunger just disappeared. The position of the scratch was determined by earlier trials as follows: a gel was prepared similarly as described above. Many pencil marks were made on the side of the plunger. The plunger was adjusted so that it just touched the surface of the gel then released and left to penetrate the gel for some time. The plunger was removed and the gel surface was tested for shearing effect. The mark which just disappeared to give that shearing was noted. This was repeated and the time and the penetration were adjusted according to the last result i.e., if the shearing was deep the plunger was allowed to rest on the gel surface for a shorter time and made less penetration in the following trial. This was also repeated until one specific mark on the side of the plunger coincided with the start of the gel shearing. This point was marked with a scratch and considered as the shearing mark.

The time starting from release of the plunger to the disappearance of the shearing point mark was measured in seconds by means of a stop watch and recorded as the shearing time. The penetration in mm read on the penetrometer dial was recorded as the penetration.

The same six samples for each variety, prepared earlier for both gel strength tests and evaluation of asidah, were served to a taste panel in Lily cups with warm "Chili Without Beans." The chili was placed around the gel samples in the cups after the gel tests were carried out. The panel members were six in number, two from each of the following countries: U.A.R., Ethiopia, and Nigeria. The panelists were chosen on the basis of the similarity of asidah and some of the food they eat at home. A scoring sheet was developed based on the following characters:

1. Gel formation
2. Texture
3. Elasticity
4. Stickiness
5. Color
6. Flavor (if any)

The scoring range allowed was 0 to 10, zero being unacceptable and 10 being excellent. The scoring sheet can be seen in Figure 1.

Five different samples were offered to each panelist each day for evaluation. The first five samples tested were again offered later on without the knowledge of the tasters and only the later scores were considered in the results.

Statistical analysis was carried out only for the evaluation of asidah eliminating the flavor because of the inconsistency of the panelists. Analysis of variance was used as a method for statistical analysis.

Figure I

DEPARTMENT OF GRAIN SCIENCE AND INDUSTRY

Score Sheet for Asidah

Name:_____ Date:_____

Please examine the Asidah samples and score these with respect to the qualities in question, using a scoring scale of 0 to 10, ten being excellent and 0 being unacceptable.

Quality in Question	Sample No.								
				SCORE IN COLUMNS BELOW					
Gel formation (firmness)									
Texture									
Elasticity									
Stickiness									
Colour									
Flavour (if any)									

Comments on general acceptability:

Score Sheet for organoleptic evaluation of Asidah

RESULTS AND DISCUSSION

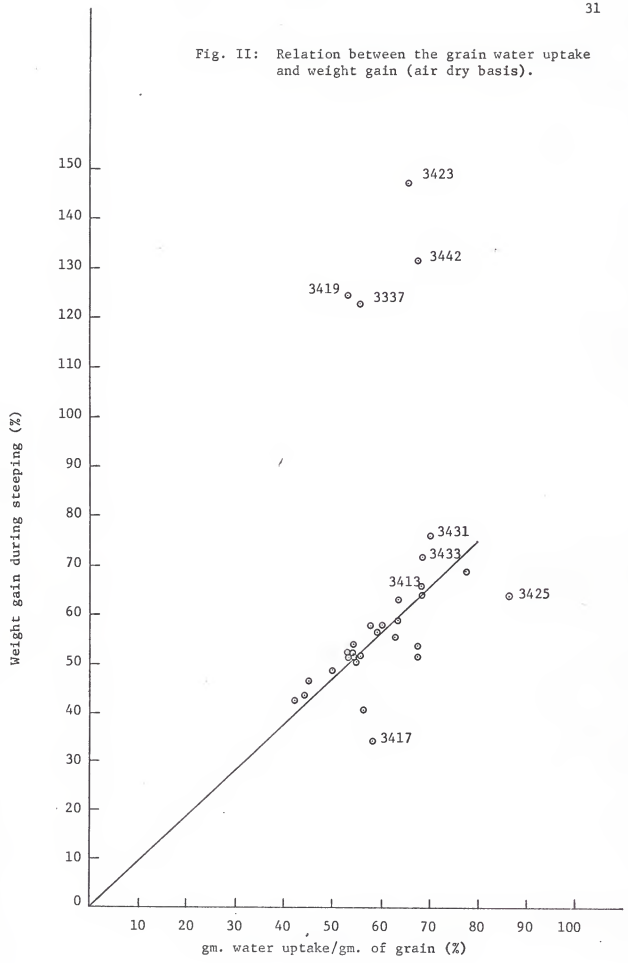
Absorption of water by the grain during steeping is affected by structural barriers such as cell wall thickening, development of the seed coat and formation of the hilar layer. In this work there was an almost linear relationship between the percentage water absorption by the grain and the percentage weight gain by the grain after steeping (air dry basis) demonstrated in Table 2 and Figure II. There was some evidence that waxy varieties absorbed more moisture and consequently gained more weight during steeping than non waxy varieties (Fig. II and Table 2). Variety 3417 showed minimum gain in weight with average water absorption. This variety also showed the highest yield in starch among all the varieties as can be seen from the data given in Table 3. This may indicate that more solids were dissolved during steeping resulting in less weight gain. Solubilizing more solids in the grain during steeping, especially in the protein matrix, results in more release of starch. This might be the reason for higher yield of starch in such a variety as 3425 which showed highest water absorption. But this was probably due to the leakage in the pump that took place during steeping. The effect of not using the pump was a high weight gain during steeping as shown in Figure II for varieties 3419 and 3423. This might have been due to the fact that the recirculation helped in dissolving soluble solids from the grain by continuous removal of the steep water around the grain surface. Comparing these two latter samples, 3423 showed slightly higher weight gain and water absorption during steeping, showing the same trend as waxy varieties mentioned earlier; sample 3423 is a waxy variety. Sample 3442 showed a very high weight gain during steeping and so did sample 3337. No reason was apparent; possibly some difference in composition or structure might be the cause.

Table 2

Water Absorption and Weight Gain by the Grain During Steeping

Hays Row No. 1966 Crop	gm water uptake gm of grain (%)	wt. gain by grain during steeping (%)	Comments
3405	44.78	43.26	
3421	56.89	48.89	
3443	67.42	51.43	
3407	45.90	46.82	
3318	42.66	42.22	
3444	57.95	57.73	
3415	50.00	48.89	
3326	55.00	50.00	
3417	58.67	34.67	
3447	59.53	56.51	
3442	67.50	131.26	
3425	86.00	63.75	Leakage from the pump.
3419	53.00	124.50	Steeping without using the pump.
3423	65.71	147.43	Steeping without using the pump.
RS-610	55.00	53.50	
3431	70.00	76.00	
3446	68.33	66.33	
3409	53.25	52.00	
3413	60.00	57.75	
3306	54.00	52.00	
3411	67.75	53.75	
3403	56.00	51.25	
3429	68.75	64.25	
3427	63.50	62.75	
3341	53.50	51.25	
3441	77.50	68.75	Fungal growth during steeping.
3433	68.75	71.75	
3401	62.50	55.00	
3301	55.00	51.50	
3337	55.50	122.50	
3439	63.50	59.00	

Fig. II: Relation between the grain water uptake and weight gain (air dry basis).



Sample 3337 gave minimum starch yield; this might have been due to low solubility of solids in the grain or high protein content , or possibly to structural barriers reported earlier by Sanders (13).

Starch yield was generally low because of priority being given to cleanness of the starch rather than to the quantity of the starch produced. The 24-hour steep without SO_2 was also a cause of the low yield, as has been reported earlier. The steeping time reported in the literature is approximately double the time used in this work. However, 30 to 34 hours is the present commercial practice. Comparing the yields of the varieties processed in this work, varieties 3417, 3421, 3326 and 3419 gave the highest yield of starch in descending order. The data is shown in Table 3.

Starch and Seed Color

Comparison of seed and starch color showed no relationship between the seed color and that of the finished starch (Tables 4 and 5). The production of white starch from both colored and white seeds excluded the probability of presence of soluble pigments in the bran under the steeping conditions used in this work. This was also confirmed by obtaining colored starches from white seeds as shown in Table 5. The white starches were all obtained from seeds with white endosperm and resorbed nucellar tissue. The yellow starches came from seeds with yellow endosperm (Table 6). Varieties 3442 and 3441 had white endosperm but the presence of remnants of nucellar tissue resulted in brown starch because of brown nucellar pigments. This confirmed what has been reported earlier, for variety Hegari, by Watson and Hirata (9). From these results it was concluded that it is only the color of the endosperm and presence of remnants of nucellar tissue with soluble pigment that determines the color of the finished starch.

Table 3

Starch Yield, % (oven dry basis)

Hay's Row No. 1966 Crop	Starch Yield, %
3405	19.38
3421	22.46
3443	17.71
3407	15.38
3318	17.43
3444	18.89
3415	18.35
3326	21.84
3417	27.55
3442	18.50
3425	12.53
3419	20.82
3423	13.63
3431	18.25
3446	16.67
3409	19.85
3413	17.75
3306	14.85
3411	11.81
3403	17.69
3429	15.35
3427	14.25
3341	12.95
3441	14.73
3433	14.93
3401	14.88
3301	15.50
3337	15.18
3439	14.85
RS-610	14.75

Table 4

Observed Starch and Seed Color (white starches)

Hay's Row No. 1966 Crop	Starch Color	Seed Color	Seed peculiarities Shape + Size
3417	White	Dirty white	None
3326	White	Yellow	Small seeds
3443	White	Dirty white	Flat seeds
3401	White	Dirty white	None
3439	White	Light red	None
3418	White	Yellow with a few brown spots	None
3413	White	White	None
3411	White	White	None
3446	White	White	Small seeds
RS-610	White	Light red	None
3429	Dirty white	White	None
3403	White	Yellowish	None
3409	White	Yellowish	None

Table 5

Observed Starch and Seed Color (Colored Starches)

May's Row No. 1966 Crop	Starch Color	Seed Color	Seed peculiarities Shape + size
3442	Brownish	Dirty white with brown spots	None (soft seeds)
3441	Brownish	White	None (soft seeds)
3341	Yellowish	Yellow	None
3427	Yellowish	Dirty white	None
3415	Yellowish	Red	None
3433	Yellowish	Dirty white	Small seeds
3425	Yellowish	White	None
3444	Yellowish	White	Flat seeds
3301	Yellowish	White	None
3419	Yellowish	Yellow	None
3405	Yellowish	Red	None
3423	Most yellowish	Dirty white	None
3407	Yellowish	Red	None
3447	Yellowish	White	Small seeds
3337	Yellowish	White	None
3421	Yellowish	Dirty white	None
3306	Yellowish	White	Small seeds
3431	Yellowish	Dirty white	None

Table 6

Starch and Endosperm Color

Hay's Row No. 1966 Crop	Endosperm Color	Starch Color	Comments
3417	White	White	
3326	White	White	
3443	White	White	
3401	White	White	
3439	White	White	
3418	White	White	
3413	White	White	
3411	White	White	
3446	White	White	
RS-610	White	White	
3429	White	White	
3403	White	White	
3409	White	White	
3442	White	Brown	Remnants of nucellar tissue
3441	White	Brown	
3341	Yellow	Yellow	
3427	Yellow	Yellow	
3415	Yellow	Yellow	
3433	Yellow	Yellow	
3425	Yellow	Yellow	
3444	Yellow	Yellow	
3301	Yellow	Yellow	
3419	Yellow	Yellow	
3405	Yellow	Yellow	
3423	Yellow	Yellow	
3407	Yellow	Yellow	
3447	Yellow	Yellow	
3337	Yellow	Yellow	
3421	Yellow	Yellow	
3306	Yellow	Yellow	
3431	Yellow	Yellow	

All the waxy starches were found to come from seeds of either white or dirty white pericarp color much like that of the early waxy variety, Cody. In this connection, it is of interest to note the report by Watson (2) of the name "white milo" for waxy varieties developed by Karper at Texas Agricultural Experiment Station and grown commercially in that state.

Identification of the waxy starches by the color given with iodine solution showed seven waxy varieties, listed in Table 7. Among the seven varieties only one (3431) was found to be pure waxy, i.e., staining only red. The rest of the waxy starches showed some contamination, as some granules stained blue, an indication of non-waxy character. This could have indicated contamination during growth of the plants, due to incomplete isolation of the waxy varieties. The waxy character is recessive and non-waxy is dominant; any pollination of a waxy variety by non-waxy pollen will result in non-waxy seeds in the same generation due to xenia.

Table 7

Identification of Waxy Starches by Iodine Color Reaction

3431	Pure	Waxy (1)
3423, 3425, 3427		Waxy, some
3429, 3433, 3446		Contamination (2)

(1) stained red
(2) stained red with some granules staining blue

Viscosity Results

Results of viscosity tests showed a clear difference between the waxy and non-waxy starches. The waxy starches gave very high viscosity compared to the non-waxy starches (Table 8). This confirmed the results of Horan and Heider (55) and Mazur et al.(64) and contradicted the results of Barham

Table 8

Viscosity Measurement
(5% paste, oven dry basis, at 90°C.)

Hay's Row No. 1966 Crop	Viscosity in seconds
3447	62.3
3413	64.0
3407	45.0
3405	43.0
3318	48.8
3431	387.0
3415	44.0
3439	39.0
3443	45.0
3411	44.8
3425	202.0
3419	39.2
3337	46.5
3301	40.0
3401	45.0
3441	42.5
3421	33.8
3403	41.0
3444	55.0
3326	46.5
RS-610	52.0
3433	372.0
3427	353.7
3423	406.0
3306	48.9
3417	47.0
3442	48.5
3446	238.0
3341	60.0
3409	51.0
3429	290.0

et al. (35) who reported the opposite. The viscosity of ordinary starches decreases with storage time. The waxy starches have the same trend but faster in the first few months. The decrease is either due to the effect of degradative enzymes or due to acid hydrolysis if SO_2 was used in the steeping medium. This is most probably the reason why Barham et al. (35) came with very low viscosity values in the case of waxy starches.

The variation in viscosity among either waxy or non-waxy varieties was not great but some of the varieties showed some variation from the average due to varietal difference, as shown in Table 8. Viscosity of the non-waxy varieties ranged between 33.8 and 64 while that of the waxy varieties ranged between 202 and 406.

The ranges are several times greater than the error inherent in the method. The highest viscosities among the non-waxy starches were shown by varieties 3413, 3447 and 3341 in descending order, and lowest by variety 3421. Among waxy varieties the highest were shown by varieties 3423, 3431 and 3433 in descending order and the lowest by 3425, 3446 and 3429 in ascending order (Table 8). Variability in results was reported by Kerr (29) using the Stormer viscometer. Barham et al. (35) reported starch viscosity for non-waxy sorghum grain varieties ranging from 42 to 211 stormer units. Both indicated varietal differences in starch viscosity, which may indicate some varietal difference most likely in the molecular weight of starches.

Gel Strength Results

Results of the gel strength of the different starch varieties listed in Table 9 showed clearly a difference between the waxy and non-waxy varieties. The waxy varieties offered no resistance to the plunger, so that as soon as it was released it dropped through the viscous paste to the bottom

Table 9

Gel Strength Measurements Using Modified Precision Penetrometer
Non-waxy Starches

Hay's Row No. 1966 Crop	Penetration in mm.	Shearing time in seconds
3409	8.0	13.5
3401	6.0	12.8
3443	7.0	17.0
3413	9.5	20.0
3318	8.0	7.0
3301	5.9	26.0
3419	8.2	4.0
3407	6.9	30.0
3411	3.3	36.0
3326	6.2	13.0
3441	7.3	27.0
3415	8.1	30.0
3447	8.2	9.0
3439	7.4	16.0
3405	4.6	38.0
3444	4.4	35.0
3442	7.3	8.0
3441	6.7	11.0
3403	7.5	7.0
3306	5.8	9.0
3417	7.0	15.0
3421	7.4	12.5
3337	6.3	13.0
RS-610	6.4	17.0

Waxy Starches: All showed no resistance and no shearing time, i.e., time 0.

of the beaker. This indicated the inability of waxy starches to form a true gel due to the lack of the linear fraction (amylose). These results confirmed what had been reported earlier by Brimhall and Hixon (68) who found no rigidity for waxy corn starch at any concentration and Barham et al. (35) who reported that the waxy starch gel showed the least gel strength among all the sorghum grain starches tested.

The penetration of the plunger into the gel seemed to be about the same for all the non-waxy varieties used in the present study, with the majority of the results ranging between 6 and 8 mm. The lowest readings were shown by varieties 3405, 3444 and 3411 in descending order. Variety 3413 showed the highest plunger penetration, 9.5 mm. The shearing time in seconds ranged for the non-waxy varieties from 4 to 38 seconds with the majority between 12 and 30 seconds. The highest shearing times were shown by varieties 3405, 3411 and 3444 in descending order, and the lowest by 3419, 3403 and 3318, 3442, 3306 and 3447 in ascending order. There seemed to be no relationship between the shearing time and the plunger penetration, except for the three varieties 3405, 3444 and 3411 for which the lowest penetration and the highest shearing time were obtained, an inverse relationship (Table 9). Such a relation indicates the firmness of the gels made from these three varieties.

Results of the Organoleptic Evaluation of Asidah

The means of the samples scores given for the asidah samples made from the starches of the different varieties of sorghum grain showed no significant differences among the non-waxy varieties. The only significant differences were shown by the waxy varieties and indicated the rejection of waxy starches for making asidah. This can be seen in Table 10. The samples are arranged in Table 10 according to the order of their means. The waxy varieties

Table 10

Ordered Samples Mean

Group I "Non-waxy" Hay's Row No.	Sample mean	Group II "Waxy" Hay's Row No.	Sample Mean
3447	9.16667	3429	3.96667
3444	9.10000	3446	3.80000
3411	9.06667	3431	3.66667
3337	9.06667	3427	3.56667
3439	9.03333	3433	3.53333
3401	8.96667	3425	3.50000
3421	8.96667	3423	3.20000
3417	8.90000		
3413	8.86667		
3443	8.86667		
3415	8.86667		
RS-610	8.86667		
3409	8.83333		
3441	8.80000		
3341	8.76667	LSD = 1.07975	
3419	8.73333	Group I, no significant difference	
3301	8.70000		
3403	8.70000	Group II, significant difference	
3306	8.63333		
3405	8.63333		
3407	8.56667		
3318	8.40000		
3442	8.13333		
3441	7.80000		

had the lowest means. The colored samples seemed to have the lowest means among the non-waxy varieties with the brown samples trailing the colored varieties. The difference was not statistically significant except for the waxy varieties, as has been mentioned before. The failure of colored samples to show statistical difference from the white non-waxy samples might have been due to the retrogradation effect which might have masked some of the color. The lower scores showed by samples 3442 and 3441 among the colored starches might have been to the distinct brown color rather than the pale yellow color which sometimes was not easy to identify.

The low scores assigned to the waxy varieties was due mainly to the inability of the waxy starches to form true gels. Furthermore, their sticky and elastic character contributed more to the low means of the waxy samples. This indicated the nature of the food and the way asidah is eaten. Most of the tasters complained that the samples made from waxy starches were not easy to pick from the cup either by hand or by spoon which indicated that the elastic and sticky characters of the waxy starches were not favored.

Analysis of variance showed significant differences among tasters, samples and qualities but the interaction between the samples and their qualities did not give any significant differences. This indicated that the quality scores within each sample did go in one and the same direction, i.e., there was no fluctuation in scoring of the qualities within a sample, as can be seen in Table 11.

The quality mean showed the following results:

	ordered quality mean
1. Texture	7.94624
2. Color	7.85484
3. Gel formation	7.74194
4. Stickiness	7.33871*
5. Elasticity	7.12903*
*Significant	LSD = 0.43364

Texture, color and gel formation scores showed no significant difference. Significant difference was offered by stickiness and elasticity which are the least qualities to be desired in asidah due to the way of eating such food.

The tasters mean resulted in the following order:

		ordered tasters mean
1.	Zewdue Omer	8.87742*
2.	Teferi Teklahimand	8.19355*
3.	Mike Ajakayie	7.78065
4.	Husain S. Ahmed	7.68387
5.	Ahmed Huzayyen	7.01935*
6.	Mike Kassubi	6.05806*

*Significant at LSD = 0.31523

The tasters demonstrated significant difference in their scoring except for taster No. 3 and 4 whose means were close. The difference could be attributed to personal differences in taste , or might be referred to the variation in food from country to country.

The average scores calculated for the flavor of each sample showed the highest scores for the samples made from non-waxy white starches, followed by non-waxy colored samples and least for the waxy starches, shown in Table 12. The lowest average score among the non-waxy samples was shown by 3441. This might be due to the tannins in the pericarp. The low average scores for the flavor of the waxy samples was expected to be due to the psychological effect of the waxy varieties in the tasters. The asidah made from waxy starches was elastic, sticky and did not form a true gel which made it hard to pick up without dropping from the spoon. Reports in the literature have already clearified this point that the flavor of the waxy starches was not worse if not better than that of the non-waxy starches.

Table 11

A Two-factor Experiment in a Randomized Complete B Block Design

"Tasters Used to Form Blocks"

Analysis of variance table

Source of variance	Degs. of Freedom	Sum of Squares	Mean Square	F Statistics
Blocks	5.	734.46022	146.89204	32.26825*
Samples	30.	4411.59570	147.05319	32.30365*
Quality	4.	92.07527	23.01882	5.05662*
Samples X Quality	120.	301.45806	2.51215	0.55185
Experimental Error	770.	3505.20645	4.55222	——

*Significant at 0.05

Table 12

Organoleptic Evaluation of Asidah for Flavor

Hay's Row No. 1966 Crop	Flavor Average Score	Type of Starch
3417	10.00	
3326	10.00	
3439	10.00	
3413	10.00	
3411	10.00	White
3403	10.00	
RS-610	10.00	Non-waxy
3401	10.00	
3443	9.00	
3318	9.33	
3444	10.00	
3447	10.00	
3421	10.00	
3337	9.75	
3419	9.67	
3405	9.67	Colored
3407	9.67	
3415	9.50	Non-waxy
3301	9.33	
3442	8.00	
3341	7.75	
3306	7.75	
3441	6.67	
3446	9.00	
3423	7.33	
3429	7.00	
3425	6.67	Waxy
3427	6.60	
3433	6.33	
3431	5.67	

SUMMARY AND CONCLUSIONS

It was concluded that it is not the pericarp pigments but only the endosperm color and presence or absence of the nucellar pigments that determine the color of the finished starch. This also indicated that the pericarp pigments were insoluble under the steeping conditions used in this work. Although the starch yield was not given as much concern as the quality of the starch, it is worth mentioning that varieties 3417, 3421, 3326 and 3419 gave the highest yields of starch among all the varieties studied. Varieties 3417 and 3326 also gave white starches which would give them the lead among the rest for such characters.

Non-waxy varieties showed a linear relationship between water absorption and weight gained by the grain during steeping while the waxy varieties absorbed more water with more weight gain during steeping.

Varietal differences were demonstrated in both gel strength and viscosity tests but no relation between the two characters was observed. The highest viscosity was shown by varieties 3413, 3447 and 3341 while varieties 3405, 3444 and 3411 showed the highest gel strength.

Organoleptic results for asidah showed great acceptability for the non-waxy varieties and also demonstrated a clear rejection of the waxy varieties for asidah. This was supported by the significant results obtained by statistical analysis of variance. Among the non-waxy varieties, asidah made from white starches seemed to get slightly higher scores but not to such an extent as to show clear statistically significant differences. As to general acceptability of asidah with "Chili Without Beans," it seemed to be liked by all the tasters although a different sauce is used in each country.

This evaluation of the different varieties of sorghum grain for

asidah was mostly concerned with the physical characters of asidah but we recommend that further nutritional evaluation be carried out to complete the picture. A change in the nature of food is not recommended at the present time but supplementation of the food with the required vitamins and the correct quality and quantity of proteins seems to be practical.

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LITERATURE CITED

1. Karper, R. E., and Quinby, J. R.
Sorghum - Its production, utilization and breeding. Econ. Bot. 1:355-371 (1947).

2. Watson, S. A.
The present importance and bright future of grain sorghum. Cereal Sc. Today 4:230-233 (1959).

3. Rooney, L. W., and Clark, L. E.
The chemistry and processing of sorghum grain. Cereal Sc. Today 13:259-265 (1968).

4. Zipf, R. L., Anderson, R. A., and Slotter, R. L.
Wet milling of grain sorghum. Cereal Chem. 27:463-476 (1950).

5. Taylor, R. L.
Starch and sugar from milo maize. Chem. Inds. 64:932-935 (1949).

6. Kao, Chang-Keng
The production of sorghum starches. J. Chem. Eng. (China) 2:133-136 (1935) (Through Chem. Abs. 30:3268).

7. Das Gupta, H. P.
Jowar starch. J. Indian Inst. Sc. 19A:19-26 (1936). (Through Chem. Abs. 30:54468).

8. Johnston, R. W.
The production of starch from grain sorghums. Masters thesis, Department of Chem. Eng., Kansas State University, 46pp. 1942.

9. Watson, S. A., and Hirata, Y.
The wet milling properties of grain sorghums. Agron. J. 47:11-15 (1955).

10. Watson, S. A.
Manufacture of corn and milo starches. In Starch Chemistry and Technology Vol. II, Industrial Aspects. Whistler, R. L. and Paschall, E. F., ed., pp. 1-51. Academic Press: New York, 1967.

11. Watson, S. A., Sanders, E. H., Wakely, R. D., and Williams, C. B.
Peripheral cells of the endosperms of grain sorghum and corn and their influence on starch purification. Cereal Chem. 32:165-182 (1955).

12. Watson, S. A., Williams, C. B., and Wakely, R. D.
Laboratory steeping procedures used in a wet milling research program. Cereal Chem. 28:105-118 (1951).

13. Sanders, E. H.
Developmental morphology of the kernel in grain sorghum. Cereal Chem. 32:12025 (1955).

14. Wolf, M. J., Buzan, C. L., MacMasters, Majel M., and Rist, C. E.
Structure of the mature corn kernel II: Microscopic structure of pericarp, seed coat and hilar layer of dent corn. Cereal Chem. 29:334-348 (1952).

15. Fan, L. T., Chu, P. S., and Shellenberger, J. A.
Diffusion of water in kernels of corn and sorghum. Cereal Chem. 40:303-313 (1963).

16. Baird, Peggy D., MacMasters, Majel M., and Rist, C. E.
Studies on a rapid test for the viability of corn for industrial uses. Cereal Chem. 27:508-513 (1950).

17. Watson, S. A., Hirata, Y., and Williams, C. B.
Study of the lactic acid fermentation in commercial corn steeping. Cereal Chem. 32:382-394 (1955).

18. Hightower, J. V.
The new corn products plant: It makes wet milling history. Chem. Eng. 56:92-96 (1949).

19. Campbell, J. D., and Jones, C. R.
The effect of temperature on the rate of penetration of moisture within damped wheat. Cereal Chem. 32:132-139 (1955).

20. Grosh, M. G., and Milner, M.
Water penetration and internal cracking in tempered wheat grains. Cereal Chem. 36:260-273 (1959).

21. Fan, L. T., Chu, P. S., and Shellenberger, J. A.
Volume increase of kernels of corn and sorghum accompanying absorption of liquid water. Biotech. and Bioeng. 4:311-322 (1962).

22. Anderson, R. A.
A note on the wet-milling of high-amylose corn containing 75 percent amylose starch. Cereal Chem. 39:406-408 (1962).

23. Anderson, R. A.
Wet-milling characteristics of Class 8 amylomaize. Cereal Chem. 42:580-581 (1965).

24. Cox, Mary J., MacMasters, Majel M., and Hilbert, G. E.
Effect of sulfurous acid steep in corn wet milling. Cereal Chem. 21:447-465 (1944).

25. Watson, S. A., and Sanders, E. H.
Steeping studies with corn endosperm sections. Cereal Chem. 38: 22-33 (1961).

26. Duvick, D. N.
Protein granules of maize endosperm cells. Cereal Chem. 38:374-385 (1961).

27. Wagoner, J. A.
Microscopical observations and procedures used in a study of industrial corn steeping. Cereal Chem. 25:354-361 (1948).

28. Watson, S. A., and Hirata, Y.
A method for evaluating the wet millability of steeped corn and grain sorghum. Cereal Chem. 31:423-432 (1954).

29. Kerr, R. W.
Chemical properties of starch. In Chemistry and Industry of Starch. 2nd ed. pp. 179-244. Academic Press, Inc. New York, 1950.

30. MacMasters, Majel M., and Hilbert, G. E.
Glutinous corn and sorghum starches. Ind. Eng. Chem. 36:958-963 (1944).

31. Blessin, C. W., VanEtten, C. H., and Dimler, R. J.
An examination of anthocyanogens in grain sorghums. Cereal Chem. 40:241-250 (1963).

32. Montgomery, E. M., and VanAssen, E.
Kafircorn malting and brewing studies XX. Isolation of starch by laboratory wet-milling of Kafircorn and malted Kafircorn after a neutral chemical steep. DieStarke 2:60-63 (1968).

33. Senti, F. R.
Industrial utilization of wheat and flour. The Northwestern Miller 38:1-70 (1959).

34. MacMasters, Majel M., Wolf, M. J., and Seckinger, H. L.
Starch identification: Microscopic characteristics of starches in the identification of ground cereal grains. J. Agr. Food Chem. 5:455-458 (1957).

35. Barham, H. N., Wagoner, J. A., Campbell, C. L., and Harclerode, E. H.
The chemical composition of some sorghum grains and the properties of their starches. Tech. Bull. 61. Kansas Agric. Exp. Sta. 47pp. 1946.

36. Meyer, A.
Botan. Zeit. 39:841-846. 1881. In Starch and Its Derivatives. 3rd ed. (revised). Radley, J. A., E. Howard Tripp, editor. Chapman and Hall Ltd., London, 1953.

37. Maquenne, L., and Roux, E.
Bull. Soc. Chem. 33:723 (1905). In Chemistry and Industry of Starch. 2nd ed. (revised). Kerr, R. W., Academic Press, Inc., New York, 1950.

38. Schoch, T. J.
Physical aspects of starch behavior. Cereal Chem. 18:121-128 (1941).

39. Kerr, R. W., Trubell, O. R., and Severson, F. M.
On the multiple amylose concept of starch II. Amylopectin and amylose. Cereal Chem. 19:64-81 (1942).

40. Bates, F. L., French, D., and Rundle, R. E.
Amylose and amylopectin contents of starches determined by their iodine complex formation. J. Am. Chem. Soc. 65:142-148 (1943).

41. Banks, W., and Greenwood, C. T.
Physicochemical studies on starches. XX The existence of an anomalous amylopectin of starch. J. Chem. Soc. 3436 (1959).

42. Erlander, S. R., McGuire, J. P., and Dimler, R. J.
An anomalous low-molecular-weight branched component in dent corn starch. Cereal Chem. 42:175-187 (1965).

43. Ulmann, M.
Structure of a potato-starch granule. J. Polymer Sci. 30:561-565 (1958).

44. Banks, W., and Greenwood, C. T.
A novel method of determining the number - average degree of polymerization of linear maltodextrins and amylose. Carbohydrate Research 6:177-183 (1968).

45. Schoch, T. J.
The starch fractions. In Starch and Its Derivatives. Radley, J. A., Vol. I, 3rd ed. (revised). pp. 123-200. Chapman and Hall Ltd. London, 1953.

46. Meyer, A.
Recent developments in starch chemistry. In Advances in Colloid Science Vol. 1:143. Interscience New York. 1942.

47. Hixon, R. M., and Sprague, G. F.
Waxy starch of maize and other cereals. Ind. Eng. Chem. 34:959-962 (1942).

48. Hassid, W. Z.
The molecular constitution of starch. Wallerstein Laboratory Communications 8:34-45 (1945).

49. Gibbons, G. C., and Boissonnas, R. A.
The position of branching in glycogen and amylopectin. Helv. Chim. Acta 33:1447 (1950).

50. Whistler, R. L., and Smart, C. L.
Starches. Polysaccharide Chemistry. pp. 229-275. Academic Press, New York, 1953.

51. Deatherage, W. L., MacMasters, Majel M., and Rist, C. E.
A partial survey of amylose content in starch of domestic and foreign varieties of corn, wheat and sorghum and from some other starch-bearing plants. Trans. Am. Assoc. of Cereal Chem. 13:31-42 (1955).

52. Kite, F. E., Schoch, T. J., and Leach, H. W.
Granule swelling and paste viscosity of thick-boiling starches. Baker's Digest 31:42-46 (1957).

53. Meyer, A.
'Uber Starkekorner, welche sich mit jod roth jarben,' Ber. deut. botan. Ges. 4, 337-362 (1886). Through Schock, T. J. In Starch and Its Derivatives . By Radley, J. A. Vol. I. pp. 123-200. Chapman and Hall Ltd. London, 1953.

54. Schoch, T. J.
Fractionation of starch by selective precipitation with butanol. J. Am. Chem. Soc. 64:2957-2961 (1942).

55. Horan, F. E., and Heider, Marie F.
A study of sorghum and sorghum starches. Cereal Chem. 23:492-503 (1946).

56. Schopmeyer, H. H., Felton, G. E., and Ford, C. L.
Waxy corn starch as a replacement for tapioca. Ind. Eng. Chem. 35:1168-1172 (1943).

57. Kesler, C. C., and Bechtel, W. G.
Recording viscometer for starches. Ind. Eng. Chem., Anal. ed. 19:16-21 (1947).

58. Hofstee, J.
A comparison of the rheological properties of starches of different origin. X Congresso Internazionate Industrie Agronie Roma-27 Maggio-1 giugno. pp. 1-12. Roma. 1952.

59. Otterbacher, T. J., and Kite, F. E.
The milo starches. The Baker's Digest 32:44-48 (1958).

60. Bechtel, W. G., and Fischer, E. K.
The measurement of starch paste viscosity. J. Colloid Sci. 4:265-282 (1949).

61. MacMasters, Majel M., and Wolff, I. A.
Characteristics of cereal starches. In the Chemistry and Technology of Cereals as Food and Feed. Matz, S. A. pp. 569-594. The Avi Publishing Company, Inc. Conn., 1959.

62. Barham, H. N., Wagoner, J. A., and Reed, G. N.
Viscosity of starches: Determination of a rotating cylinder viscometer. Ind. Eng. Chem. 34:1490-1495 (1942).

63. Gallay, W.
The effect of concentration on the viscosity of starch pastes and of lyophilic sols. Can. J. Res. B14:391-403 (1936).

64. Mazurs, E. G., Schoch, T. J., and Kite, F. E.
Graphical analysis of the Brabender viscosity curves of various starches. Cereal Chem. 34:141-152 (1957).

65. Mitchel, W. A., and Zillmann, Elizabeth
Effect of fatty acids on starch and flour viscosity. Trans. Am. Assoc. of Cereal Chem. 9:64-79 (1951).

66. Kesler, C. C., and Bechtel, W. G.
Physical methods of characterising starch. In Starch and Its Derivatives. Radley, J. A. Vol. II. 3rd ed. (revised). pp. 402-437. Chapman and Hall Ltd. London, 1953.

67. Hixon, R. M., and Brimhall, B.
A gelometer for starch pastes. Ind. Eng. Chem. 13:193-194 (1939).

68. Brimhall, B., and Hixon, R. M.
Rigidity of starch pastes. Ind. Eng. Chem., Anal. Ed. 11:358-361 (1939).

69. Knowles, Darline, and Harris, R. H.
Observation on the behavior of starch gels from different classes and varieties of wheats. Food Research 8:409-419 (1943).

70. Woodruff, S., and MacMasters, Majel M.
Gelatinization and retrogradation changes in corn and wheat starches shown by photomicrographs. Ill. Exp. Sta. Bull. 445. 43 pp. 1938.

71. Whittenberger, R. T., and Nutting, G. C.
Potato-starch gels. Ind. Eng. Chem. 40:1407-1413 (1948).

72. Woodruff, S., and Nicoli, Laura
Starch gels. Cereal Chem. 8:243-251 (1931).

73. Bechtel, W. G.
Measurements of properties of corn starch gels. J. Colloid Sci. 5:260-270 (1950).

74. Sterling, C.
Relationship of age with strain retardation in a starch gel. Food Research 21:680-688 (1956).

75. Schoch, T. J.
The corn wet-milling industries. From Communications of the Master Brewers Assoc. pp. 9-15 (1956).

76. Cohee, R. F.
Prevent syneresis and setback in thickened foods. Food Processing 17:24-26 (1956).

77. Ford, W. T.
How this new starch helps bakers increase sales of their fruit pies.
Bakers Weekly 173 (4): 37-39 (1957)

EVALUATION OF NEW VARIETIES OF SORGHUM GRAIN FOR WET-MILLING

by

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Thirty-one samples of different varieties of sorghum grain were processed for starch production using a laboratory method. The starch was evaluated for some of the wet milling characteristics, viscosity, gel strength and asidah making. The color of the starch was evaluated visually. The viscosity was measured by Stormer Viscometer. The gel strength was evaluated using a modified Precision Penetrometer. Organoleptic evaluation of the asidah was carried out by six panel members from three countries.

Results showed a linear relationship between the water uptake by the grains during steeping and the weight gained by the grains for all the varieties, except for the waxy varieties which showed slightly higher weight gain than the non-waxy. The color of the starch seemed to be correlated with the endosperm color and not the visual seed color, probably due to the pericarp pigments being insoluble under the steeping conditions used in this work. The waxy starches showed very high viscosity values compared to the non-waxy varieties. Variation among the non-waxy varieties was also apparent indicating the probability of differences in molecular weight of the starches. The gel strength results also showed a clear-cut difference between the waxy and non-waxy starches. The waxy starches showed no resistance to the plunger unlike the non-waxy starches. This was due to the lack of the linear fraction (amylose) in waxy starch. Evaluation of the starches for asidah making showed a significant difference between the waxy varieties and the non-waxy. The panelists showed a complete rejection of the waxy starches for making asidah indicated by low scoring of the waxy varieties for all character, including flavor. Previous workers had reported flavor to be better in waxy starches than in non-waxy. The reason for the poor flavor reported for asidah could be a psychological effect, due to the poor performance of waxy starches from the point of view of other characteristics.