Composition and hardness of malting red and white kaffir sorghum [*Sorghum bicolor* (L.) Moench] dried under the sun

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Abstract This investigation determined how changes in chemical composition of malting red and white kaffir sorghum grains dried under the sun affected the resistance of the malts to fracture as determined by the Monsanto Hardness Tester. The sorghum grains were malted by a modification of the 2-step wet steep method and dried under the sun. The results showed that malting increased diastatic activity to peak values of 78.40°L and 56°L in the red and white malts; moisture content from 115 to 165 g/kg and 125 to 170 g/kg, crude protein from 104.20 to 183 g/kg and 92.8 to 153.20 g/kg respectively but decreased the fat content. Grain hardness decreased from 83.20 to 42.50 N in the red malts and from 72.70 to 39.30 N in the white. The increases in diastatic activity, moisture, crude protein and reduced fat contents appear to have contributed most to the reduction in grain hardness.

Keywords Sorghum · Malting · Diastatic power · Composition · Grain hardness

Introduction

Sorghum (*Sorghum bicolor* L. Monech) is the fifth most important cereal crop in the world after wheat, rice, corn and barley. Sorghum is a major cereal in the diets of people in the developing countries of Africa, Asia and Latin America (FAO

1995). More than 35% of sorghum is grown directly for human consumption. The rest is used primarily for animal feed, alcohol and industrial products. Its protein content is higher than that of corn although its nutritional quality is lower (Dowling et al. 2002). The protein however, has lower digestibility compared to other cereals (Dewar 2000) because of the presence of antinutrients such as phenolic compounds. They are of low nutritional quality, deficient in lysine, threonine and tryptophan, and rich in leucine, proline and glutamic acid (Duodo et al. 2003). The crude protein (CP) content of sorghum grains is highly variable (5.44–12.9%). The storage proteins in sorghum grain are mostly kafirins (Watterson et al. 1993), which are prolamins that are soluble in aqueous alcohol in the presence of a reducing agent.

All sorghums contain phenolic acids (hydroxybenzoic and hydroxycinnamic acids), which are located in the pericarp-testa, aleurone layer and endosperm and exist in the free and bound forms (Dykes and Rooney 2007). Free and bound phenolic acids are extracted in methanol and in boiling water. Free phenolic acids are found in the outer layers of the kernel (pericarp, testa, and aleurone), whereas the bound phenolic acids are associated with the cell walls (Dykes and Rooney 2007). The phenolic acids in sorghum are present mostly in bound form with ferulic acid being dominant (24–47%). Gallic acid is extracted with 70% ethanol (4 × 50 mL) and hexane (4 × 50 mL) and is found only in bound form at 12.9–46 µg/g, dry wt, whereas cinnamic acid is found only in free form (2.0–10.7 µg/g), concentrated in the pericarp and pigmented testa, which is also reported to contain cinnamic acids in bound form only (19.7 µg/g). Tannins bind to proteins, carbohydrates and minerals and thus reduce digestibility of these nutrients. To reduce these negative effects, decortication, fermentation, germination and chemical treatments (i.e. HCl, formaldehyde and alkali) are used (Beta et al. 2000; Dicko et al. 2005).

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In the conventional brewing industry, sorghum is used mainly as an adjunct in the production of lager beers. Sorghum is however, the main raw material in the production of traditional opaque beers in Africa—*burukutu* in Nigeria, *pombe* in East Africa and *bil-bil* in Cameroon (Odunfa 1985). These beers require a prior malting stage in which the sorghum is dried under the sun before they are fermented. The suitability of the malts for opaque beer brewing is largely determined by the lengths of the root and shoot although sorghum malt quality is industrially assessed primarily in terms of diastatic activity, free amino nitrogen content (Dewar 2000) and the soluble nitrogen ratio (SNR).

However, the unstable supply of electricity in much of the developing countries where sorghum is malted for food and beverage use and the absence of equipment necessary to produce good and consistent malt quality has made the traditional maltster to continue using sun drying to complete the malting process. Work in our laboratories has shown that hardness could be used as an index for monitoring the degree of modification of malting red and white Nigerian sorghum grains (Uvere et al. 2014). It correlates well with other indices of grain modification such as diastatic activity ($r = -0.936$) and free amino nitrogen content ($r = -0.981$). This study therefore focused on evaluating the changes in chemical composition of finished malts from red and white sorghum grains dried under the sun (39.56 ± 2.60 °C) and its relationship to the hardness of the malts.

Materials and methods

Materials

Local Kaffir sorghum [*Sorghum bicolor* (L.) Moench] grains of the red and white varieties were purchased from Nsukka market, Nigeria. The Monsanto Hardness Tester (Monsanto Chemical Coy, St. Louis, MO, USA; Mht-20, Tab-machine Ltd., India) was obtained from the Pharmaceutical Technology Department, University of Nigeria, Nsukka, Enugu State, Nigeria. The Monsanto Hardness Tester (Appendix 1) was adapted for use in measuring the peak force required to fracture a grain when the force generated by a coil spring is applied diametrically to the grain. The same equipment has been used for monitoring of grain hardness by Uvere et al. (2014).

Methods

The red and white sorghums known to be used for *burukutu* production were sorted, cleaned by air aspiration and screened to 2.5–3 mm diameter to minimize variations in rate of water uptake. Eight (8) batches of the red and white sorghum grain varieties (200 g each) were weighed into

malting bags (25 cm × 45 cm) with perforations to allow for air and moisture exchange. Malting was carried out for 144 h (6 days) by a modification of the two step, wet-steep method as described by Uvere et al. (2014). Ten (10) germinating grains from each malting bag were used for determination of approximate root length on each day of germination using a meter rule (Ilori and Adewusi 1991).

One batch of each variety was harvested every 24 h and dried to constant weight under the sun (mean daily temperature = 39.56 ± 2.60 °C; air flow rate/wind speed = 33 m/s; R. H. = 97.5%, these parameters were monitored using Vantage Pro 2, Davis instrument, USA. Twenty (20) finished grain malts were used to determine the hardness of the grain malts using the Monsanto Hardness Tester. The malts were then milled into flour in a Thomas Wiley Laboratory mill (Model 4, Arthur H. Thomas Company, Philadelphia, USA) and stored at 4 °C for analyses. Malting was carried out three times and the grain malts analyzed accordingly.

Analyses

Malting loss was determined as the loss in weight between the unmalted grain and the dried and cleaned malts (Ilori and Adewusi 1991). The diastatic activities of the malts were determined by the method of Hulse et al. (1980) and expressed in degrees Lintner (°L). The proximate composition (content of moisture, crude protein, fat and ash) were determined using methods described by the A. O. A. C (1995). The phytate content was determined by the spectrophotometric method of Pearson (1976) and expressed in mg/kg. The tannin and phenol contents were determined as described by Harborne (1973) while the dhurrin content of the malts was determined by the method of Eustace and Dorothy (2000).

The resistance to fracture of 10 grain malts was measured in the longitudinal direction and the other 10 in the transverse direction and the grand mean calculated and expressed as grain hardness. The fracture/breaking strength (in Newton, N) of the grains and malts was determined according to the method described by Subramanian et al. (1997) using a hand-held Monsanto Hardness Tester. Twenty (20) malted grains of each of the red and white sorghums were selected; ten (10) grains were each placed transversely and the other 10 placed longitudinally in the hardness tester. The peak force needed to fracture the grain in either direction was read off and averaged. Hardness index (HI) was calculated as the hardness of the malt in relation to the hardness of the respective unmalted grains.

Statistical analysis

All experiments were repeated three times and the means and standard deviation were calculated using SPSS versión 17.0 for Windows, SPSS inc. IL, USA. Data analysis was based on

a Completely Randomized Design (CRD). Mean separation was carried out by least significant difference (LSD) at $p < 0.05$. Correlation analysis was used to determine how changes in the chemical composition affected the hardness of grain malts over the 144 h of malting.

Results and discussion

Germinative energy and germinative capacity

The germinative energy of the red and white sorghum grains were 68.15 (± 0.7155) and 62.25 (± 0.6350) respectively while the germinative capacity were 82.85% (± 0.2856) and 80.70% (± 0.80). The high percentage of viable grains within 48 h (82.85% for the red and 80.70% for the white) suggests that the germinative energy will probably increase to higher values within the 96–144 h required for adequate sorghum malting for burukutu production (Ilori and Adewusi 1991; Uvere et al. 2000). The red grains had significantly ($p < 0.05$) higher germinative capacity which could account for the higher diastatic activity (Uvere et al. 2014) and alcohol content of burukutu produced from the red grain malts (Uvere et al. 2000).

Root length and malting loss

The mean root length of the germinating red and white sorghum grains increased to a peak of 3.21 cm after 72 h and 3.10 cm after 96 h respectively after which, shrinkage to 1.15 cm and 1.68 cm occurred by the 144th hour (Fig. 1). The most rapid increases in root length occurred between the 0–48 and 24–72 h periods in the red and white green malts respectively. This possibly confirms the higher germinative capacity and germinative energy of the red compared to the white malts and that the red grains may resemble barley. In barley, active gibberellin secretion and increased physiological changes in the endosperm (Palmer 1979) occur within the first 48 h.

Root outgrowth and extension is thought to be affected by pericarp thickness (Abiodun 2002) which suggests that the red grains may have a thinner pericarp and that hydrolysis of high molecular weight structures (modification) in the kernel (Briggs et al. 1981) was better in the red malts. The longer root length of the red malts are however at variance with our earlier results (Uvere et al. 2000, 2014) due possibly to the subjective nature of the measurements and that root length was measured on randomly selected grain malts (Ilori and Adewusi 1991).

Loss in weight due to malting (Fig. 1) increased to a peak of 159.90 g/kg and 196 g/kg in the red and white malts after 144 h of malting. The increasing malting loss may have resulted from increased respiratory activities and removal of

the root and shoot (Beta et al. 1995) after cleaning. The higher malting loss in the white may therefore be due to higher respiratory activities resulting from a higher free space potential (Palmer et al. 1989b) after cleaning. These values fall within the 150–200 g/kg reported for sorghum grains (Palmer et al. 1989a). The pattern of change in malting loss suggests that in the out-of-steep grains, it was due to leaching and respiration, following which respiration, loss of volatiles and root outgrowth probably became predominant factors.

Diastatic activity

The diastatic activities of the sorghum grains increased with malting time (Fig. 2). Peak diastatic activities were observed at 78.40°L in the red after 72 h and 56°L in the white malts after 120 h. The red malts had higher diastatic activity throughout the 144 h of malting during which secreted and/or activated diastatic activities contributed 64°L and 44.8°L to the total activity in the red and white malts respectively. The earlier and higher increase in diastatic activity in the red malts may reflect a more active gibberellin secretion and translocation mechanism within the first 48 h (Palmer 1979), a more active secretory (scutellar) epithelium and β -amylase activation mechanism. The results also suggest that the carbohydrate content of the red malts may be higher since enzymes occur in proportion to available substrates or that tannins in the red grain malts are not inhibitory to the diastatic enzymes.

Proximate composition

The changes in proximate composition are shown in Table 1.

Moisture

The moisture content of the red and white sorghum varieties increased with malting time and ranged from 115 to 165 g/kg and 125 to 170 g/kg respectively, reflecting increases of some 43.49% and 36% during the 144 h of malting. The increases in moisture content may be due to increases in soluble matter content resulting from increasing hydrolytic enzyme activities (Uvere et al. 2014). These suggest that more soluble matter was produced in the red malts.

Crude protein

The crude protein content of both varieties increased with malting time with the red malts having the higher values. The crude protein content increased from 104.22 to 183.01 g/kg and 92.81 to 153.24 g/kg for the red and white sorghum malts respectively. This is possibly due to synthesis of new proteins and dry matter loss as a result of leaching, mobilization and drying (Dewar 2000). The

Fig. 1 Time course variations of malting loss with root length of the germinating red and white sorghum grains. *C* unmalted grains, *stg* out of steep grains

higher increase of 75.60% in the red suggests a more effective protein synthesizing machinery, higher loss of dry matter and a lower mobilization of protein compared to the white malts.

Fat content

The fat content increased from 25.30 g/kg to a peak of 28.8 g/kg in the red after steeping (Stg) and then decreased to 17.60 g/kg in the white malts, it increased from 26.90 to 38.60 g/kg in the white after 24 h of germination, followed by a progressive decrease to 20.70 g/kg in the white grain malts at the 144th hour. The initial increases could be relative and may be explained by leaching and mobilization of water-soluble constituents which reflect the structural differences in the pericarp-testa and endosperm of the two sorghum varieties. The earlier peak in the red therefore suggests that more soluble matter was lost and/or mobilized during steeping compared to the white and may be due to a thinner and more porous pericarp-testa. Subsequent decreases would be due to increasing lipase activity suggesting that the higher fat content in the white malts would be due to a lower lipase activity (Uvere and Orji 2002).

Ash

The ash content of both varieties increased from 18.30 and 16.10 to peak values of 24 g/kg and 20.4 g/kg after steeping, due possibly to leaching and mobilization of more organic constituents. Thereafter, it decreased to 10 g/kg and 8.40 g/kg in the red and white varieties respectively. These suggest that the mineral composition in the native grains may be bound into a non-leachable complex (such as phytate-mineral or tannin-mineral) that was hydrolyzed during germination. The subsequent decreases in ash content during germination may be attributed to the increasing moisture contents, utilization of the mineral contents by the germinating grains and/or leaching. At the end of malting, the red malt had higher ash content than the white, due possibly to a lower moisture content, lower utilization of the mineral content by the germinating grains and lower loss of mineral matter due to a less porous pericarp-testa and lower free space potential.

Crude fibre

The crude fibre contents of the red and white sorghum malts increased from 23.86 and 23.76 g/kg in the unmalted

Fig. 2 Time course variation of diastatic activity and hardness of malting red and white sorghum grains. *C* unmalted grains, *stg* out of steep grains

grains to 32.57 and 33.72 g/kg for the red and white malts respectively after 144 h. This may be due to the reduction of other more digestible and less branny components of the grains (Murwam and Amna 2008) and the porosity of the endosperm, and pericarp-testa. The white grain malts had higher crude fibre content suggesting a higher reduction of the more digestible components, a higher free space potential and a more porous pericarp-testa structure.

Carbohydrate

The carbohydrate content of both varieties decreased with malting time from 770.58 to 616.29 g/kg and 745.79 to 655.76 g/kg in the red and white malts respectively over the 144 h of malting. This trend is in agreement with the results of Murwam and Amna (2008). This may be attributed to leaching and mobilization by malt enzymes during germination. The higher percentage reduction in the red grain malts (154.29 g/kg vs 98.03 g/kg) suggests a higher

diastatic activity, better carbohydrate mobilization and that diastatic activity may play a higher role than leaching because of the less porous pericarp-testa and endosperm.

Anti-nutrients

Total phenol and tannin

The total phenol content of both sorghum types decreased progressively (Fig. 3) from 280.84 to 113.68 mg/kg in the red and 300.87 to 89.12 mg/kg in the white sorghum grain malts during the 144 h of malting. The more phenolic constituents lost in the white malts (211.75 mg/kg vs 167.16 mg/kg) may reflect the presence of a more porous pericarp-testa and an endosperm with a higher free space potential while the progressive decrease may be attributed to leaching, complexation with proteins or other metabolic activities. Dykes et al. (2005) observed increased level of free phenolic acids in certain sorghums with pigmented

Table 1 Proximate composition [mean (SD)] of malting red and white sorghum dried under the sun

Malting time (h)	Proximate composition (g/kg)									
	Moisture		Crude Protein		Fat		Ash		Crude Fibre	
	Red	White	Red	White	Red	White	Red	White	Red	White
C	115	125	104.22 ± 0.001	0.92.81 ± 0.002	25.30 ± 0.002	26.90 ± 0.002	18.30 ± 0.100	16.10 ± 0.006	23.86 ± 0.003	23.76 ± 0.001
Sig	107.6	120	108.57 ± 0.004	96.34 ± 0.002	28.80 ± 0.001	27.70 ± 0.002	24.00 ± 0.001	20.40 ± 0.100	32.44 ± 0.002	33.74 ± 0.001
24	132	135	109.37 ± 0.001	108.66 ± 0.001	26.20 ± 0.006	38.60 ± 0.001	14.20 ± 0.100	12.20 ± 0.100	35.12 ± 0.001	34.36 ± 0.001
48	132.5	140	121.72 ± 0.001	112.07 ± 0.002	25.70 ± 0.001	26.20 ± 0.001	12.20 ± 0.100	14.20 ± 0.100	34.12 ± 0.002	34.29 ± 0.002
72	142.6	145	129.53 ± 0.001	126.56 ± 0.002	23.20 ± 0.002	24.80 ± 0.001	16.30 ± 0.100	10.10 ± 0.265	33.74 ± 0.002	33.68 ± 0.003
96	150	147	137.44 ± 0.003	126.95 ± 0.002	22.00 ± 0.001	22.90 ± 0.001	12.20 ± 0.100	10.20 ± 0.100	32.76 ± 0.004	32.86 ± 0.001
120	160	150	150.61 ± 0.002	136.58 ± 0.003	18.30 ± 0.002	21.40 ± 0.008	10.10 ± 0.100	12.20 ± 0.208	32.87 ± 0.003	32.82 ± 0.003
144	170	165	183.01 ± 0.003	153.24 ± 0.003	17.60 ± 0.002	20.70 ± 0.002	10.10 ± 0.100	8.40 ± 0.100	32.57 ± 0.002	33.72 ± 0.005

C = unmalted sorghum grain subjected to sundrying (39.56 ± 2.60 °C), Sig = Out-of-steep; values are mean ± standard deviation of three replicates

testa (containing tannin) compared to the ones without pigmented testa.

The tannin content of both varieties decreased progressively from 35.24 to 16.79 mg/kg and 27.84 to 11.47 mg/kg in the red and white sorghum malts respectively (Fig. 3). The decrease is attributable to leaching during steeping, enzymic breakdown and pH modification during germination. The red malts lost more tannin (18.45 mg/kg) than the white malts (16.37 mg/kg) which shows that much of the phenolics lost in the white malts may not be tannins. This decreasing trend is supported by the results of Traore et al. (2004).

Phytate

The phytate content of the red and white malts decreased from 9.764 to 3.893 mg/kg in the red grain, while in the white, it decreased from 8.849 to 3.898 mg/kg with malting time (Fig. 4). The decrease could be attributed to phytase activity (Murwam and Amna 2008) and leaching. The effect of leaching during steeping was more pronounced in the white, which lost 1.184 mg/kg while the red lost 0.502 mg/kg. This suggests a more porous endosperm cell wall and the pericarp-testa of the white malts. The subsequent loss of 5.369 mg/kg in the red and 3.772 mg/kg in the white during germination may be attributed to phytase activity which was presumably higher in the red than in the white malts. These results are similar with that of Mahgoub and Elhag (1998) and Traore et al. (2004).

Dhurrin

The dhurrin content of the unmalted samples were 40.46 and 58.93 mg HCN/kg for the red and white sorghum grains respectively and decreased to 11.54 and 15.74 mg HCN/kg after 144 h of malting (Fig. 5). This may be attributed to leaching during steeping and dhurrinase activities during germination. This tends to be supported by our earlier results (Uvere et al. 2000) which showed that dhurrinase activities increased to a peak after 96 h although dhurrin content decreased in the red malts only. Prasad and Dhanya (2011); Traore et al. (2004) had reported increases in dhurrin contents which are in agreement with our results for the red malts.

Grain hardness

Grain hardness decreased from 83.20 N in the unmalted grain to 42.50 N in the red malts (a loss of 40.70 N) while in the white, it decreased from 72.70 to 39.30 N (a loss of 33.40 N) over the 144 h of malting (Fig. 2). The mean rate of hardness reduction were 6.783 N and 5.566 N every 24 h for the red and white malts and by the 144th hour, the red malt was significantly ($p < 0.05$) harder than the white.

Fig. 3 Total phenol and tannin content of malting red and white sorghum grains. *C* unmalted grains, *stg* out of steep grains

This suggests a more compact endosperm packing in the red grains and malt.

The reduction in grain malt hardness may reflect structural changes due to the activities of secreted enzymes (proteases, amylases, glucanases, etc.) in the grain. The red malts were harder possibly due to a more compactly packed endosperm starch-protein matrix (Palmer et al. 1989b; Hogg et al. 2004) which restricted water and enzyme movement within the endosperm (Gamlath et al. 2007). When water enters the endosperm, the protein-starch bonds that contribute to hardness are broken or weakened suggesting that the amount of moisture absorbed by the grain influences the hardness. The activities of hydrolytic enzymes may therefore be secondary to the plasticizing effect of water and free space potential of the grain. The moisture content of the red malts was higher as from the 96th to the 144th hour during which shriveling may have become a significant factor in hardness.

The percentage increase in moisture content (red = 43.91%; white = 36%) was significantly ($p < 0.05$) lower than the percentage decrease in hardness (red = 48.44%; white = 45.94%) suggesting that other factors such as fat content may play a role in hardness reduction. The white malts had a higher fat content which may contribute to its softer texture/lower resistance to fracture. The pattern of reduction in hardness is similar to the reduction in milling energy input (Okon and Etuk 1992) used to determine the extent of modification.

Relationship between grain hardness and relevant chemical parameters

Grain hardness was significantly ($p < 0.05$) affected by dhurrin content ($r = 0.9600$), carbohydrate ($r = -0.9451$), malting loss ($r = -0.9398$), tannin ($r = 0.9357$), phytate

Fig. 4 Time course variation of phytate content in malting red and white sorghum grains. C unmalted grains, *stg* out of steep grains

(0.9336), moisture ($r = -0.9284$), diastatic activity ($r = -0.8907$) and crude protein ($r = -0.8190$) in the red malts. In the white variety, grain hardness correlated significantly ($p > 0.05$) with dhurrin and crude fibre ($r = 0.9650$), diastatic activity ($r = -0.8246$), phytate ($r = 0.9208$), carbohydrate ($r = -0.9212$), crude protein ($r = -0.9051$), malting loss (-0.8988), phenol ($r = 0.8872$), moisture (-0.8761), and tannin (0.8383) contents (Appendix 2).

The contribution of diastatic activity to hardness reduction was stronger in the red ($r = -0.8910$) than in the white ($r = -0.8250$) suggesting that more carbohydrates were hydrolysed in the red. Grain/malt hardness per unit of diastatic activity (H/DA) had a stronger relationship with crude protein content in the red ($r = -0.8220$) than in the white malts ($r = -0.8010$). This possibly suggests that much of the protein associated with the starch granule in the red were hydrolyzed compared to the white and may have resulted from differences in hydrophobicity.

Grain/malt hardness per unit of diastatic activity had an equally stronger relationship with fat content in the red (0.5699) than in the white malts (0.3150), none of which was significant. This suggests that fat content plays a less significant role in grain hardness, but may be more important in the red. Grain/malt hardness per unit of diastatic activity had significant ($p < 0.05$) negative relationship with moisture content in the red ($r = -0.7710$) and white ($r = -0.7800$) showing that it contributes significantly to hardness reduction in both grains.

Conclusion

Malting led to an increase in loss of dry matter, the friability of the grain and consequently to a decrease in the resistance to fracture as malting time increased. Malting increased the moisture, crude protein, crude fibre contents and diastatic activity while the carbohydrate, ash, fat and

Fig. 5 Changes in dhurrin content of malting red and white sorghum grains. *C* unmalted grains, *stg* out of steep grains

anti-nutrient contents of both sorghum grain malts decreased. In the red grain malts which appeared to have a more compact structure, dhurrin, carbohydrate, malting loss, tannin, phytate, and moisture content affected the hardness of the red grain malts. In the white, dhurrin, crude fibre, diastatic activity, phytate and protein contents were the most significant in the reduction of grain hardness of the malts.

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Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

Appendix 1

See Fig. 6 and Table 2.

Fig. 6 The Monsanto Hardness Tester

Hardness	RED _{Ban3}	RED _{Ban}	WHITE _{Ban2}	WHITE _{Ban}
Root length	− 0.77	− 0.82417	− 0.91	− 0.8255
Phenol	0.79	0.840936	0.86	0.887167
Tannins	0.902	0.935656	0.854	0.838337
Phytate	0.971	0.933605	0.951	0.92079
Dhurrin	0.929	0.960041	0.94	0.964992
Diastatic activity (°L)	− 0.84	− 0.85702	− 0.96	− 0.94596
Moisture content	− 0.95	− 0.92842	− 0.89	− 0.87614
Crude protein	− 0.89	− 0.84096	− 0.93	− 0.90506
Fat	0.868	0.797967	0.566	0.414825
Ash	0.801	0.801855	0.738	0.79007
Crude fibre	− 0.54	− 0.64418	− 0.66	0.964992
Carbohydrate	0.956	0.945118	0.94	− 0.81058
Malting loss	− 0.98	− 0.93977	− 0.91	− 0.89882

Malting time(h)	Hardness (N)		Diastatic activity (°L)		Hardness/diastatic activity (N/°L)		Crude protein (g/kg)		Fat (g/kg)		Moisture content (g/kg)	
	R_s	W_s	R_s	W_s	R_s	W_s	R_s	W_s	R_s	W_s	R_s	W_s
C	83.20	72.70	14.4	11.2	7.6563	9.3402	104.22	92.81	25.30	26.90	115	125
Stg	72.30	61.30	25.6	16	3.8254	5.4556	108.57	96.34	28.80	27.70	107.6	120
24	62.8	51.50	30.4	27.2	2.8961	2.9658	109.37	108.66	26.20	38.60	132	135
48	56.00	50.60	44.8	38.4	1.7634	1.6995	121.72	112.07	25.70	26.20	132.5	140
72	53.00	44.30	78.4	48	0.9291	1.2576	129.53	126.56	23.20	24.80	142.6	145
96	49.00	42.50	65.6	54.4	0.9864	1.0893	137.44	126.95	22.00	22.90	150	147
120	43.10	40.20	60.8	56	0.8705	0.9193	150.61	136.58	18.30	21.40	160	150
144	42.50	39.30	64	48	0.7905	1.0284	183.01	153.24	17.60	20.70	170	165
			$rR_s = -0.891$				$rR_s = -0.822$		$rR_s = 0.5699$		$rR_s = -0.771$	
			$rW_s = -0.825$				$rW_s = -0.801$		$rW_s = 0.315$		$rW_s = -0.78$	

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