Mashing with Malted Grain Sorghum[1]

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ABSTRACT

Malted grain sorghum is used in southern Africa to brew traditional sorghum (opaque) beer. Sorghum malt has good α-amylase activity but low β-amylase. Its starch has a high gelatinization temperature of 65–68°C. Sorghum beer mashing is performed with a large quantity of cooked starchy adjunct. Some of this adjunct starch is not saccharified and contributes to the opaque character of the beer. The sorghum malt starch is not substantially hydrolyzed because the normal mashing temperature, 55–60°C, is below its gelatinization temperature. Investigation of a wide range of mashing conditions revealed that a large increase in extract occurred over the temperature range of 65–70°C because of gelatinization and saccharification of the sorghum malt starch. Fermentable sugar formation was, however, maximal at only 65°C. When mashing was performed with an all-sorghum malt grist, high extract but low fermentable sugars were obtained at a constant mashing temperature of 75°C. Best all-around results were achieved with a triple-decoction mashing process that facilitated gelatinization and saccharification of starch and fermentable sugar formation. The particular properties of sorghum malt apparently enable mashing at elevated temperatures to produce worts rich in nutritionally desirable complex carbohydrates (dextrins) and low in fermentable sugars. Thus, sorghum malt possibly could be used to produce novel low-alcohol beers.

Keywords: Dextrin, Fermentable sugar, Mashing, Sorghum beer, Sorghum malt

In southern Africa, malted grain sorghum (*Sorghum bicolor* (L.) Moench) is used to brew the traditional alcoholic beverage of the region, known as sorghum or opaque beer (12,15). Sorghum beer is characterized by its sour taste—it is flavored by lactic acid produced by bacterial fermentation and is not hopped. Sorghum beer is of moderate alcohol content (approximately 3% w/w) and the opaque appearance is attributable, in part, to incomplete hydrolysis of starch during mashing. The presence of high levels of complex carbohydrates in sorghum beer makes it a nutritious beverage as well as an alcoholic drink. Sorghum beer brewing in southern Africa has developed during this century from a home industry into a large-scale industrial enterprise. In 1989, some 10 million hectoliters of sorghum beer was brewed in South Africa (12).

Malted grain sorghum differs in many respects from barley malt, particularly in terms of the properties of its starch and diastatic enzymes (Table I). Sorghum malt starch has a gelatinization temperature in the range 64–68°C, some 10°C higher than that of barley malt starch. The total diastatic activity (approximately 10° Lintner) of sorghum malt is less than half that of barley. This is probably because of the apparently very low β-amylase activity of sorghum malt. In contrast, the α-amylase activity of sorghum malt appears to be slightly higher than that of barley malt. This article describes an investigation into starch hydrolysis when mashing with sorghum malt under a wide range of conditions. Both mashing with high levels of starchy adjunct, as is performed in sorghum beer brewing, and all-sorghum malt mashing were studied. In addition, it will be shown how the particular characteristics of sorghum malt could possibly be used to produce novel beers rich in nutritionally desirable complex carbohydrates and low in alcohol.

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EXPERIMENTAL

Materials

Sorghum malts used in this investigation were obtained from industrial maltsters and produced in the laboratory. Malting of sorghum in the laboratory was performed as described (21). The germination time was 6 days. In sorghum beer brewing, the sorghum malt, complete with rootlets, is used. Except when stated otherwise, this practice was followed throughout. Brewer's maize grits were used as adjunct.

Mashing

Mashing was carried out either at the 60-L pilot scale, or in a BRF laboratory mashing bath (Crisp Malting Ltd., Great Ryburgh, England).

Sorghum Beer Mashing

Figure 1 shows a flow sheet for the Reef-type sorghum beer brewing process used in this investigation, at the pilot scale. For the pilot-scale mashing, tap water at a calcium ion concentration

TABLE I
Comparison Between Sorghum Malt and Barley Malt

Factor	Sorghum Malt	Barley Malt
Starch gelatinization temperature range (°C)	64–68[a]	55–59[a]
Diastatic power (° Lintner)	19[b]	53[c]
	20[d]	80[d]
β-Amylase activity (° Lintner)	10[e]	56[e]
α-Amylase activity (Dextrinizing units)	53[d]	35[d]
	29[f]	24[f]

[a]From (22).
[b]Determined by standard method for sorghum (20).
[c]Determined by EBC method (6).
[d]From (18).
[e]Determined by modified sorghum diastatic power method (25).
[f]Determined by Phadebas method (1).

of approximately 30 μg/ml was employed. A bacterial lactic acid fermentation, or souring, was carried out with a slurry of sorghum malt. The product, referred to as the sour, was added to maize grits and the adjunct was cooked. After cooking, the adjunct was cooled to 60°C, malt was added, and mashing was carried out for 90 min. The pH during mashing was 3.9–4.0. Wort separation was done using a centrifugal decanter, set to produce a wort containing suspended particles <250 μm in diameter.

When mashing at the laboratory scale, distilled water was used. A grist comprising 71.0% maize grits and 7.9% malt as the adjunct and 21.1% malt for enzymic hydrolysis was used. The solids content of the mash was 13.8% (w/w). The adjunct was cooked at 100 kPa for 10 min. Mashing was performed at constant temperature for 2 hr using a range of temperatures (40–75° C) at a number of different pH values over the approximate pH range of 3.5–6.0. Either 1 *M* lactic acid or 1 *M* sodium hydroxide was added before malt addition to obtain the desired mash pH. Calcium chloride also was added before malt addition give a calcium concentration of 0.02% (w/w) in the mash after malt addition. Wort separation was by centrifugation at 10,000 × *g* for 10 min at 4°C. This produced a clear wort without any suspended starch, as opposed to the opaque, starch-containing wort produced by centrifugal decanter at the pilot scale or in industrial brewing.

Laboratory-scale mashes also were performed with enzymatic sorghum malt extracts—either extracts containing both α- and β-amylase or extracts containing essentially only α- or β-amylase. The extract containing α- and β-amylase was produced by extraction of 7 g of malt at 30°C with 100 ml of distilled water, followed by centrifugation. α-Amylase extract was prepared by extraction of the malt with 0.2% (w/v) calcium acetate. The clear extract obtained by centrifugation was held at 70°C for 15 min to inactivate the β-amylase (19). β-Amylase extract was prepared by extraction of the malt with 0.2% (w/v) ammonium oxalate, which inactivates the α-amylase (25). Mashing was performed at 60°C, pH 4.0, for 2 hr.

All-Malt Mashing

Mashing was done in the BRF mashing bath, using an all-sorghum malt grist at a solids content of 14% (w/w). A number of different mashing procedures were investigated.

1. Constant temperature infusion mashing for 2 hr over the temperature range of 60–80°C.
2. A rising temperature mash according to the European Brewery Convention (EBC) procedure (6). This comprises a temperature program of 45°C for 30 min, raised to 70°C over 30 min, then held at 70°C for 60 min.
3. A triple-decoction mash, with mashing periods at 45°C for 30 min, 60°C for 60 min, 70°C for 15 min, and 75°C for 15 min. After the 45, 60, and 70°C mashing periods, one third of the mash was removed, brought to boiling, and returned to the main mash.

Distilled water was used in these mashes and, except where stated otherwise, calcium chloride was added before mashing to give a calcium ion concentration of 0.02% (w/w) in the mash after malt addition. Wort separation was by conventional centrifugation, as described above.

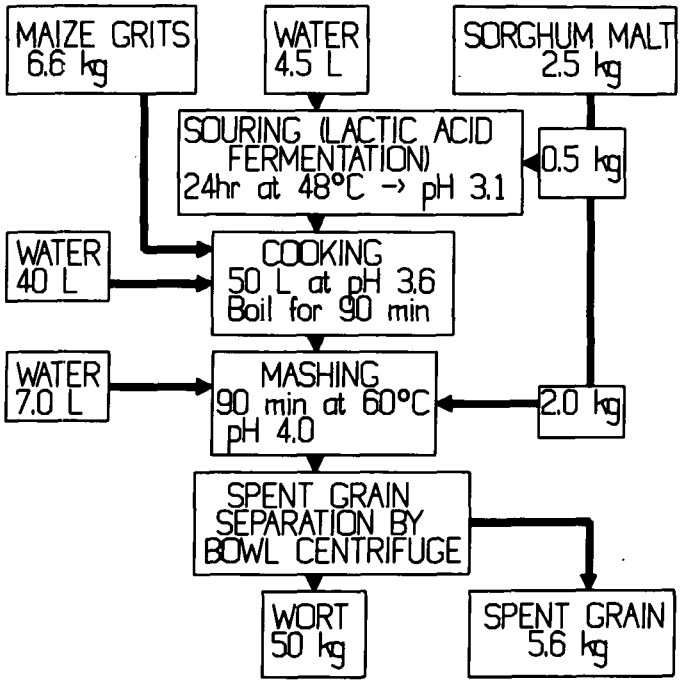

Fig. 1. Reef-type sorghum beer brewing process.

Analyses

Diastatic power was determined according to the standard method for sorghum malt (20) after extraction of the malt with water. Diastatic power is expressed in sorghum diastatic units (SDU), where one SDU equals approximately 2° Lintner.

Starch in the mash and wort was determined after first removing the water-soluble dextrins and fermentable sugars by three repeated steps of centrifugation, decanting off the clear supernatant, and resuspending the residue in water. The samples were then cooked at 100 kPa for 10 min, after which the starch was hydrolyzed to glucose with bacterial α-amylase and amyloglucosidase (11). Glucose was measured colorimetrically by the glucose oxidase procedure (7). Enzyme-susceptible (gelatinized) starch was determined as above, but the samples were not cooked before enzymatic hydrolysis. Raw (ungelatinized) starch was calculated by difference.

Fermentable sugars were determined by first specifically hydrolyzing the maltotriose and maltose to glucose using maltase (α-glucosidase) (Boehringer, Mannheim). The enzyme preparation has been found to be effectively free of interfering amylase side activities. The incubation mixture comprised 200-μl wort containing up to 200 μg of glucose equivalents of dextrins, 10 μl of maltase, and 190 μl of 0.1 *M* citrate-phosphate buffer, pH 6.0. Incubation conditions were 2 hr at 30°C. Glucose then was measured colorimetrically (7). Fermentable sugars (the sum of maltotriose, maltose, and glucose) are expressed as glucose equivalents.

Water-soluble dextrins were calculated as the difference between the total α-glucan content of the sample and its fermentable sugar content. The water-soluble dextrins and fermentable sugars were determined by high-performance liquid chromatography (HPLC) using a Bio-Rad HPX-42A column and methods previously published (11).

Extract was determined by specific gravity (13) and calculated using the Plato table.

RESULTS AND DISCUSSION

Sorghum Beer Mashing

The high gelatinization temperature of sorghum malt starch, 64–68°C (Table I), makes simultaneous gelatinization and saccharification to fermentable sugars as occurs in barley malt mashing difficult. Possibly as a consequence, sorghum beer mashing processes have always involved the cooking of a large quantity of unmalted cereal adjunct followed by mashing with sorghum malt under moderate temperature conditions of 55–60°C (Fig. 1). In the Reef-type sorghum beer mashing process, some starch remains at the end of mashing, amounting to more than 25% of total carbohydrate (Table II). This starch occurs in two forms: enzyme-susceptible (gelatinized) and raw. The gelatinized

starch comes from the cooked maize grits and soured sorghum malt adjunct, which is incompletely saccharified during mashing. Incomplete saccharification is a result of the deliberately adverse conditions of the mashing process. A low ratio of sorghum malt to adjunct is used (approximately 1:4) and the mash pH ranges from 3.9 to 4.0, which is below the optimum pH (4.7) for sorghum malt α-amylase activity (2). The raw starch comes from the sorghum malt, as the mashing temperature of 55–60°C is below the gelatinization temperature of sorghum malt starch. Wort separation by a centrifugal decanter results in the removal of much of the starch from the wort (Table II). Virtually all of the raw starch is centrifuged out because of its high density. The starch that remains in the wort has been found to be reduced in amylose content and molecular size compared with that in the maize grits, as a result of the action of the malt diastatic enzymes (9).

HPLC analyses of the water-soluble carbohydrates in sorghum beer wort (Fig. 2A) revealed that the fermentable sugars glucose, maltose, and maltotriose are present in approximately the same ratio as in barley malt wort, 1:3:1. Maltose is the predominant fermentable sugar in sorghum beer wort, despite the low β-amylase activity of sorghum malt. The water-soluble dextrins show an unusual pattern in that there are very few with a chain length of 4–7 glucose units (Fig. 2A). This contrasts with the situation in barley malt worts, where dextrins of this size can make up

TABLE II
Carbohydrate Composition of Mash and Wort from the Reef-Type Sorghum Beer Brewing Process

Carbohydrate	Mash[a]	Wort[a]
Enzyme-susceptible (gelatinized) starch	1.34 (10.6)	0.75 (7.1)
Raw starch	2.18 (17.2)	0.12 (1.1)
Total starch	3.52 (27.8)	0.87 (8.2)
Water-soluble dextrins	2.93 (23.2)	3.07 (29.2)
Fermentable sugars	6.20 (49.0)	6.58 (62.5)
Total	12.65	10.52

[a]Number in parentheses is grams of glucose equivalent per 100 g of mash or wort.

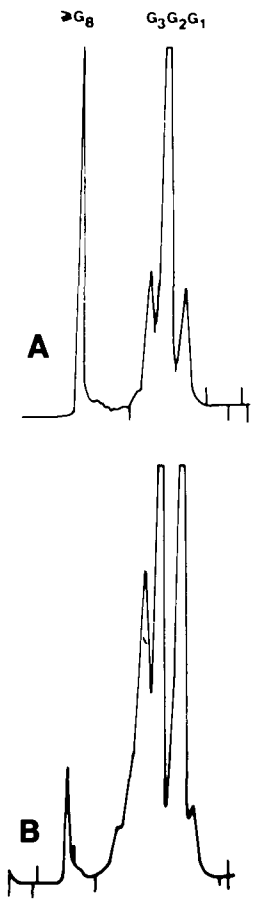

Fig. 2. High-performance liquid chromatographic traces of water-soluble carbohydrates in worts from mashes with sorghum malt. **A**, Sorghum beer wort (malt plus starchy adjunct mash); **B**, wort from all-sorghum malt grist (EBC Congress mash). G_1 = glucose, G_2 = maltose, G_3 = maltotriose, G_8 = malto-octaose.

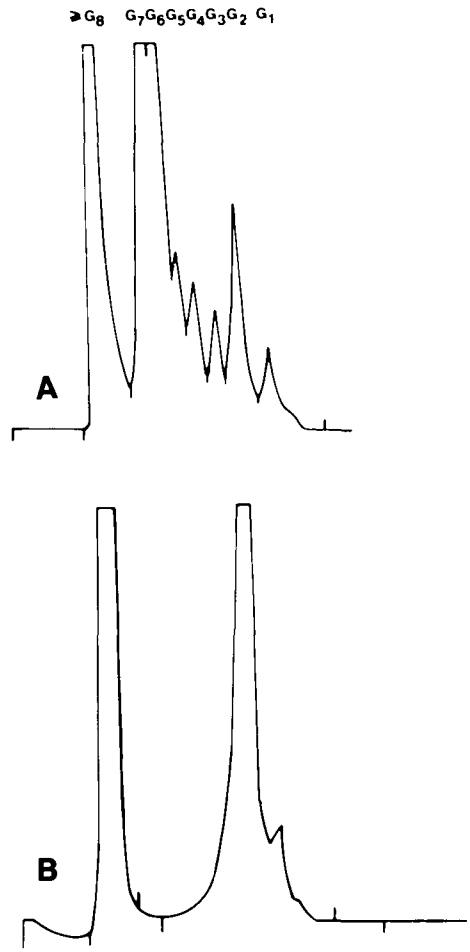

Fig. 3. High-performance liquid chromatographic traces of water-soluble carbohydrates in worts from mashes with sorghum malt extracts in α-amylase only extract (**A**) and β-amylase only extract (**B**). G_1 = glucose, G_2 = maltose, G_3 = maltotriose, G_4 = maltotetraose, G_5 = maltopentaose, G_6 = maltohexaose, G_7 = maltoheptaose, G_8 = malto-octaose.

TABLE III
Composition of Worts After Mashing with Sorghum Malt Extracts

Factor	Control (α- and β-Amylase)[a]	α-Amylase Only[a]	β-Amylase Only[a]
Extract	9.91	9.59	7.77
Total fermentable sugars	6.92	1.74	2.46
Free glucose	0.17	0.18	0.15

[a]Grams per 100 g of wort.

25% of total carbohydrate (5). It has been suggested that this difference is attributable to the different ratios of α- and β-amylases in sorghum and barley malts (11). When the β-amylase in sorghum was inactivated and mashing carried out with a malt extract containing essentially only α-amylase, the resulting wort contained high levels of dextrins of degree of polymerization (DP) 4–7 (Fig. 3A). As may be expected, the quantity of extract was not substantially reduced in comparison with mashing with the control extract containing α- and β-amylase (Table III). However, the quantity of fermentable sugars was greatly reduced. In contrast, when α-amylase was inactivated and mashing performed with an extract containing essentially only β-amylase, the resulting wort contained relatively high levels of maltose and no dextrins of DP 4–7 (Fig. 3B). The extract level was about 20% less than that obtained when mashing with α-amylase only (Table III). These data show that although the level of β-amylase in sorghum malt is low, the enzyme is active during sorghum beer mashing and considerably influences the dextrin composition and fermentability of the wort.

In the sorghum beer brewing process, it is not essential to add all of the sour (the malt slurry acidified by lactic acid fermentation) before mashing. Industrial processes exist where it is added after mashing or, in parts, both before and after mashing. This facilitates a wide range of possible mash pH values from very acidic (3.9) to the natural pH of the mash (5.5–6.0). Similarly, mashing temperature can be adjusted. Changes in mash pH and temperature have a great effect on the activity of malt diastatic enzymes and on their starch substrate, hence, on the carbohydrate composition of the wort. Figure 4 shows the effect on extract. There was a progressive increase in mash solubilization up to 70°C. The greatest increase occurred between 65 and 70°C. This is attributable to the partial gelatinization and saccharification of the sorghum malt starch. Simultaneous gelatinization and saccharification was made possible by the addition of 200 μg/ml of calcium ions to these mashes. This concentration of calcium ions in sorghum beer mashes has been shown to help prevent inactivation of the sorghum malt α-amylase and increase extract, sugar production, and wort yield (23). At a mashing temperature of 75°C, there was a decline in extract and the wort contained starch despite being centrifuged at 10,000 × *g*. This indicates that at 75°C, there was rapid inactivation of the α-amylase. In general, the highest extract was obtained in the mash pH range of 4.5–5.5, which coincides with the pH optimum for sorghum α-amylase (4.7) (2). At acid pH (4.0), below the optimum for α-amylase, extract was reduced at mashing temperatures of 60°C and above. Hence, in sorghum beer brewing, where mashing is frequently performed at this pH and temperature, starch saccharification is reduced, thereby giving sorghum beer its opaque character.

The effect of different mashing conditions on fermentable sugars is shown in Figure 5. The optimum pH for sugar formation, 5.0–5.5, was much higher than that for extract. This is probably attributable to the fact that the pH optimum for sorghum malt β-amylase is in the range of 5.2–5.5 (3), somewhat higher than the α-amylase optimum. Fermentable sugar production increased with mashing temperature up to 65°C. At 70°C, there was a dramatic decline. The difference between the temperature optimum for extract and of fermentable sugars is because β-amylase is more temperature-sensitive than α-amylase (14). The temperature differences between α- and β-amylase and the intrinsically low ratio of β-amylase to α-amylase in sorghum malt apparently facilitate the production of beers of low alcohol content but rich in complex carbohydrates. Figure 6A shows an HPLC trace of carbohydrates in a beer produced by mashing sorghum malt and

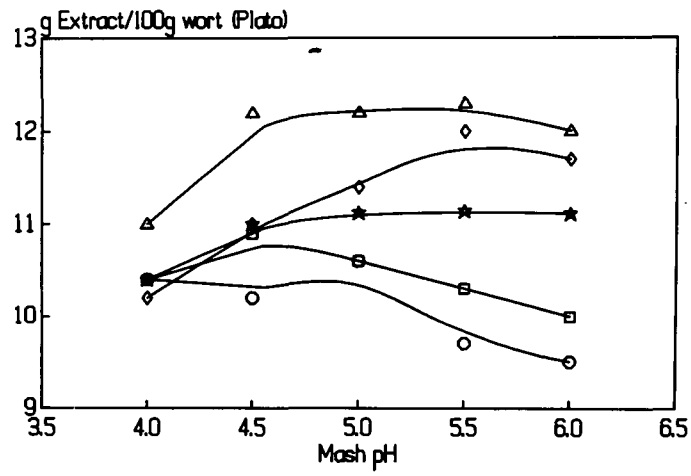

Fig. 4. Effect of mash pH and temperature on extract in sorghum beer wort at 50°C (○), 60°C (□), 65°C (*), 70°C (△), and 75°C (◇).

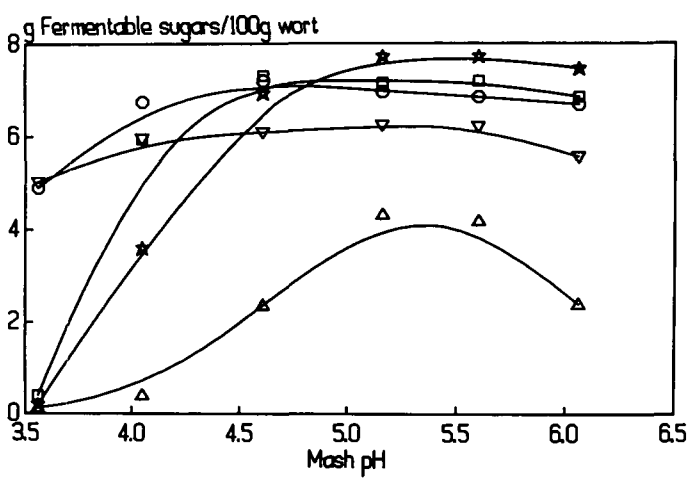

Fig. 5. Effect of mash pH and temperature on fermentable sugars in sorghum beer wort at 40°C (▽), 50°C (○), 60°C (□), 65°C (*), and 70°C (△).

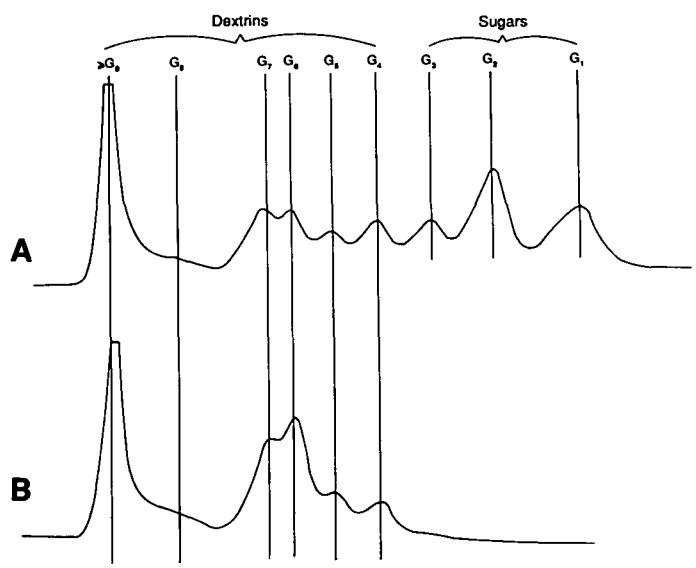

Fig. 6. HPLC traces of dextrin-rich beverages from mashes with sorghum malt at 75°C constant temperature. **A**, Low-alcohol beer from a grist of sorghum malt plus cooked maize grits adjunct; **B**, wort from an all-sorghum malt grist. G_1 = glucose, G_2 = maltose, G_3 = maltotriose, G_4 = maltotetraose, G_5 = maltopentaose, G_6 = maltohexaose, G_7 = maltoheptaose, G_8 = malto-octaose, G_9 = maltononoaose.

maize grits at 75°C, pH 5.95, in the presence of 200 μg/ml of calcium ions. In contrast to conventional sorghum beer wort (Fig. 2A), the beer was rich in dextrins of DP 4–7. However, it contained just 1.4% (w/w) alcohol, in comparison with conventional sorghum beer, which contains approximately 3% (15).

Mashing with All-Sorghum Malt Grists

Figure 7 shows the effect on extract and fermentable sugar formation when mashing with all-sorghum malt grists under a range of different conditions. Using constant temperature infusion mashing, extract increased with a mashing temperature up to 75°C and fermentable sugar formation increased up to 70°C. These temperature optima are considerably higher than those for barley malt mashing, where maximum extract is obtained at 65–68°C and highest fermentable sugars at 60–62°C (4). Direct comparison of mashing temperature optima are, however, difficult because the solids content of the mash also influences starch solubilization and fermentable sugar production (14). The normal infusion mashing temperature for barley malt of 65°C resulted in an average extract of only 67% from sorghum malt compared with the 86% obtained at 75°C. The large difference in the optimum temperature for extract between sorghum malt and barley malt is apparently attributable to the difference in the starch gelatinization temperature of the two cereals—namely 64–68°C for sorghum malt starch and 55–59°C for barley malt starch (Table I). The high extract and fermentable sugars that could be obtained at an elevated mashing temperature is attributable in part to the addition of calcium ions to the mash. Calcium ions reduce the rate of inactivation of the sorghum malt α-amylase enzyme at high temperature and low pH (23). It can be seen that when mashing was carried out at 70°C in the absence of added calcium ions, there was a significant reduction in both extract and fermentable sugars compared with mashing at the same temperature with calcium.

The EBC rising temperature mashing procedure gave similar extract and fermentable sugars, as did mashing at 70°C constant temperature. Highest extract and high fermentable sugars were obtained with a triple-decoction mashing process. Decoction-type mashing also has been found by other workers to be an effective process for sorghum malt (16–18). The removal and boiling of portions of the mash enables complete gelatinization of the sorghum malt starch in those portions removed. This facilitates rapid saccharification of the starch by the malt α-amylase when the portions are returned to the main mash. The low temperature (60°C) mashing period facilitates sugar formation by the β-amylase. Decoction mashing processes were originally devised for irregularly or poorly modified barley malts. Sorghum malt

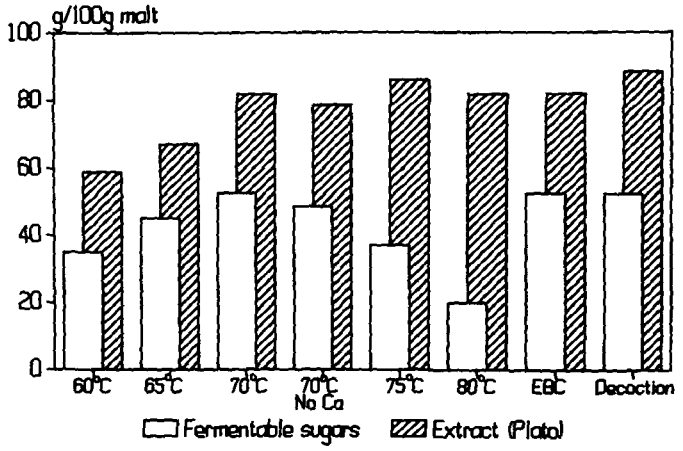

Fig. 7. Effect of different mashing conditions with all-sorghum malt grists on extract and fermentable sugars. Mean data from five different sorghum malts.

is similar in a number of respects to poorly modified barley malt. High temperatures are necessary for complete starch gelatinization; a protein matrix may envelop the starch granules (10,24); and the endosperm cell walls persist in the malt (8). However, the average level of extract obtained from sorghum malt by the decoction procedure (88%) is much higher than that which can be obtained from barley because sorghum is a huskless grain; hence, the starch-containing endosperm tissue forms a higher proportion of the kernel than in barley (18).

The relative proportions of the different fermentable sugars in worts from all-sorghum malt mashes (Fig. 2B) differed considerably from those in sorghum malt plus starchy adjunct worts (Fig. 2A) and barley malt worts. Glucose occurred in a quantity similar to maltose. The ratio of maltotriose to maltose to glucose was approximately 1:1.4:1.4, compared with 1:3:1 in sorghum malt plus adjunct worts and 1:4:1 in barley malt worts (4). This difference in sugar composition between all-sorghum malt and all-barley malt worts has been attributed to the low β-amylase activity of sorghum malt (17).

With all-sorghum malt mashing, as with mashing with adjunct, the temperature differential between α- and β-amylases and the intrinsically low β-amylase activity in sorghum malt apparently facilitate the production of beverages that are rich in dextrins and low in fermentable sugars. Figure 6B shows an HPLC trace of the carbohydrates in an all-sorghum malt wort mashed at 75°C constant temperature. The wort contained high levels of dextrins of DP 4–7 but low levels of fermentable sugars, only one third of the total extract.

Both this wort and the beer produced with malt plus adjunct (Fig. 2A) were made from sorghum malt from which the rootlets and shoots (which are external to the malt berries in sorghum) had been removed. The removal of the vegetative parts of the malt was necessary because their presence imparted a strong grassy flavor to the products. Even after removal of the rootlets and shoots, the products retained a sorghum flavor, but this was not pervasive.

CONCLUSIONS

The high gelatinization temperature of sorghum malt starch dictates that mashing processes for sorghum malt should differ from those for barley malt. A large quantity of starchy adjunct can be used, as in sorghum beer brewing. The adjunct is cooked first and mashing is performed at a moderate temperature to saccharify and produce fermentable sugars from the adjunct starch. Gelatinization and saccharification of the sorghum malt starch are possible at elevated mashing temperatures, but fermentable sugar formation is low. With all-sorghum malt grists, decoction-type mashing procedures give the best results, as they facilitate complete gelatinization of the malt starch, saccharification, and fermentable sugar production. The low ratio of β-amylase to α-amylase in sorghum malt and the temperature differential between the enzymes appear to facilitate mashing at an elevated temperature, which produces worts rich in complex carbohydrates and low in fermentable sugars, from which novel low-alcohol beers could be made.

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