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COMPARATIVE ANALYSES OF IMPACT OF VARYING GERMINATION PERIODS ON MALT QUALITY AND WORT CHARACTERISTICS OF *SORGHUM BICOLOR* (L) MOENCH AND *SORGHUM VULGARE* VARIETIES

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ABSTRACT

Three *Sorghum bicolor* [L] Moench and two *Sorghum vulgare* varieties were steeped for 20 h at 30 ℃ and germinated for 2 to 6 d. The varieties differed in 1000-grain weight, germination energy, germination capacity, water sensitivity, nitrogen, protein, tannin and moisture contents. Sprouts length increased with germination days and varied with sorghum varieties. Malting loss increased with germination days and differed with cultivars. Cold water extract and hot water extract increased from 2-day to 4-day malts and thereafter decreased. Tannin content varied among cultivars, grains>malts>worts. Diastatic power (DP) and amylase activities increased in both sweet and non-sweet sorghum cultivars from day-2 to day-4 malts and then declined. Sweet sorghum malts revealed higher DP (ca 142.1 °L) than the non-sweet malts (ca 119.6 °L). Malts of sweet sorghum varieties had α-, β- and γ-amylase activities while non-sweet cultivars indicated only α- and β-amylase activities. Sweet sorghum worts had more reducing sugars than non-sweet sorghum varieties. Wort-yields (43.9-68.7%) and reducing sugars differed and increased from day-2 to day-4 malts and then decreased. Worts pH (5.1-6.7) varied with cultivars and the sweet generally had higher pH than non-sweet sorghum cultivars. Generally, the 4-day sweet sorghum malts yielded the best quality malts.

Contribution/Originality: *Sorghum bicolor* (sweet sorghum) varieties produced better quality malt than *Sorghum vulgare* (non-sweet sorghum). Sweet sorghum malt showed higher diastatic power and contained amyloglucosidase absent in non-sweet sorghum malt. Germinating sorghum for 4 days yielded the best quality malt with the highest diastatic power and the best fermentable worts.

1. INTRODUCTION

Sorghum has been acknowledged as a feasible alternative substrate to barley for beer brewing, particularly in the tropics (Owuama, 1999). And because sorghum lacks gluten, it can be used to brew beer which is safe for consumption by celiacs (allergic to gluten present in barley) (Cela et al., 2020). In Nigeria, farmers have over several years cultivated improved sorghum varieties in large scale to satisfy brewery industry demands for sorghum and consequently reduced large amounts of valuable foreign exchange reserves spent on importing barley malt. Presently, large quantities of non-sweet sorghum varieties (*Sorghum vulgare*), are used as unmalted adjuncts for brewing beer and stout, and little attention has been paid to malts from sweet sorghum varieties (*Sorghum bicolor*

[L] Moench). Customarily, sweet sorghum varieties are cultivated in limited quantities in Northern Nigeria, usually close to farmer's residence, and commonly harvested for their sugary stalks and consumed. Although, extensive literature exists on large scale commercial cultivation of sweet sorghum cultivars, importance has been placed on their sugary stalks usually exploited for bioenergy and ethanol production (Regassa & Wortmann, 2014). Sorghum cultivars with acceptable malt quality such as, diastatic power, malting loss, water extracts, soluble protein and total soluble nitrogen are desirable for brewing beer (Owuama, 1999). Recently, it has been shown that malts of certain *Sorghum bicolor* [L] Moench varieties possess diastatic power comparable to some barley malts. Also, variations have been observed in levels and types of malt carbohydrase activity (viz., alpha amylase, beta amylase and amyloglucosidase [AMG]/glucoamylase/γ-amylase activities) present in *Sorghum bicolor* and *Sorghum vulgare*. Malts of *S. bicolor* unlike *S. vulgare* have been shown to exhibit AMG (comprising limit dextrinase and α-glucosidase) activity which enhances diastatic power (Owuama, 2019). Specifically, limit dextrinase and α-glucosidase are known to have synergistic activity with β-amylase and α-amylase respectively, in solubilizing starch and yielding glucose (MacGregor, Bazin, Macri, & Babb, 1999; Presečki, Blažević, & Vasić-Rački, 2013; Zhang, Dhital, & Gidley, 2013). It has been shown that starch from sweet vis-à-vis non-sweet sorghum varieties have larger granules, lower amylose content, higher water solubility index, starch particles with smooth surface and small dents. But, starch particles in grain sorghum are smooth without dents and have higher swelling power than sweet sorghum varieties (Ahmed, Zhang, & Liu, 2016).

The search for sorghum cultivars with greater potential for brewing and optimising malting conditions to yield high quality malt is a continuous process. During malting, hydrolytic enzymes responsible for partial degradation of the cell walls, starchy endosperm and storage protein are produced by the grain at the germination stage (Osman et al., 2002). Malts with high levels of diastatic enzymes are desirable and yield increased reducing sugar levels in wort and enhance its fermentability (Okoli, Okolo, Moneke, & Ire, 2010). Germination time during malting and grain variety are known to influence malt quality (Jaeger, Zannini, Sahin, & Arendt, 2021). Optimization of the germination period and identification of sorghum varieties with desirable grain characteristics are therefore necessary for producing high quality malt. This work therefore assesses the influence of germinating periods on malt quality including diastatic power, α-, β- and γ-amylase activities, malting loss, cold and hot water extracts, total nitrogen and protein contents, and wort characteristics of improved sweet sorghum (*Sorghum bicolor* [L] Moench) varieties and non-sweet sorghum (*Sorghum vulgare*) varieties.

2. MATERIAL AND METHODS

2.1.Sorghum Varieties

Three sweet sorghum varieties, sweet 'Bakin samadu' (SBS), Sweet Farin Masakwa (SFM), and sweet Jan samadu (SJS); and 2 non-sweet sorghum varieties, Farin dawa (FD) and Jan dawa (JD) were obtained from sorghum farms in Adamawa and Bornu States, Nigeria.

2.2. Steeping and Germination

Grains were initially screened to remove broken or damaged kernels and foreign materials and then surface sterilized by immersing them in sodium hypochlorite (3.5%) for 5 min. Thereafter the grains were drained of the disinfectants and then washed 3 times with distilled water (Owuama & Adeyemo, 2009). Grains of sweet and non-sweet sorghum cultivars were steeped for 20 h in water, germinated for periods of 2, 3, 4, 5 and 6 days at 30 ℃. Green malts were kilned and percentage malting loss determined as described by Owuama and Asheno (1994).

2.3. Grain, Malt and Wort Analyses

- Germination Energy, Germination Capacity and Water Sensitivity were Determined using a Modification (I.E. At 30 ℃) Of ASBC Method (Anon, 1997).

- Percentage Vegetative Malting Loss Was Calculated as Described by Owuama (2019).

Total nitrogen content of malt was determined using Kjeldahl method and protein content was obtained by multiplying the nitrogen content by 6.25.

- Cold water extract (CWE) and Hot water extract (HWE) were determined as described by Owuama (2019).
- Determination of diastatic power, alpha amylase activity, beta-amylase activity and amyloglucosidase activity were determined by slight modifications of diastatic method as described in Owuama (2019).
- Wort was prepared and analysed as described (Owuama, 2019). Reducing and total sugars were determined using Lane and Eynon constant volume technique. Non-reducing sugars were obtained by subtracting the reducing sugars from the total sugars. Percentage wort yield (as is) was determined as described by Taylor and Daiber (1988) while percentage wort yield (dry basis) was determined as described by Owuama (2019).
- Total soluble nitrogen content was determined using the Kjeldahl method. Protein content was determined by multiplying the total nitrogen value by a factor of 6.25. Tannin content was determined as described by Swain (1979).

3. RESULTS

The results in this work are the mean values of three separate experiments. In Table 1, grain characteristics of three sweet sorghum varieties (SBS, SFM and SJS) and two non-sweet sorghum varieties (FD and JD) revealed differences in 1000-grain weights (16.7–36.5 g) and moisture contents (10–12.6 %). Except for SBS grains (possessing recalcitrant husk) with germination energy and germination capacity of 70 and 70.6 % respectively, the values for the rest of the cultivars were within 96.0–99.3% and 97.0–99.3% respectively. Analyses of the sorghum grains revealed the following values for water sensitivity (0–22.4 %), nitrogen content (1.5–2.1 %), protein content (9.4–13.1 %) and tannin content (0.21–0.63). Tannin contents of sorghum varieties varied with pigmentation viz., light maroon >orange >brown >white Table 1.

Table 1. Grain properties of different sweet sorghum varieties and sorghum varieties.

Characteristics	Sorghum varieties				
	SBS	**SFM**	**SJS**	**FD**	**JD**
Grain pigmentation	**Brown**	**White**	**Light maroon**	**White**	**Orange**
1000 grain wt.(g)	25.8	36.5	16.7	35.2	32.9
Moisture content (%)	12.6	10.6	12.0	12.0	10.0
Germination energy (%)	70.0	98.3	96.0	98.7	99.3
Germination capacity (%)	70.6	99.0	97.0	98.7	99.3
Water sensitivity (%)	22.4	1.0	6.7	0.6	0.0
Total nitrogen content (%)	2.1	2.0	1.5	1.5	1.8
Protein content (%)	13.1	12.5	9.4	9.4	11.3
Tannin content (%)	0.32	0.21	0.63	0.22	0.45

Note: SBS - Sweet sorghum 'Bakin samadu', SFM-Sweet sorghum 'Farin masakwa', SJS-Sweet sorghum 'Jan samadu', FD-Sorghum 'Farin dawa', JD-Sorghum 'Jan dawa.

Malts analyses showed increase in lengths of sprouts (plumules and radicles) in all varieties with days of germination, although differences exist in rate of increase with various sorghum varieties (Table 2). The percentage malting loss rose with the days of germination, and differed among the cultivars and ranged from 8 to 61 %. Generally, the malting loss was higher in sweet sorghum than non-sweet sorghum malts. The vegetative malting loss increased with germination days, varied with the sorghum varieties and ranged from 2.32–12.98 %, but showed no correlation with the sum of vegetative outgrowths or sprouts (radicle + plumule). The cold water extract (CWE) and hot water extract (HWE) increased from 2-day to 4-day malts and thereafter declined to 6-day malts, in all cultivars. HWE values ranged from 4.67–21.30 g and were higher than CWE (2.03–10.70 g). Largely, the sweet malt varieties had higher CWE and HWE values than the non-sweet cultivars. Percentage total nitrogen and protein contents revealed no clear variation pattern with germination days, however, the utmost values virtually occurred in 4-day malts, in all varieties. The percentage tannin contents (0.11–0.56 %) of malts were less than those in the grains and varied among the cultivars from different days, though showed no definite discrepancy pattern.

Table 2. Malt characteristics of five sorghum varieties germinated for 2 to 6 days.

Days	Sorghum Variety	Rootlet/ Plumule lengths (cm)	Malting loss (%)	VML (%)	CWE (g/100g)	HWE (g/100g)	TN (%)	Protein (%)	Tannin (%)
2	SBS	2.64±0.5 (0.49±0.3)	08	3.26	5.67	8.00	2.38	14.88	0.28
	SFM	3.31±0.1 (0.41±0.1)	06	2.32	5.67	8.40	1.40	8.75	0.21
	SJS	2.34±0.5 (1.33±0.4)	07	4.83	4.60	8.30	0.70	4.37	0.56
	FD	1.47±0.4 (0.35±0.1)	10	5.51	3.67	7.73	1.98	12.25	0.26
	JD	1.87±0.2 (0.42±0.2)	06	2.35	2.67	6.33	1.82	11.38	0.19
3	SBS	4.12±1.7 (1.02±0.3)	17	4.81	7.67	10.20	1.96	12.25	0.18
	SFM	5.26±0.7 (0.98±0.3)	11	5.60	8.30	13.00	1.26	7.87	0.18
	SJS	5.56±1.9 (1.95±0.6)	16	8.30	7.20	10.30	1.54	9.63	0.38
	FD	3.88±1.2 (1.36±0.4)	15	7.95	6.00	10.90	1.68	10.50	0.16
	JD	3.15±1.0 (1.19±0.4)	16	5.90	5.67	8.67	1.40	8.75	0.27
4	SBS	5.23±1.0 (2.54±0.6)	22	7.69	9.60	15.90	2.80	17.50	0.29
	SFM	5.34±0.9 (1.70±0.7)	14	6.97	10.70	21.30	1.54	9.63	0.11
	SJS	6.76±1.6 (2.94±0.7)	21	9.49	8.60	17.23	2.52	15.75	0.21
	FD	4.38±1.4 (2.41±0.7)	18	8.53	8.23	17.33	1.96	12.25	0.16
	JD	3.94±1.7 (1.83±0.4)	17	10.84	6.67	13.67	2.10	13.13	0.22
5	SBS	5.58±0.7 (3.21±0.4)	37	9.30	7.30	9.83	2.80	17.51	0.23
	SFM	6.71±2.5 (1.89±0.6)	23	7.79	7.30	10.50	2.10	13.13	0.20
	SJS	7.50±2.1 (3.12±0.9)	30	10.40	6.56	11.33	1.12	7.00	0.43
	FD	4.56±0.5 (3.06±0.3)	20	9.50	5.90	9.46	0.90	5.63	0.20
	JD	4.03±0.6 (2.32±0.3)	22	11.30	4.30	6.67	1.54	9.63	0.17
6	SBS	7.21±0.7 (4.35±0.3)	41	10.25	3.30	6.56	2.13	13.31	0.17
	SFM	8.81±2.1 (2.79±0.6)	24	9.20	3.80	6.67	1.72	10.75	0.43
	SJS	8.55±2.4 (3.51±0.8)	47	11.43	4.03	6.67	1.34	8.38	0.21
	FD	6.25±0.8 (5.42±0.8)	21	10.00	2.30	6.20	0.76	4.75	0.39
	JD	5.51±0.5 (4.02±0.6)	23	12.98	2.03	4.67	1.64	10.25	0.19

Note: SBS - Sweet sorghum 'Bakin samadu', SFM-Sweet sorghum 'Farin masakwa', SJS-Sweet sorghum 'Jan samadu', FD-Sorghum 'Farin dawa', JD-Sorghum 'Jan dawa'. R – Rootlet, P – Plumule (in parenthesis), VML – Vegetative malting loss, CWE – Cold water extract, HWE – Hot water extract. TN – Total nitrogen.

Analyses of the malts carbohydrase (Table 3), revealed a rise in diastatic power (DP) in both sweet and non-sweet sorghum cultivars from day-1 to day-4 malts followed by a declined to day-6 malts. Malt DP of sweet sorghum varieties were higher than those of non-sweet varieties. The highest diastatic powers were detected in 4-day malts from SBS (142.1 L) and SJS (142.8 L) varieties. Higher DP was recorded in non-sweet sorghum 4-day malt of FD (119.6 L) than JD (115.7 L) variety. Malts of sweet sorghum varieties revealed the presence of α-, β- and γ-amylase activities while only α- and β-amylase activities were observed in non-sweet cultivars. DP of the sweet sorghum malts were virtually the sum of α-, β- and γ-amylase activities while those of non-sweet cultivars were approximately the sum of α- and β-amylase activities. Activities of α- and β-amylases values differed among all the varieties and rose from day-2 to day-4 malts and thereafter reduced to day-6 malts.

In Table 4, reducing sugars and total sugars of the worts differed among the sweet (SBS, SFM and SJS) and non-sweet (FD and JD) sorghum varieties. In both the sweet and non-sweet sorghum cultivars, the reducing and total sugars increased from day-2 malts to day-4 malts and then decreased till day-6 malts. However, worts from sweet sorghum varieties had more reducing sugars (5.43–10.44 mg/ml) and total sugars (7.52–13.97 mg/ml) than non-sweet sorghum varieties with reducing sugars of 3.05–6.28 mg/ml and total sugars of 4.89–9.57 mg/ml. Wort-yields fell between 43.9 and 68.7 %, also increased from day-2 to day-4 malts and then reduced to day-6 malts in all varieties. Tannin contents in worts of 2- to 6-day malts varied, ranged from 0.02–0.10 % and were lower than those in malts, while the wort pH varied from 5.1 to 6.7. However, the pH of the worts of sweet varieties were generally slightly higher than those of the non-sweet cultivars. The percentage total soluble nitrogen and protein contents of worts derived from 2- to 6–day malts, differed with sorghum varieties and showed no distinct change pattern.

Table 3. Characteristics of malt carbohydrase from five sorghum varieties germinated for 2 to 6 days.

Days	Sorghum Varieties	Diastatic power (as is)	Diastatic power (dry basis)	α-Amylase (as is)	α-Amylase (dry basis)	β-Amylase (as is)	β-Amylase (dry basis)	γ-Amylase (as is)	γ-Amylase (dry basis
2	SBS	125.9	130.1	80.8	83.5	26.5	26.4	16.0	16.5
	SFM	126.3	129.3	80.6	82.5	25.5	27.1	16.3	16.7
	SJS	130.9	137.6	84.7	89.0	27.1	28.5	16.1	16.9
	FD	103.3	109.7	78.2	83.0	23.9	25.4	ND	ND
	JD	103.5	105.9	78.1	79.9	23.9	24.5	ND	ND
3	SBS	138.1	145.1	88.0	92.4	28.9	30.4	18.3	19.2
	SFM	135.5	143.5	86.2	91.3	27.8	29.2	19.1	20.2
	SJS	134.8	147.0	87.3	95.2	28.7	31.3	18.8	20.5
	FD	111.4	121.0	83.6	90.8	27.8	30.2	ND	ND
	JD	111.1	118.1	82.8	88.0	27.6	34.9	ND	ND
4	SBS	142.1	153.9	92.6	100.3	29.8	32.3	19.0	20.6
	SFM	138.1	146.9	87.7	94.3	28.8	30.9	20.6	22.1
	SJS	142.8	157.8	90.9	100.4	29.9	33.0	21.3	23.5
	FD	119.6	130.8	88.8	97.0	28.4	31.0	ND	ND
	JD	115.7	129.8	87.1	97.7	27.8	31.2	ND	ND
5	SBS	132.9	146.5	84.8	93,5	28.1	30.9	18.3	20.2
	SFM	134.0	145.3	84.7	91.9	27.1	29.4	18.2	19.7
	SJS	133.6	149.1	85.9	95.8	27.8	31.0	18.3	20.4
	FD	107.1	118.3	80.3	88.7	26.3	29.1	ND	ND
	JD	108.2	122.3	79.1	89.4	23.8	26.9	ND	ND
6	SBS	128.6	143.3	81.9	91.3	27.2	30.3	17.3	19.3
	SFM	128.2	141.2	81.9	90.2	26.4	29.1	17.2	18.9
	SJS	131.9	148.9	84.9	95.9	27.5	31.1	17.5	19.8
	FD	105.7	117.4	79.7	88.6	24.6	27.3	ND	ND
	JD	104.6	120.2	77.2	88.7	23.5	27.0	ND	ND

Note: SBS - Sweet sorghum 'Bakin samadu', SFM-Sweet sorghum 'Farin masakwa', SJS-Sweet sorghum 'Jan samadu', FD-Sorghum 'Farin dawa', JD-Sorghum 'Jan dawa'.

Table 4. Characteristics of worts from five sorghum varieties germinated for 2 to 6 days.

Days	Sorghum Variety	pH	Reducing sugars (mg/ml)	Total sugars (mg/ml)	Wort yield (as is) %	Wort yield (dry basis) %	TSN (%)	Protein (%)	Tannin (%)
2	SBS	6.5	5.43	7.52	43.9	76.6	0.56	3.5	0.08
	SFM	6.7	5.49	7.86	58.6	75.7	0.14	0.9	0.04
	SJS	6.1	5.81	7.94	47.8	78.8	0.70	4.4	0.08
	FD	5.9	3.36	5.02	52.8	78.9	0.84	5.3	0.04
	JD	6.7	3.12	5.14	47.9	76.8	0.50	3.1	0.03
3	SBS	6.1	8.17	9.78	49.2	85.4	0.14	0.9	0.10
	SFM	6.3	8.11	10.48	61.8	77.2	0.28	1.8	0.09
	SJS	6.4	6.32	9.42	55.0	83.4	0.42	2.6	0.08
	FD	6.2	5.26	8.02	58.2	96.6	0.56	3.5	0.09
	JD	5.7	5.34	7.67	58.9	83.1	0.42	2.6	0.02
4	SBS	6.2	8.65	10.17	59.1	90.5	0.28	1.8	0.04
	SFM	6.3	10.44	13.97	67.4	87.3	0.56	3.5	0.02
	SJS	6.0	8.98	10.78	60.1	88.9	0.14	2.6	0.04
	FD	6.7	6.28	9.57	68.7	91.4	0.70	4.4	0.03
	JD	6.2	5.63	7.83	61.8	90.8	0.63	3.9	0.08
5	SBS	6.2	7.96	9.62	46.6	83.7	0.70	4.4	0.06
	SFM	6.1	7.55	9.47	57.1	77.3	0.14	2.6	0.10
	SJS	6.1	6.48	8.61	49.3	82.4	0.56	3.5	0.05
	FD	6.0	5.35	7.73	54.8	83.2	0.28	1.8	0.06
	JD	5.1	5.08	7.43	56.1	83.8	0.21	1.3	0.09
6	SBS	6.7	5.32	7.34	43.9	75.8	0.84	5.3	0.06
	SFM	6.5	5.38	7.83	56.2	74.2	0.42	2.6	0.03
	SJS	6.7	5.41	7.88	46.3	77.4	0.28	1.8	0.07
	FD	6.5	3.18	4.89	51.3	76.1	0.14	2.6	0.05
	JD	6.3	3.05	4.93	46.0	74.8	0.28	1.8	0.04

Note: SBS - Sweet sorghum Bakin samadu, SFM-Sweet sorghum 'Farin masakwa', SJS-Sweet sorghum 'Jan samadu, FD-Sorghum 'Farin dawa', JD-Sorghum 'Jan dawa, TSN – Total soluble nitrogen.

4. DISCUSSION

The differences in thousand grain weight, moisture content, germination energy, germination capacity, protein and tannin content among sweet and non-sweet sorghum cultivars could be attributed to variations in physiology, physicochemical structure in endosperm starch, storage conditions, age and maturity of the grains (Ahmed et al., 2016; Bekele, Bultosa, & Belete, 2012; Owuama, 1999) and compare favourably with the report of Ogbonna, Obi, and Okolo (2003). Also, variations in the rate of increase in lengths of sprouts of all sorghum varieties with days of germination (Table 2) is attributable to physiological and physicochemical differences among the cultivars. Except for the SBS variety (grains largely covered with recalcitrant husks), which had germination energy and germination capacity of about 70 %, those of other varieties fell within the acceptable limits (>90 %) for producing brewing malt (Agu & Palmer, 2013).

The dissimilarity in tannin content (0.21 to 0.63%) among grains of the sorghum cultivars with different pigments (light maroon>orange>brown>white) closely resembles 0.25 – 0.67 % observed by Osuntogun, Adewusi, Ogundiwin, and Nwasike (1989) and for the malts, largely fall within 0.1 -0.6 % reported by Stellah, Ivan, and Yusuf (2021). Tannin [tannic acid] contents among the sorghum varieties is known to differ (light coloured<dark coloured sorghum) with concentration of condensed tannins (proanthocyanidins) in the pigmented grain testa (Chavan, Kadam, & Beuchat, 1989; Dykes, 2019). However, sorghum seed colour has been shown to be a poor indicator of tannin content (Boren & Waniska, 1992). The general decrease in tannin content from grain to malt (i.e. grain>malt) is consistent with earlier reports (Ogbonna, Abuajah, Ide, & Udofia, 2012; Osuntogun et al., 1989). Tannin content has been shown to decrease during malting of sorghum (Keyata, Tola, Bultosa, & Forsido, 2021). However, it is unclear why a further tannin decrease was observed in wort, perhaps the mashing pH, temperature and enzymic activities may be contributory (Ojo, 2022).

The increase and disparity in malting loss (ML) and vegetative malting loss (VML) with germination periods in all sorghum varieties (Table 2), are due to losses from metabolism during germination and the outgrowth of sprouts, and perhaps varietal differences in physiological activities and starch-protein structure in endosperm (Ahmed et al., 2016; Owuama, 2019; Wong et al., 2009). Nevertheless, the malting losses which are considerably low and fall within acceptable range, compare favourably with values in earlier reports (Owuama & Asheno, 1994; Subramanian, Rao, Jambunathan, Murty, & Reddy, 1995). Low malting loss and high diastatic power are usually desirable for brewing malt as more carbohydrates are available for conversion into sugars by diastatic enzymes during mashing (Agu & Palmer, 2013). All grains of the sorghum cultivars revealed less than 30 % water sensitivity, thus indicating that they were not water sensitive and as such did not require air rest time during steeping (Owuama, 2021).

The largely higher HWE and CWE in malts of sweet than non-sweet sorghum cultivars from all germination periods, with HWE values 1.5 to 3.0 fold of CWE, can be attributed to higher enzyme activity in sweet sorghum malts (see Table 3), and are comparable with the report by Owuama (2019). Highest extracts observed in 4-day malts indicate adequate modification for the germination period. Insufficient modification has been shown to cause low extract yields and low fermentability (Osman et al., 2002). However, the correlation between subsequent decrease in extracts from 5-day and 6-day malts, and increase in malting and vegetative losses (Table 2) are consistent with earlier report (Jaeger et al., 2021).

Total nitrogen contents in malts were generally higher than in grains apparently due to proteolytic activity (endoproteases and carboxypeptidases) during germinations that hydrolysed proteins interlocked with starch in the endosperm and released nitrogen (Wong et al., 2009). The generally higher sugar, protein and total nitrogen contents, and malting loss in 4-day malts of sweet sorghum than non-sweet sorghum reflect higher carbohydrase activity and perhaps higher proteolytic activity in 4-day malts (Bekele et al., 2012; Owuama, 2021). The variation in protein contents of the malts from both the sweet and non-sweet sorghum varieties with germination, showed no distinct pattern between and within the varieties apparently due to differences in their physiology and levels of modification during germination (Wong et al., 2009).

The increase in diastatic power (DP), α-, β- and γ-amylase activities in sweet sorghum malts and only DP, α-, β-amylase activities in malts of non-sweet sorghum varieties from 2 to 4 days of germination, and thereafter a decrease through 5- to 6-day malts, indicate physiological differences between sweet and non-sweet sorghum cultivars, and that 4-day malts had the highest diastatic activities with the best modification (Jaeger et al., 2021). The detection of γ-amylase activity in sweet sorghum malt unlike non-sweet sorghum malt is consistent with earlier report by Owuama (2019) and may account for higher diastatic power in sweet sorghum malts due to its synergistic activity with α- and β-amylases (Presečki et al., 2013; Zhang et al., 2013). Invariably, higher diastatic power in sweet sorghum vis-à-vis non-sweet sorghum varieties resulted in greater starch hydrolysis and higher reducing sugars (Dewar, Taylor, & Berjak, 1997). The 4-day malts showed the highest diastatic activity in all sorghum cultivars and consequently worts derived from mashing the malts gave utmost wort yields and reducing sugars from sweet sorghum at pH 6.0-6.3 close to the optimum for sorghum beta amylases (Coulibaly, N'guessan, Alloue-Boraud, & Djè, 2014; Owuama. & Okafor, 1990).

The variations in reducing sugars increased in worts of different sorghum varieties from 2- to 4-day malts (ca 70 to 80 % of total sugars) and non-reducing sugars (ca 20 to 30 % of total sugars), and subsequent decrease through 5- to 6-day malts (Table 4). *These can be attributed to cultivar differences in the structure of starch granules, extent of modification of their malts and physiological variations which influences the activity of hydrolytic enzyme (particularly amylases)* (Ahmed et al., 2016; Osman et al., 2002; Wong et al., 2009).

In conclusion, the grains of *S. bicolor* and *S. vulgare* cultivars varied in their physiognomy and physiological properties. Grain pigmentation differed within and between varieties and their tannin values decreased with malting and mashing. *S bicolor* malts showed greater malt extracts (CWE and HWE) and malting loss than *S. vulgare*. The malts of sweet sorghum (*Sorghum bicolor*) varieties, in addition to containing AMG which is absent in non-sweet varieties, exhibited higher diastatic power, α-, and β-amylase activities than non-sweet sorghum (*Sorghum vulgare*) varieties, as well as yielded higher reducing and total sugars in their worts. However, the 4-day malts in both sweet and non-sweet varieties revealed the highest malt extracts, diastatic activity, reducing and total sugars, and wort yields. Between the sweet and non-sweet varieties studied, the sweet sorghum varieties produced better quality malts than non-sweet varieties, thus has greater potential for beer brewing.

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