11-2010

Water and Fertilizer Influence on Sorghum Grain Quality for Traditional Beer (Dolo) Production in Burkina Faso

S. Palé
Intitut de l'Environnement et de Recherches Agricoles (Burkina Faso), siebout.pale@yahoo.fr

S. J.B. Taonda
Intitut de l'Environnement et de Recherches Agricoles (Burkina Faso)

B. Bougouma
2Institut de Recherches en Sciences Appliquées et Technologie (Burkina Faso)

Stephen C. Mason
University of Nebraska - Lincoln, smason1@unl.edu

African Journal of Food Science Vol. 4(11), pp. 723 - 734, November 2010
Available online http://www.academicjournals.org/ajfs
ISSN 1996-0794 ©2010 Academic Journals

Full Length Research Paper

Water and fertilizer influence on sorghum grain quality for traditional beer (*dolo*) production in Burkina Faso

S. Palé[1]*, S. J. B. Taonda[1], B. Bougouma[2] and S. C. Mason[3]

[1]Intitut de l'Environnement et de Recherches Agricoles, 04 B. P. 8645 Ouagadougou 04, Burkina Faso.
[2]Institut de Recherches en Sciences Appliquées et Technologie, 03 B. P. 7047 Ouagadougou 03, Burkina Faso.
[3]University of Nebraska-Lincoln, Department of Agronomy and Horticulture, 279 Plant Science, P. O. Box 830915, Lincoln, NE 68583-0915, USA.

Accepted 3 October, 2010

In the Central Plateau of Burkina Faso, grain sorghum [*Sorghum bicolor* (L.) Moench] is the major cereal crop used to produce the traditional beer called *dolo*. Grain sorghum grain samples collected in 2004 and 2005 from experiments combining five water management techniques and four fertilizer treatments in a randomized complete block design with a split plot arrangement of treatments were analyzed for the physicochemical properties of raw grain, and quality of malted grain. Water management techniques were allocated to main plots and fertilizer treatments to subplots. The objective was to determine the best combination of water management technique and fertilizer treatment to optimize grain quality of the red grain sorghum varieties IRAT9 and ICSV1001 (Framida) for *dolo* production. Results showed that the grain physicochemical properties and malt quality of the two varieties were influenced by both water management technique and fertilizer treatment. Pearson correlations indicated that grain yield was rarely correlated with the physicochemical properties of raw grain and malt quality parameters. Diastatic power was positively correlated with protein concentration and malting losses, but negatively with tannin concentration. Based upon results, recommendation for the production of sorghum grain and malt with the needed characteristics for high *dolo* quality would be the use of water management techniques that sufficiently improve soil water conditions in combination with a microdose + 20 kg P ha^{-1} + 30 kg N ha^{-1} fertilizer application that provides sufficient nutrients and particularly nitrogen to the crop.

Key words: Diastatic power, malting losses, starch, tannins, tie-ridging technique, Burkina Faso, zaï technique.

INTRODUCTION

Grain sorghum [*Sorghum bicolor* (L.) Moench] originated in Africa and India, and has historically been one of five major world cereal crops [along with rice (*Oryza sativa L.*), maize (*Zea mays L.*), wheat (*Triticum aestvum L.*) and pearl millet (*Pennisetum glaucum (L.) R. Br.*)] used as human food. Grain sorghum, along with pearl millet, constitutes the staple cereal of millions of people living in the very hot, drought-prone tropical regions in West Africa and India (Maunder, 2002). In addition to its use as food, grain sorghum is used as feed for animals and feedstock for ethanol, mainly in the western hemisphere. The primary quality criterion of selection of sorghum varieties for traditional beer is their potential to produce malt with high *alpha*- and *beta*-amylase activities (Taylor and Dewar, 2001). Red sorghum grain generally has higher amylase activities than white grain which likely explains the preference of red grain sorghums for *dolo*

*Corresponding author. E-mail: siebout.pale@yahoo.fr. Tel: +226 70 33 11 64. Fax: (226) 50 34 02 71.

Abbreviations: ANOVA, analysis of variance; **DM,** dry matter; **DMSO,** dimethyl sulfoxide; **DNS,** dinitrosalicyclic acid; **DP,** diastatic power; **FT,** fertilizer treatment; **INERA,** institut de l'environnement et de recherches agricoles; **INTSORMIL,** international sorghum and millet collaborative research program; **IRSAT,** institut de recherches en sciences appliquées et technologies; **NF,** norme française homologuée; **TML,** total malting losses; **WMT,** water management technique.

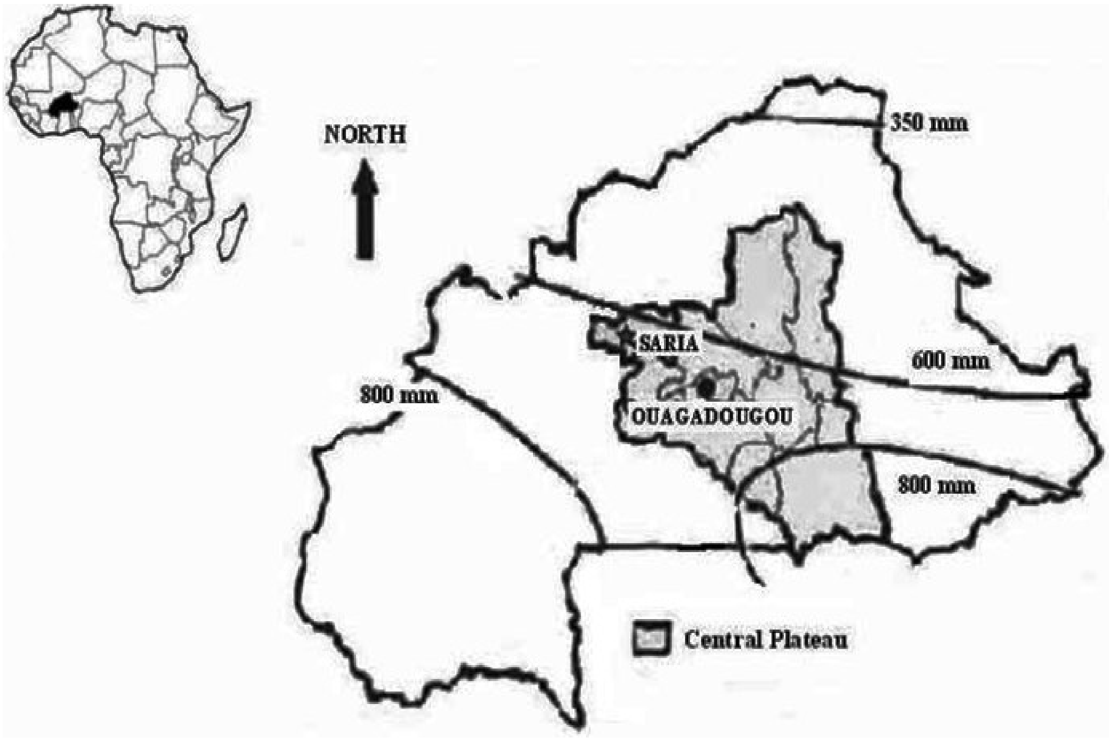

Figure 1. Map of Burkina Faso showing the Central Plateau and Saria (study site). Source: Remote Sensing and Geographical Information Unit (CTIG)/Environmental and Agricultural Research Institute (INERA), 2009. Ouagadougou, Burkina Faso: CTIG/INERA.

production (Dicko et al., 2006). In Burkina Faso, especially in the Central Plateau Region, red grain sorghum is the major cereal crop used to produce the traditional *dolo* beer.The use of grain sorghum in *dolo* production requires a constant economic supply of high quality grain which can be achieved through better cropping practices. In previous studies in Burkina Faso, white and red grain sorghum varieties have been assessed for grain quality for malting and brewing with Framida and IRAT9 (two red grain sorghum varieties) being identified as having the best grain qualities for *dolo* production (Bougouma, 2002). Other studies have determined the influence of water management techniques (WMT) and fertilizer treatments (FT) on grain yield and yield components (Palé et al., 2009), and malt and traditional beer (*dolo*) producer and consumer preferences for *dolo* quality (Palé et al., 2010). The objective of this study was to identify the best combination of WMT and FT to produce optimal quality of Framida and IRAT9 for *dolo* production. High quality grain will improve the brewing processes, and thus *dolo* quality. Meeting this objective would further increase the economic potential of sorghum in Burkina Faso and neighboring countries since a commercialized traditional product has a greater chance of being popular and culturally acceptable than an exotic or novel product (Murty and Kumar, 1995).

MATERIALS AND METHODS

Study site

The study was conducted at the Saria Agricultural Research Station (12° 16’ N lat; 2° 09’ W long) in the Central Plateau of Burkina Faso (Figure 1). The Central Plateau of Burkina Faso is a semi-arid, low yield potential area typical of the Sudanian belt of Sahelian West Africa. The area has a tropical climate with a dry season from November to April and a rainy season from May to October. It is characterized by 600 to 800 mm yr^{-1} rainfall and production of low yields of sorghum and pearl millet (Sanders et al., 1996). The soil type at the Saria Agricultural Research Station was a Ferric Lixisol (FAO-UNESCO, 1994).

Field work

To optimize grain quality of ICSV1001 (Framida) and IRAT9 for traditional beer production, two experiments combining different soil water management techniques (WMT) and fertilizer treatments (FT) were conducted under rain fed conditions on separate (about 400 m apart) fields to avoid crossing and allow pure grain production for each of the varieties. One of the fields was planted with Framida and the other with IRAT9, thus no statistical comparison between the sorghum varieties was possible. Framida has a relative maturity of 120 days and IRAT9 of 100-110 days (Chantereau and Nicou, 1991). Field history indicated that the Framida experimental field had been fallowed for 4 years and the IRAT9 experimental field for 10 years before initiating the experiments.

Soil WMT and FT treatments were studied in a randomized complete block design with a split-plot arrangement of treatments

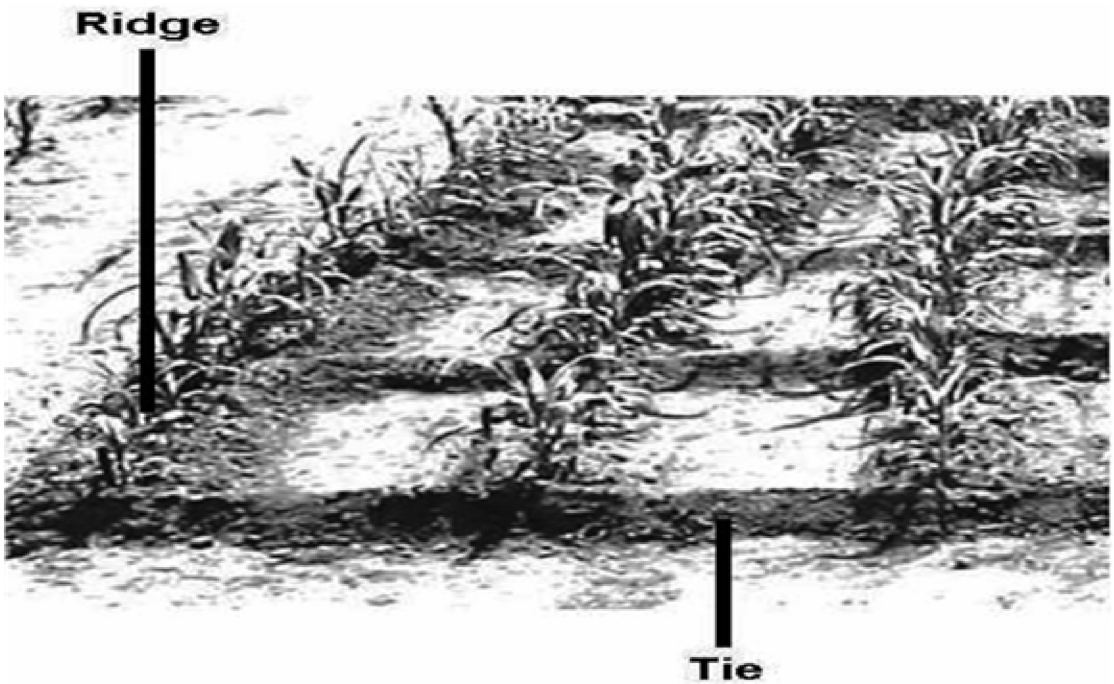

Figure 2. Tie-ridging technique (Ridge : made along the planting rows ; Tie : made at 1 m distance and tying ridges).

Figure 3. Zaï technique (Hole of zaï : sorghum plants are in the holes of the zaï).

with four replications in both experiments. The main plots were WMT and the sub-plots were FT. The treatments were applied to the same experimental units in each field in both years.

Five soil water management techniques were applied in the main plots:

1. Scarifying (or shallow cultivation) using a Manga hoe, which is an animal drawn tool. This practice is commonly used by farmers in the study area and was used in this study as the control.
2. Tied ridges. Ridges were made before planting along the planting rows (Figure 2). Ties were made at 1 m distance one month after planting, using an animal drawn ridger. The average height was 0.22 m for the ridges and 0.19 m for the ties, and the average width was 0.33 m for the ridges and 0.25 m for the ties.
3. Manual zaï (Figure 3) without organic fertilizer was done using a traditional hoe. The average dimensions of the hole estimated after making the zaï were 0.28 m diameter and 0.12 m depth.
4. Mechanized zaï without organic fertilizer done by crossing the

planting rows (consecutive and within) using an IR12 [reversible tool implemented by the Environmental and Agricultural Research Institute (INERA)], which is an animal drawn tool, and then removing the soil in the 2-row intersection. This tool can penetrate the soil up to 0.10 m and cuts the soil into clods, thus increasing water infiltration and improving the soil moisture content at the beginning of the rainy season (Barro et al., 2005). The dimensions of the hole of this zaï were 0.25 m diameter and 0.10 m depth.

The traditional (conventional) "zaï" treatment consists of digging holes in the ground with a diameter of 0.20 - 0.30 m and a depth of 0.05 - 0.15 m during the dry season, putting organic matter-compost or dung into them and covering them up with a thin layer of soil. The dug-out soil is deposited downstream of the hole that will trap organic matter transported by the wind and water. Sowing is done in the holes. In the present study, the manual zaï and mechanized zaï did not contain compost (organic fertilizer) as in traditional zaï and they were used as soil water management techniques.

5. Dry soil tillage using the reversible tool IR12 applied only along the planting rows. In the dry soil tillage technique, the planting rows are not crossed as in the mechanized zaï.

Four fertilizer treatments were the sub-plots:

1. Control (no fertilizer).
2. Microdose (4g per hill at planting of the complex fertilizer NPK) application of 19 kg of nitrogen (N) ha^{-1}, 19 kg of phosphorus (P) ha^{-1} and 19 kg of potassium (K) ha^{-1} at planting.
3. Recommended fertilizer rate consisting of application of 11 kg N ha^{-1}, 11 kg P ha^{-1} and 11 kg K ha^{-1} as complex fertilizer NPK at planting or within one week after planting, and 23 kg N ha^{-1} as urea, applied 45 days after planting.
4. Microdose (4g per hill at planting of the complex fertilizer NPK) application of 19 kg N ha^{-1}, 19 kg P ha^{-1} and 19 kg K ha^{-1} with addition of 20 kg P ha^{-1} as triple super phosphate at planting in the planting hole, and 30 kg N ha^{-1} as urea applied 45 days after planting.

Planting was done at the recommended density of 0.80 m between rows and 0.40 m within the row (Chantereau and Nicou, 1991), which gave 31626 hills ha^{-1} with 1 or 2 plants per hill after thinning. Plots consisted of six rows, 6-m long. Planting date was July 19 in the two experiment fields in 2004. In 2005, planting date was July 12 in the Framida experiment and July 14 in the IRAT9 experiment. Weed control was done by hand hoeing as needed. In all two years, Apron® Star 42 WS, a fungicide/insecticide mixture was used to treat seeds, at a rate of 10 g for 4 kg of seed.

Laboratory analysis

Soil and water holding capacity

Soil samples were taken from each field at 0-20 cm depth before initiating the experiments. Organic carbon (C) was measured using the Walkley-Black method (Walkley and Black, 1934), total nitrogen (N) and total phosphorus (P) by the spectrophotometric method (Novozamsky et al., 1984) and pH (H_20) by potentiometric method (Baize, 1988). Soil water holding capacity (WHC) was measured on undisturbed soil samples in the laboratory by the combined methods of Hillel (1980), Mathieu and Pieltain (1998), and Wang and Benson (2004). The samples were taken in the field from 0 to 40 cm depth in the Framida field, and from 0 to 60 cm depth in the IRAT9 field, using 100 cm^3 sample rings. Soil water holding capacity was calculated using the following equation:

WHC (mm) = 1/10 x (water content at pF 2.5 - water content at pF 4.2) x BD x Z = 1/10 x AW x BD x Z,

where BD (g cm^{-3}) is the dry bulk density, Z the depth or the thickness of the soil in cm and AW (% dry weight) the available soil water. Precipitation data were collected from the Meteorological Station at the Saria Agricultural Research Station.

Grain physicochemical properties and malt quality

Grain samples were collected in 2004 and 2005 for all treatment combinations in both experiments, and analyzed for physicochemical properties of raw grain and malt quality. Samples were analyzed in triplicate for the physicochemical properties and malt quality parameters indicated by Bougouma (2002) to be the most important parameters affecting quality of sorghum grain in *dolo* production. These parameters included (1) moisture content, (2) tannin concentration, (3) starch (amylose and amylopectin) concentration, (4) total protein concentration, (5) diastatic power and (6) malting losses.

Moisture, tannin and protein concentration determination

Moisture concentration was determined by the international organization for standardization (ISO) 712 method (1998). Tannin (polymeric polyphenols) concentration was determined by the ISO 9648 method (1988). Nitrogen was determined by the French Standard of Manufacture (NF) V03 050 method (1970) and protein concentration was calculated by multiplying percent nitrogen by 6.25.

Starch and starch components determination

Five mg samples of raw grain flour ground to 0.2 mm fineness were successively defatted with hexane (grade HPLC) and ethanol (grade HPLC) and dried in the open air. The starch granules were suspended in 0.5 ml dimethyl sulfoxide (DMSO) then raised to 100°C for 45 min. After cooling, the solution was then mixed with 0.5 ml distilled water and raised to 100°C for 30 min. to gelatinize the starch. The gelatinized starch was then centrifuged at 1000 rpm for 2 min. to remove all residues in suspension. Samples of the gelatinized starch were then used for the determination of total starch and amylose by the iodine method described by Jarvis and Walker (1993). The grain starch, amylose and amylopectin concentrations were determined using wheat standard starch and amylose.

Diastatic power and malting losses

Malting procedure: Malting involves steeping of cereal grain, germination of the grain for several days in high humidity air (90 - 95% relative humidity) under controlled conditions and drying of the malt produced to obtain the required diastatic power (DP) for brewing (Novellie, 1962; Beta et al., 1995; Taylor and Dewar, 2001).

To determine DP and malting losses, samples of 25 ± 0.01 g of grain was cleaned by using a forced-air cleaner and washed three times to remove undesirable solid particles, dust and micro-organisms. The wet grain was then immersed in 150 ml of water containing a 0.5% sodium hypochlorite solution for 10 min to retard fungal growth during germination, then washed three times in running tap water and drained for 5 min to remove the residual sodium hypochlorite. Germination temperature of 30°C is required for optimal sorghum malt qualities, even though excessively high malting loss of 21.3 to 28.5% can occur at this temperature (Novellie, 1962; Agu and Palmer, 1998). The treated grain was steeped in 300 ml of distilled water at 30°C for 24 h. At the end of the steeping step, the grain was rinsed two times, drained for 5 min, and placed in small plastic bowls perforated at the bottom to ensure aeration. During malting the upper side of the bowl had an aerating hole. Germination was carried out in an incubator at 30°C for 4 days. Germinating grain was turned and watered two times a day (morning and evening) by immersion in 150 ml of distilled water for 5 min, then drained. The malt was then dried in the incubator with forced-air for 24 h at a temperature of 50°C and the primary roots and shoots were removed.

Malting loss determination: Total malting dry matter loss included losses due to respiration during germination and losses due to root and shoot removal (Novellie, 1962) and was indicated by the ratio of the weight difference before soaking and after drying of the germinated grains to that of the original grain weight. The following formula was used to determine the total malting loss (TML):

$$TML = \frac{M_1\,(1 - H_1/100) - M_2\,(1 - H_2/100)}{M_1\,(1 - H_1/100)}$$

where TML is the total malting loss, M_1 is the weight of the raw grains (in g), M_2 is the weight of the malted grains with roots and shoots removed (in g), H_1 is the moisture content of the raw grains and H_2 is the moisture content of the malted grains.

Diastatic power determination

Extraction of 0.5 g ground malt at 0.2 mm fineness was done at 40°C water bath for 1 h in 50 ml distilled water. The extracted enzymes were filtered and a 0.5 ml aliquot was added to a 0.5 ml soluble starch solution and incubated at 40°C for 30 min in 1 ml of acetate buffer at pH = 5.0. The reaction was stopped with 1 ml acid 3, 5 - dinitrosalicylic (DNS) solution prepared with 100 ml distilled water, 2 g DNS , 3.2 g NaOH and potassium sodium L (+)-tartrate and distilled water added to obtain a total volume of 200 ml. A blank containing 1 ml of DNS solution, 0.5 ml extract, 0.5 ml starch solution and 1 ml buffer solution was carried out in order to make allowance for preformed sugar that already present in the malt extract. The color was developed in a 100°C water bath for 10 min. The sample was diluted with 5 ml of distilled water and the optic density was read at wave length = 540 nm. Maltose concentrations of 0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, and 4.0 g/l were obtained in the same conditions as the sample by successive dilutions of pre-prepared solution of 0.8 g of maltose in 200 ml distilled water. A concentration curve was drawn using results from successive dilutions of the standard maltose solution. Diastatic activity was expressed as mg of maltose equivalent per g of dry weight malt per minute according to the following formula:

$$\text{Enzyme activity} = \frac{(\text{average } [Maltose\ T_{30}] - \text{average } [Maltose\ T_0]) * (D_1 * D_2)}{T_r * WS * DM}$$

where [$Maltose\ T_{30}$] is the average maltose concentration in equivalent maltose from the tests after 30 min of reaction; [$Maltose\ T_0$] is average maltose concentration in equivalent maltose in the blanks after 0 min of reaction, in mg maltose /ml, calculated based on the coefficient director of the maltose concentration curve; D_1 = volume of the extract; WS = weight (in g) of the sample extract; D_2 = dilution factor of the extract (100); DM = Dry matter content (in %) of the malt and T_r is the reaction time (30 min).

All the physicochemical properties were analyzed across years, using standard analysis of variance and pair-wised comparisons by the General Linear Model Procedure on the software SAS/STAT®, version 9.1. Pearson correlations were used to relate grain yield, malt quality parameters and physicochemical properties of the raw grain. Results were considered significant when $P \leq 0.05$.

RESULTS AND DISCUSSION

Soil and precipitation

Soil analyses indicated that the soil in the Framida field was a sandy loam (50% sand, 33% silt and 17% clay) susceptible to surface crusting. In the 0 to 0.30 m horizon, the soil in this Framida experiment had 0.5 g kg^{-1} of total N, 123 mg kg^{-1} of total P, 8 g kg^{-1} of organic C, and a pH (H_2O) of 5.6. The soil in the IRAT9 experimental field was a sandy loam (44% sand, 31% silt and 25% clay) susceptible to surface crusting. In the 0 to 0.30 m horizon, the soil in this IRAT9 experimental field had 0.6 g kg^{-1} of N, 117 mg kg^{-1} of total P, 8 g kg^{-1} of organic C, and a pH (H_2O) of 5.3. An iron hardpan limited soil depth to 0.40 m for the Framida field and to 0.60 m for the IRAT9 field. The average water holding capacities to these depths were 24 mm for the Framida field and 77 mm for the IRAT9 field. The total seasonal precipitation was 742 mm in 2004 and 736 mm in 2005, with highest rainfall from June to September and peaks occurred in July in 2004 and August in 2005; the seasonal precipitation in both years was lower than the 26-year average of 778 mm.

Grain physicochemical properties and malt quality

The analysis of variance indicated complex interaction effects for most of the measured parameters for raw grain and malt quality (data not presented). The three-way interactions seemed to have little biological meaning. For that reason, the significant two-way interactions year-by-water management, year-by-fertilizer management and water management-by-fertilizer management interactions are presented and discussed for most parameters. However, the FT main effects for amylopectin concentration of Framida and malting losses of IRAT9 are presented and discussed since interaction effects were not present.

Protein and starch

Year-by-water management interactions

In contrast to previous studies that have shown

Table 1. Pearson correlation coefficients between physicochemical properties of raw grain and malt quality parameters for grain sorghum varieties Framida and IRAT9 produced for *dolo* at Saria Agricultural Research Station, Burkina Faso, from 2004 to 2005.

	Tannin	Protein	Starch	Amylose	Amylopectin	Malting losses	Diastatic power
Framida							
Protein	0.14						
Starch	-0.41*	0.20					
Amylose	0.19	-0.02	-0.61*				
Amylopectin	-0.19	0.02	0.61*	-1.00*			
Malting losses	-0.05	0.57*	-0.02	0.25	-0.25		
Diastatic power	-0.31*	0.39*	0.27	-0.12	0.12	0.60*	
Grain yield	-0.40*	-0.22	0.29	-0.24	0.24	-0.26	0.12
IRAT9							
Protein	-0.50*						
Starch	0.00	0.01					
Amylose	-0.32*	0.00	-0.64*				
Amylopectin	0.32*	-0.00	0.64*	-1.00*			
Malting losses	-0.55*	0.53*	0.10	0.15	-0.15		
Diastatic power	-0.54*	0.57*	-0.09	0.20	-0.20	0.57*	
Grain yield	-0.06	-0.14	0.12	-0.03	0.03	0.13	-0.08

* Values significant at P = 0.05 or less (N = 40).

correlations between grain yield, protein and starch concentrations, no significant correlations were present among grain yield and these quality factors in both experiments (Table 1). These non-significant correlations can be related to the differences in the fertilizer treatments and the water management techniques that probably affected the nutrient uptake and the grain physicochemical properties and malt quality. However, a negative correlation of grain yield and grain tannin concentration was found in the Framida experiment (Table 1). Protein and starch are major components of the sorghum kernel comprising 75 to 90% of the kernel (Griess et al., 2010), and thus their concentrations are often inversely related (Calderón-Chinchilla et al., 2008; Griess et al., 2010). Starch concentration often is positively correlated to grain yield (Griess et al., 2010) and protein concentration often is negatively correlated (Kaye et al., 2007; Calderón-Chinchilla et al., 2008) to grain yield. Starch, an important biochemical component for sorghum processing (Dicko et al., 2006), is the most abundant component of the grain carbohydrates and the main source of energy during germination (Waniska and Rooney, 2000). Results from this experiment previously published (Palé et al., 2009) indicated production of higher grain yields in 2005 than in 2004 related to a better rainfall distribution in 2005 and with tied ridge water management, and with application of microdose + 20 kg P ha^{-1} + 30 kg N ha^{-1} fertilizer.

Water management influence on grain protein concentration varied with different treatments across years, however, the tied ridge treatment produced the highest grain yields (Palé et al., 2009) and the lowest protein concentrations in both years in the IRAT9 experiment (Table 2) and in 2004 in the Framida experiment (Table 3). This inverse relationship between protein and starch concentrations has been widely documented for grain crops (Mason and D'Croz-Mason, 2002). Waniska and Rooney (2000) indicated that production of sorghum grain under ample soil water conditions increases grain starch synthesis while decreases protein concentration. The lowest protein concentrations observed with the use of tied ridge in the IRAT9 experiment (Table 2) can be attributed to the depth of the soil that ensured greater water holding capacity in both years. Data showed that scarified plots and dry soil tillage plots produced higher protein concentration of raw grain of IRAT9 in the two years (Table 2). In 2005 with lower rainfall, the use of tied ridge in the shallow soil of Framida field apparently did not allow sufficient soil water conditions to produce the lowest grain protein concentrations for this year. In 2004 the tie-ridging technique produced the lowest protein concentration (Table 3). In this Framida field, the use of mechanized zaï in 2004 and manual zaï in 2005 increased the grain protein concentrations (Table 3). Lower protein concentrations occurred when mechanized zaï was used in 2005.

Starch and its major component (amylose and amylopectin) concentration levels were quite variable, thus no differences in starch in the IRAT9 experiment and starch component concentrations in both experiments were observed in the IRAT9 experiment and only two

Table 2. Year x water management and Year x fertilizer interaction effects and fertilizer main effects on physicochemical properties of raw grain and malt quality for grain sorghum variety IRAT 9 produced for *dolo* at Saria Agricultural Research Station, Burkina Faso, from 2004 to 2005.

Water management	Protein concentration [a]		Tannin concentration [a]		Diastatic Power [b]	
	2004	2005	2004	2005	2004	2005
Scarifying	11.8a	10.2a	0.70a	0.88a	71c	38b
Tied-ridges	10.4d	8.8c	0.64d	0.84c	54d	40a
Manual zaï	11.5b	9.3b	0.66c	0.87ab	78a	36c
Mechanized zaï	10.8c	9.4b	0.68b	0.84c	73c	29d
Dry soil tillage	11.9a	10.0a	0.66c	0.86b	76b	38ab
Fertilizer						
No fertilizer	11.1b	9.31c	0.68a	0.92a	52c	29c
Microdose	10.6c	9.9a	0.66b	0.84c	70b	42a
Recommended fertilizer	11b	9.1c	0.68a	0.87b	80a	37b
Microdose + 20 P + 30 N	12.5a	9.7b	0.65c	0.79d	79a	37b

[a] Units are in % of grain dry matter weight. [b] Units are in mg of maltose equivalent per g of dry malt weight per minute. Values followed by the same letter in a column are not significantly different at P = 0.05 or less.

Table 3. Year x water management and Year x fertilizer interaction effects and fertilizer main effects on physicochemical properties of raw grain and malt quality for grain sorghum variety Framida produced for *dolo* at Saria Agricultural Research Station, Burkina Faso, from 2004 to 2005.

Water management	Protein concentration [a]		Tannin concentration [a]		Diastatic power [b]		Starch concentration [a]	
	2004	2005	2004	2005	2004	2005	2004	2005
Scarifying	13.7d	13.2b	1.18d	1.30c	103c	91b	60bc	64ab
Tied-ridges	13.5e	12.4d	1.21c	1.31b	102c	80d	65ab	58b
Manual zaï	14.4b	13.5a	1.56a	1.31b	97d	85c	52c	64ab
Mechanized zaï	15.0a	11.2e	1.30b	1.33a	123a	93a	70a	58b
Dry soil tillage	14.1c	12.7c	1.14e	1.33a	119b	76e	65ab	60a
Fertilizer								
No fertilizer	13.6c	12.5b	1.40a	1.44a	104c	76.d		
Microdose	13.8c	12.7a	1.21c	1.37b	115b	81c		
Recommended fertilizer	14.2b	12.9a	1.34b	1.31c	87d	88b		
Microdose + 20 P + 30 N	14.9a	12.2c	1.16d	1.15d	120a	94a		

[a] Units are in % of grain dry matter weight. [b] Units are in mg of maltose equivalent per g of dry malt weight per minute. Values followed by the same letter in a column are not significantly different at P = 0.05 or less.

differences in the Framida experiment (Table 3). In this Framida experiment, the higher grain starch concentrations occurred with the use of mechanized zaï in 2004 and the use of either manual zaï or scarifying in 2005 (Table 3); the grain starch concentration for the mechanized zaï was higher than for the manual zaï in 2004 (Table 3).

Year-by-fertilizer interactions

Fertilizer applications generally increased the grain protein concentrations (Tables 2 and 3), although the degree of increase was different among years and experiments. Based on previous research it was expected that the grain protein concentration would be higher in the most drought conditions with concomitant lowest yield (Mason and D'Croz-Mason, 2002; Waniska and Rooney, 2000) and highest N input in the soil (Kamoshita et al., 1998; Kaye et al., 2007). In contrast to these previous findings, results from this study indicated higher grain protein concentrations in 2004 (with higher rainfall) than in 2005 (with lower rainfall) (Tables 2 and 3). The microdose + 20 kg P ha^{-1} + 30 kg N ha^{-1} was the treatment with the highest N application, and produced the highest grain protein concentration in both experiments in 2005, and was only 0.2 to 0.7% lower than highest grain protein concentration in 2005 in both

IRAT9 and Framida experimental fields. The year-by-fertilizer management interaction had no significant effect on the starch concentration or starch type in both experiments.

Water management-by-fertilizer interactions

Previous published results from these experiments indicated water-by-nitrogen interaction influences on sorghum grain yield (Palé et al., 2009) and protein concentration (Kamoshita et al., 1998), which were confirmed in the present study. Results indicated that fertilizer application generally increased grain protein concentration in both experiments (Tables 4 and 5). The microdose + 20 kg P ha^{-1} + 30 kg N ha^{-1} treatment had the greatest N application rate, and resulted in the highest protein concentration in 2/5 WMT-FT combinations in the Framida experiment and 4/5 combinations in the IRAT9 experiment (Tables 4 and 5), suggesting that in most of the cases, WMT-FT combinations which provide sufficient nitrogen to the sorghum crop do increase the grain protein concentration. Application of microdose that resulted in the highest protein concentrations for the scarified plots in both experiments (Tables 4 and 5) can be attributed to the lower moisture conditions in these plots. Waniska and Rooney (2000) reported that higher protein concentration of grain grown under limited water conditions is the result of reduced starch synthesis. Grain with low protein and high starch (Agu and Palmer, 1998) and malt concentrations (Owuama and Asheno, 1994) have been reported to be more desirable for beer production as high protein levels lead to the formation of haze that affect the clearness of the beer produced in the brewing industries. *Dolo* is a relatively cloudy beer (Taylor, 2002) and haze is not considered to be a problem. In contrast to brewing industry beer, haze in *dolo* indicates a good texture (heavy texture) which implies high nutritional value of *dolo* related to high protein concentration. This criterion of texture was used by 43% of surveyed consumers in Burkina Faso to assess high dolo quality (Palé et al., 2010). Based upon these results, the combination of any WMT that improves soil water conditions for higher grain starch production and Microdose + 20 kg P ha^{-1} + 30 kg N that generally increases grain protein concentrations (Tables 4 and 5) would be most desirable for sorghum grain produced for *dolo*. The water management-by-fertilizer treatment interactions had no effect on the starch concentration or type of starch present in both experiments.

Tannin

Year-by-water interactions

Water management influence on grain tannin concentration varied with different water management treatments across years in both experiments (Tables 2 and 3). In the IRAT9 field and for the two years, lower production of tannin was observed in plots with higher soil water conditions and higher tannin in the scarified (control) plots with more water stress (Table 2). In this IRAT9 experiment, data indicated the lowest grain tannin concentration with the use of tied-ridge technique in the two years. In the Framida experiment, results showed the lowest tannin concentration that occurred in the dry soil tillage plots in 2004 (Table 3). The tannin concentrations generally increased in 2005 in this Framida field. These increases can be attributed to the lower rainfall of year 2005 compared to 2004.

Year-by-fertilizer interactions

Fertilizer application generally decreased the raw grain tannin concentrations while non-fertilized plots produced higher tannin concentrations in both experiments in the two years (Tables 2 and 3). Previous studies reported high levels of phenolics were associated with nutrient poor soils and slow growth rates of plants (Bryan et al., 1987). The lowest tannin concentrations occurred in plots that received microdose + 20 kg P ha^{-1} and 30 kg N ha^{-1} suggesting that fertilizers be used in grain sorghum production to improve the quality of grains for *dolo* production. In the IRAT9 experiment, tannin concentration appeared to be higher in plots that received the recommended fertilizer in 2004 (Table 2).

Water management-by-fertilizer interactions

Water management-by-fertilizer treatment interaction effects on grain tannin concentrations in both experiments varied and showed significant differences among treatment combinations (Tables 4 and 5). In both experiments, tannin generally decreased for all water management levels with application of fertilizers and the lowest decreases were observed in plots with application of microdose + additional 20 kg P ha^{-1} and 30 kg N ha^{-1} (Tables 4 and 5). Increases in tannin concentration occurred in mechanized zaï plots with application of microdose in Framida experiment (Table 4) and in scarified plots with application of microdose + 20 kg P ha^{-1} and 30 kg N ha^{-1} in IRAT9 experiment (Table 5). Tannin concentration was negatively correlated with (1) the diastatic power of the malted grain in both experiments; (2) the protein, amylose and malting losses in IRAT9 experiment and (3) the starch, total sugar and amylopectin concentrations in Framida experiment (Table 1). Germination of grains is an essential part of the malting process. Agu and Palmer (1998) indicated that ungerminated grains may be ready sources of microbial infection during malting that will affect the dolo quality.

Chavan et al. (1981) suggested that tannins are responsible for retarding the seedling growth by

Table 4. Soil water management x fertilizer treatment interaction effects on physicochemical properties of raw grain and malt quality parameters for grain sorghum variety Framida produced for dolo at Saria Agricultural Research Station, Burkina Faso, from 2004 to 2005.

Fertilizer Treatment	scarifying	Tied ridges	Manual zaï	Mechanized zaï	Dry soil tillage
		Total protein concentration (% of dry matter weight)			
Zero Fertilizer	13.5a	13.3c	11.8d	13.3b	
Micro dose	13.8a	11.9c	13.4c	14.3a	13c
Recommended rate	12.7c	12.8b	15.2a	12.5c	14.5a
Microdose + 20 P + 30N	13.8a	13.5a	13.8b	13.8b	12.7c
		Tannin concentration (% of dry matter weight)			
Zero Fertilizer	1.52a	1.64a	1.52a	1.13d	1.28b
Micro dose	1.23b	1.10c	1.47c	1.47a	1.19c
Recommended rate	1.23b	1.15b	1.50b	1.38b	1.34a
Microdose + 20 P + 30N	0.97c	1.15b	1.25d	1.28c	1.12d
		Diastatic power *			
Zero Fertilizer	81d	77d	83bc	108b	102b
Micro dose	107b	94b	83c	108b	97c
Recommended rate	86c	80c	85b	103c	82d
Microdose + 20 P + 30N	112a	113a	112a	113a	109a

* Units are in mg of maltose equivalent per g of dry malt weight per minute. Values followed by the same letter in a column are not significantly different at P = 0.05 or less.

decreasing the rate of starch and protein degradation in tannin rich seeds. The results in the two fields suggest that good water management with sufficient nutrients will reduce the grain tannin concentration and is more desirable for high malt quality and high dolo quality production.

Diastatic power and malting losses

Year-by-water interactions

Diastatic power in sorghum malt is a measure of the joint *alpha*- and *beta*-amylase activities required during brewing to hydrolyze starch into fermentable sugars. DP is probably the most important indicator of malt quality for beer brewing, although other criteria such as free amino nitrogen and resistance to mold infection are also of importance (Novellie, 1962; Taylor and Dewar, 2001). Water management influence on malted grain diastatic power varied substantially with different water management treatments across years in both experiments (Tables 2 and 3). In the IRAT9 experiment, data showed the highest diastatic power that occurred with the use of manual zaï in 2004 and the use of tied-ridges in 2005, and the lowest diastatic power produced with the use of tied-ridges in 2004 and the use of mechanized zaï in 2005 (Table 2). In the two years, the highest diastatic power production in the Framida experiment occurred in grain from plots with the use of mechanized zaï (Table 3). Results showed significant decreases in malted grain diastatic power for Framida with the use of manual zaï in 2004 and the use of dry soil tillage technique in 2005. Malting loss levels were quite variable, thus no differences in malting losses related to year-by-water interaction effects were observed in either experiment (data not presented).

Year-by-fertilizer interactions and main effects of fertilizers

Sorghum malting quality is affected by soil fertility status (or nutrient supply), particularly available nitrogen that improves the enzyme concentration and the grain protein concentration (Daiber, 1978). Beta et al. (1995) reported positive correlation of diastatic power with malting losses. Application of fertilizers and especially microdose + 20 kg P ha^{-1} + 30 kg N ha^{-1} treatments with greatest N application have produced higher grain protein concentrations. Correlations (Table 1) indicated a positive relationship between the grain protein concentration with the malted grain diastatic power and malting losses in both experiments. Thus, the increases in protein concentration would be expected to increase the diastatic power in the two years and in both experiments. The higher malting losses, influenced by fertilizer main effects in the IRAT9 experiment and particularly in microdose + additional 20 kg P ha^{-1} and 30 kg N ha^{-1} plots (Tables 2 and 3) was also expected. Results showed lower diastatic power in plots where recommended fertilizer was applied in 2004

Table 5. Soil water management x fertilizer treatment interaction effects on physicochemical properties of raw grain and malt quality parameters for grain sorghum variety IRAT9 produced for dolo at Saria Agricultural Research Station, Burkina Faso, from 2004 to 2005.

Fertilizer Treatment	scarifying	Tied ridges	Manual zaï	Mechanized zaï	Dry soil tillage
	Total protein concentration (% of dry matter weight)				
Zero Fertilizer	10.2c	9.4b	10.1c	10.4a	10.9b
Micro dose	12.3a	9.4b	10.4b	9.6b	9.5c
Recommended rate	9.8d	9.5b	10.3b	9.8b	10.8b
Microdose + 20 P + 30N	11.6b	10.0a	10.8a	10.4a	12.7a
	Tannin concentration (% of dry matter weight)				
Zero Fertilizer	0.81a	0.77a	0.85a	0.76b	0.81a
Micro dose	0.79b	0.77a	0.71c	0.75b	0.73c
Recommended rate	0.74c	0.74b	0.79b	0.81a	0.79b
Microdose + 20 P + 30N	0.81a	0.69c	0.69d	0.71c	0.70d
	Diastatic power *				
Zero Fertilizer	39d	38c	47c	25d	54b
Micro dose	59b	44b	62a	53c	61a
Recommended rate	42c	62a	59b	69a	61a
Microdose + 20 P + 30N	79a	43b	59b	57b	53b

* Units are in mg of maltose equivalent per g of dry malt weight per minute. Values followed by the same letter in a column are not significantly different at P = 0.05 or less.

in the Framida experiment. Subramanian et al. (1992) indicated that in all stages of germinating sorghum grain, no relationship was observed between the sorghum diastatic units and total sugar concentration. Our results indicated a positive correlation for raw grain total sugar concentration and malted grain diastatic power (Table 1). Malting losses in the IRAT9 experiment were higher in fertilized. Losses were 41% in microdose + additional 20 kg P ha^{-1} and 30 kg N ha^{-1} plots, 39% in microdose plots and 38% in recommended fertilizer plots. The lowest losses of 34% occurred in plots that did not receive fertilizers.

Water management-by-fertilizer interactions

Water management-by-fertilizer interaction affected malted grain diastatic power in both experiments (Tables 4 and 5). Results showed that in all water management levels combined with fertilizers, diastatic power generally increased. Data in the IRAT9 experiment showed the highest diastatic power that resulted from the combination of scarifying and microdose + additional 20 kg P ha^{-1} and 30 kg N ha^{-1} and the lowest diastatic power that occurred for all water management levels when plots were not fertilized (Table 5). Previous results published from the IRAT9 experiment (Palé et al., 2009) indicated higher yield was produced with the application of microdose + additional 20 kg P ha^{-1} and 30 kg N ha^{-1} in the five water management levels studied. In the Framida field and for all water management levels, the highest diastatic power occurred with application of microdose + additional 20 kg P ha^{-1} and 30 kg N ha^{-1} and compared to the absolute control (scarifying + no fertilizer), the increases in diastatic power ranged from 34% to 38% depending on the water management technique used (Table 4). Malting loss levels were quite variable, thus no differences in malting losses related to water management-by-fertilizer treatment effects were observed in either experiment (data not presented). Taylor and Dewar (2001) indicated that the primary quality criterion of selection of sorghum varieties for beer is their potential to produce malt with high diastatic activities. The results in the two fields suggest that appropriate water management with sufficient nutrients supplied by particularly microdose + additional 20 kg P ha^{-1} and 30 kg N ha^{-1} would result in higher malt yield with high diastatic activities to ensure high *dolo* quality.

Conclusion

Water management techniques and fertilizer treatments combinations greatly affected grain quality for *dolo* production. Bougouma (2005) suggested a diastatic power of at least 70 mg of maltose equivalent per g of dry malt weight per minute for commercially acceptable sorghum malt in Burkina Faso, though the diastatic power of grain sorghum malt produced under traditional conditions was found to be 53.13 mg of maltose equivalent per gram of dry malt weight per minute. In the

IRAT9 experiment in 2004, results showed that for four out of five water management techniques and three out of four fertilizer treatments the minimum specification for sorghum malt for sale in Burkina Faso was met (Table 2). In this IRAT9 field, only microdose + additional 20 kg P ha^{-1} and 30 kg N ha^{-1} combined with scarifying produced a diastatic power with the minimum specification (Table 5). In the Framida experiment, diastatic power minimum specification was met for all water management techniques and all fertilizer treatments in the two years (Table 3), and for all water management technique and fertilizer treatment combinations (Table 4).

The current findings suggest that grain quality can be optimized by the application of microdose + additional 20 kg P ha^{-1} and 30 kg N ha^{-1} in all water management techniques for Framida. Recommendations to optimize grain quality for IRAT9 will depend on the type of fertilizer and the water management technique in presence. Pearson correlation data indicated that grain yield was rarely correlated with the physicochemical properties of raw grain and malt quality parameters. These correlation data also showed that diastatic power was positively correlated with protein concentration and malting losses, but negatively with tannin concentration. For unknown reasons, the malting losses in the two experiments were high compared to the amounts of losses usually reported in the litterature suggesting further research is needed on this issue. Based upon results from this study, recommendation for the production of sorghum grain and malt with high quality for high traditional beer quality would be the use of water management technique that insured ample soil water in combination with fertilizer that provides sufficient nutrients and particularly nitrogen to the crops.

ACKNOWLEDGEMENTS

We would like to thank USAID Grant No. DAN 1254-G-0021 through INTSORMIL, the Sorghum and Millet Collaborative Research Program, the Environmental and Agricultural Researches Institute (INERA); and the Applied Sciences and Technology Researches Institute (IRSAT) for their financial and administrative support for the present study.

REFERENCES

Agu RC, Palmer GH (1998). A reassessment of sorghum for lager-beer brewing. Bioresource Technol., 66: 253-261.

Barro A, Zougmore R, Taonda SJB (2005). Mécanisation de la technique du zaï manuel en zone semi-aride (Mechanizing the manual zaï technique in the semi-arid zone). Cahiers Agric., 14: 549-559.

Beta T, Rooney LW, Waniska RD (1995). Malting characteristics of sorghum cultivars. Cereal Chem., 72 : 533-538.

Bougouma B (2002). Etude de l'empatage au cours du brassage du dolo (Mashing-in study during dolo brewing). Mémoire DEA, Université de Ouagadougou.

Bougouma B (2005). Elaboration de spécifications techniques sur les produits céréaliers bruts et transformés (mil, sorgho et maïs) [Determination of technical specifications for raw and processed cereal products (pearl millet, sorghum and maize)]. *Cellule de Gestion Plan d'Actions sur les Céréales*, Ouagadougou, Burkina Faso, p. 89.

Braize D (1988). Guide des analyses courantes en pédologie. Choix-expressions-présentation-interprétation (Basic soil analyses guide. Selection – expressions – presentation - interpretation). Institut National de la Recherche Agronomique, Paris, France.

Bryant JP, Clausen TP, Reichardt PB, McCarthy MC, Werner RA (1987). Effect of nitrogen fertilization upon the secondary chemistry and nutritional value of quaking aspen (*Populus tremuloides* Michx.) leaves for the large aspen tortrix (*Choristoneura conflictana* (Walker)). *Oecologia*, 73: 513-517.

Calderón-Chinchilla VR, Hernández-Valle M, Mason SC, Rooney LW (2008). Influencia del nitrógeno en la calidad del grano de sorgo en El Salvador (Influence of nitrogen on sorghum grain quality in El Salvador). *Agronomía Mesoamericana*, 19: 47-56

Chantereau J, Nicou R (1991). Le sorgho (Sorghum). *In* Maisonneuve et Larose (ed.). Le technicien d'agriculture tropicale (The technician of tropical agriculture). Paris, France, p. 159.

Chavan JK, Kadam SS, Salunkhe DK (1981). Changes in tannin, free amino acids, reducing sugars, and starch during seed germination of low and high tannin cultivars of sorghum. J. Food Sci., 46: 638-639.

Daiber KH (1978). BB 118. The selection of sorghum for malting. Sorghum Beer Unit, Council for Scientific and Industrial Research (CSIR), Pretoria, South Africa.

Dewar J, Taylor JRN, Berjak P (1997). Effect of germination with optimised steeping, on sorghum malt quality- with particular reference to free amino nitrogen. J. Inst. Brew., 103: 171-175.

Dicko MH, Gruppen H, Traoré AS, van Berkel WJH, Voragen AGJ (2006). Sorghum grain as human food in Africa: relevance of content of starch and amylase activities. Afr. J. Biotechnol., 5 : 384-395.

FAO-UNESCO (1994). Carte mondiale des sols. Légende révisée. (World soil map. Revised legend.) Rapport sur les ressources en sols du monde 60, FAO, Rome.

Griess JK, Mason SC, Jackson DS, Galusha TD, Yaseen M, Pedersen JF (2010). Environment and hybrid influences on food-grade sorghum grain yield and hardness. Crop Sci., 50: 1480-1489.

Hillel D (1980). Applications of soil physics. Academic Press, New York.

International Organization for Standardization (ISO) 9648 (1988). Sorghum – Determination of tannin content. Geneva, Switzerland.

International Organization for Standardization (ISO) 712 (1998). Cereals and cereal products – Determination of moisture content (Routine reference method). Geneva, Switzerland.

Jarvis CE, Walker JRL (1993). Simultaneous, rapid spectrophotometric determination of total starch, amylose and amylopectin. J. Sci. Food Agric., 63: 53-57.

Kamoshita A, Fukai S, Muchow RC, Cooper M (1998). Genotypic variation for grain yield and grain nitrogen concentration among sorghum hybrids under different levels of nitrogen fertilizer and water supply. Aust. J. Agric. Res., 49: 737-747.

Kaye NM, Mason SC, Jackson DS, Galusha TD (2007). Crop rotation and soil amendment alters sorghum grain quality. Crop Sci., 47: 722-729.

Mason SC, D'Croz-Mason NE (2002). Agronomic practices influence maize grain quality. J. Crop Prod., 5: 75-91.

Mathieu C, Pieltain F (1998). Analyse physique des sols: Méthodes choisies (Physical analysis of soils: Selected methods). Lavoisier Tec and Doc, Paris, France.

Maunder AB (2002). Sorghum worldwide. *In*: JF Leslie (ed.). Sorghum and millet diseases. Iowa State Press, Ames, IA, USA, pp. 11-17.

Murty DS, Kumar KA (1995). Traditional uses of sorghum and millets. *In* David AV, Dendy (ed.). Sorghum and Millets: Chemistry and Technology. Am. Assoc. Cereal Chem. Inc., pp. 185-221.

Norme Française Homologuée (NF) V 03-050 (1970). Produits agricoles alimentaires – Directives générales pour le dosage de l'azote avec minéralisation selon la méthode de Kjeldahl. AFNOR Courbevoie, France.

Novellie L (1962). Kaffircorn malting and brewing studies XII. Effect of malting conditions on malting losses and total amylases activity. J. Sci. Food Agric., 13: 121-123.

Novozamsky I, Houba VJG, Temminghoff E, Van der Lee JJ (1984). Determination of total N and total P in a single soil digest. Neth. J. Agric. Sci., 32: 322-324.

Palé S, Mason SC, Taonda SJB (2009). Water and fertilizer influence on yield of grain sorghum varieties produced in Burkina Faso. South Afr. J. Plant Soil, 26: 91-97.

Palé S, Taonda SJB, Bougouma B, MASON SC (2010). Sorghum malt and traditional beer (dolo) quality assessment in Burkina Faso. Ecol. Food Nutr., 49: 129-141.

Sanders JH, Shapiro BI, Ramaswamy S (1996). The economics of agricultural technology in semi-arid sub-Saharan Africa. Johns Hopkins Univ. Press, Baltimore, MD., p. 328.

Subramanian V, Murty DS, Rao NS, Jambunathan R (1992). Chemical changes and diastatic activity in grains of sorghum (Sorghum bicolor) cultivars during germination. J. Sci. Food Agric., 58: 35-40.

Taylor JRN, Dewar J (2001). Developments in sorghum food technologies.In Taylor S L (ed.), Advances in Food and Nutrition Res. Academic Press San Diego, CA, USA, 43: 4

Taylor JRN, Belton PS (2002). Sorghum. In Belton PS, and Taylor, JRN, Pseudocereals and less common cereals. Springer, Berlin, pp. 25-91.

Walkley A, Black IA (1934). An examination of the Degtjareff method for determining organic carbon in soils: Effect of variations in digestion conditions and of inorganic soil constituents. Soil Sci., 63: 251-263.

Wang X, Benson CH (2004). Leak-free pressure plate extractor for measuring the soil water characteristic curve. Geotech. Testing J., 27: 1–10.

Waniska RD, Rooney LW (2000). Structure and chemistry of the sorghum caryopsis. In Smith CW (ed.), Sorghum: Origin, History, Technology, and Production. John Wiley and Sons, Inc., New York, pp. 649-688.