QUANTITATIVE AND QUALITATIVE STUDIES ON GRAIN SORGHUM FOR TRADITIONAL BEER (*DOLO*) PRODUCTION IN BURKINA FASO

By

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LIST OF ABBREVIATIONS

ANOVA, analysis of variance;

DM, dry matter;

DMSO, dimethyl sulfoxide;

DNS, dinitrosalicyclic acid;

DP, diastatic power;

FT, fertilizer treatment;

FUE, fertilizer use efficiencies;

IMGS, inter-professional minimum guaranteed salary;

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;

IRWH, infield rain-water harvesting;

NF, norme française homologue;

TML, total malting losses;

WMT, water management technique,

WUE, water use efficiency

GENERAL ABSTRACT

In the Central Plateau of Burkina Faso, grain sorghum [*Sorghum bicolor* (L.) Moench] is the major cereal crop used to produce the traditional beer commonly called *dolo*. Improvement of the *dolo* chain supply that requires quantity and quality grain for *dolo* production to improve the supply chain constitutes a big challenge for processors and police-makers. To that end, studies were conducted (1) to determine the best cropping practice to optimize grain yields and grain quality for IRAT9 and Framida (two red grain sorghum varieties) for *dolo* production, through experiments combining water management techniques and fertilizer treatments and conducted from 2003 to 2005, (2) to evaluate sorghum malt and *dolo* quality criteria and parameters affecting quality and (3) to assess costs and profits of malt and traditional beer (*dolo*) production through surveys conducted from December 2006 through January 2007.

Results indicated that combination of water management techniques and fertilizer treatments largely influenced grain yield production and grain quality of the two red grain sorghum varieties. The best cropping system to optimize grain yield of Framida and IRAT9 was the use of tied-ridges and application of microdose with additional phosphorus and nitrogen. Tie-ridging technique produced the highest yield benefit of 241 kg ha^{-1} for Framida and 395 kg ha^{-1}. Microdose with additional phosphorus and nitrogen produced the highest grain yield increases from 420 to 756 kg ha^{-1} for Framida and from 812 to 1346 kg ha^{-1} for IRAT9. Previous studies 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 g of dry malt weight per minute. Results from these studies indicate that for Framida the combination of water management techniques such as scarifying, tie-ridging, manual zai, mechanized zai or dry soil tillage with application of microdose + additional 20 kg P ha^{-1} and 30 kg N ha^{-1}

produced a sorghum malt with higher diastatic power than the commercially acceptable one (Table 4.4) . For IRAT9, this targeted dp is only achieved in an agronomic practice combining scarifying and microdose + additional 20 kg P ha^{-1} and 30 kg N ha^{-1} (Table 4.5). 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 application with additional phosphorus and nitrogen to provide sufficient nutrients and particularly nitrogen to the crop.

The malt and traditional beer (*dolo*) quality assessment study indicated that the major quality criteria for malt quality assessment were perceived to be taste (82% of respondents) and presence/absence of roots in the malt (76%). Taste (82%), alcohol content (73%) and wort sufficiently cooked (63%) were perceived as major criteria for the *dolo* quality assessment. The major parameters affecting malt quality were perceived to be malt production period (100% of respondents), proportions of grain and the amount of water entering malting (100%), presence of pesticide residues in the malting grains (62%) and age of grain (64%). Processing method (100%), yeast source (100%), proportions of the components (crushed grain, water, mucilage, yeast) entering *dolo* production (97%), malt quality (97%), wort temperature at time of inoculation (96%), amount of energy available for cooking wort and sediment boiling time (92%), quality of mucilage (78%), malt with non-sweet taste (75%), presence/absence of roots in the malt (73%) and ease of filtering crushed malt (64%) were perceived as major parameters affecting the *dolo* quality.

The economic study showed differences in costs, sales and profits in the dolo chain from one group of members to another and from one category to another within each group. The study also indicated that, though equipment and raw materials were readily available throughout the year, their high cost limited accessibility and acquisition. Actions must be undertaken by policy-makers and developers to make credit available for farmers to produce quality sorghum grain and women processors to purchase equipment needed for malt and *dolo* processing, conservation and distribution, thus increasing profits. Other important aspects to consider when designing programs to improve the *dolo* supply chain were the organization of malt and dolo production and marketing systems and suitable training programs to the benefit of all members to improve production skills and increase profit per unit cost in all *dolo* activities. Results from this study will help in the improvement of the *dolo* supply chain in Burkina Faso by providing more reliable information for (1) development of best cropping practices to improve grain quality, and providing better selection criteria for sorghum breeding programs, (2) development of training programs for efficient *dolo* brewing processes and (3) development of training programs to improve marketing systems and skills for chain members. It is expected that results from this study would further help 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..

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DEDICATION

TO:

My late parents Holènè and Liridjèna

My late fiancée Signon Charlotte

My daughter Yéri Fanny

DECLARATION

I Siébou PALE __________ declare that:

(i) The research reported in this thesis, except where otherwise indicated, is my original work.

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As the candidate's supervisors, I agree to the submission of this thesis

Signed……………………………………. Date…………………………..…………..

Professor Mark Laing (Supervisor)

Signed……………………………….. Date…………………………..

Professor Pangirayi Tongoona (Co-supervisor)

Signed

…………………………………….. Date………………..……………………..

Professor Walter De Milliano (Co-supervisor)

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Chapter 1

GENERAL INTRODUCTION

1.1. CONSTRAINTS TO QUANTITATIVE AND QUALITATIVE SORGHUM GRAIN FOR TRADITIONAL BEER (DOLO) PRODUCTION

Grain sorghum [*Sorghum bicolor* (L.) Moench] originated in Africa and India. Domestic sorghum named *Sorghum bicolor* (L) Moench is an annual crop of a perennial grass preferentially adapted to tropical semi-arid hot rainfall (Kondombo, 2004).Today sorghum is present in all continents and in Burkina Faso the area devoted to this crop was estimated 1.3 million hectares (Chantereau and Nicou, 1991).

The traditional beer, commonly called *dolo* in Burkina Faso, is obtained by brewing starch from sorghum, millet and maize. In Burkina Faso, especially in the Central Plateau Region, grain sorghum is the major cereal crop used in *dolo* production. *Dolo* is culturally and historically a product with a number of processing steps improved over the last 1000 years. The red grain varieties are exclusively used in *dolo* production throughout the country, but in some places (Western and South-Western Burkina Faso) white grain varieties may also be used. Over 30% of the total grain sorghum production is thus used for traditional beer production (DSA-BF, 2001). Traditional beer production has mainly been an economic activity of women for decades, but men have also started to become interested in this activity particularly in cities, where dolo production has become one of the most profitable agro-based activities (INSD-BF, 1996). *Dolo* also is omnipresent in the daily life of Burkinabé (people of Burkina Faso) living in cities, as well as in rural areas. The use of grain sorghum in *dolo* production requires a constant supply of high quality grain, available at a reasonable price. This can only be achieved through better cropping practice.

Grain sorghum is usually grown in stressful environments with high temperatures, lack of predictable water supply, fragile soils with low nutrient status, and limited growing season length. Lack of water is usually the most critical environmental factor controlling growth and limiting yield in Africa. Sanders (1999) indicated that the diffusion of new agricultural production technologies into the semiarid region is a critical issue and the principal constraint to this diffusion is insufficient water, and once there is sufficient available water, soil fertility becomes the primary constraint.

The International Sorghum and Millet (INTSORMIL) Collaborative Research Program Support (CRPS) Project UNL (University of Nebraska-Lincoln)-213 with international research efforts developed in collaboration with investigators in West Africa and Central America focuses primarily on crop production systems which increase the probability of obtaining higher pearl millet and sorghum grain and stover yields. This involves cropping systems to optimize yield, water and nutrient use efficiency to growing pearl millet and grain sorghum and produce desired uniform stands. Collaboration with national extension services and Non-Governmental Organizations (NGOs) in transferring improved pearl millet and grain sorghum agronomy practices is also developed. Studies have been initiated with collaborators in Burkina Faso on fertilizer rates and water management techniques with genotypes for pearl millet and grain sorghum production which are critical issues in this country. The present study aims to strengthen these international efforts developed in collaboration with investigators in Burkina Faso.

1.2 STUDY AREA

The study was conducted in the Central Plateau of Burkina Faso, a semi-arid and 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 cropping systems based on low yields of sorghum and pearl millet (Sanders *et al.*, 1996). Experiments were conducted at the Saria Agricultural Research Station (12^{o} 16’ N lat; 2^{o} 09’ W long) located in the Central Plateau of Burkina Faso (Figure 1.1).

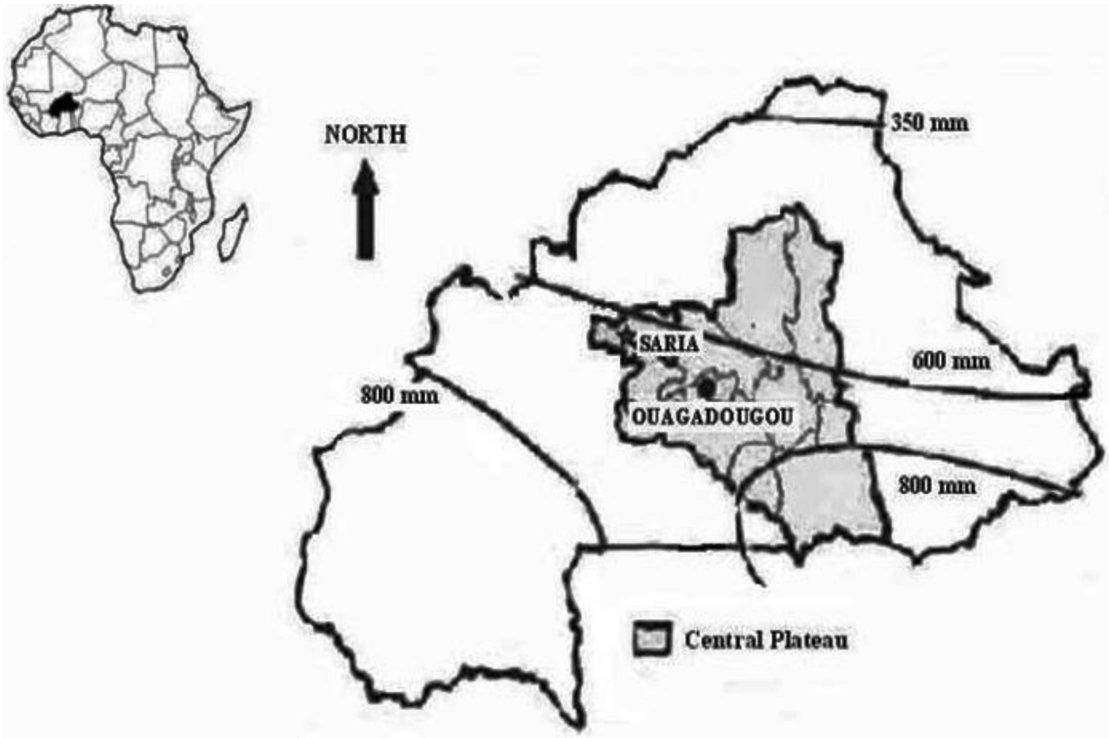

Figure 1.1. Map of Burkina Faso showing the Central Plateau and Saria (study site).

Source: Remote Sensing and Geographical Information Unit (CTIG)/ Institute of Environment and Agriculture Researches (INERA), 2009. Ouagadougou, Burkina Faso: CTIG/INERA.

The survey was conducted in six cities in the Central Plateau of Burkina Faso: Ouagadougou (capital of Burkina Faso), Manga, Pouytenga, Mogtédo, Pabré and Kamboinsé (Figure 1.2).

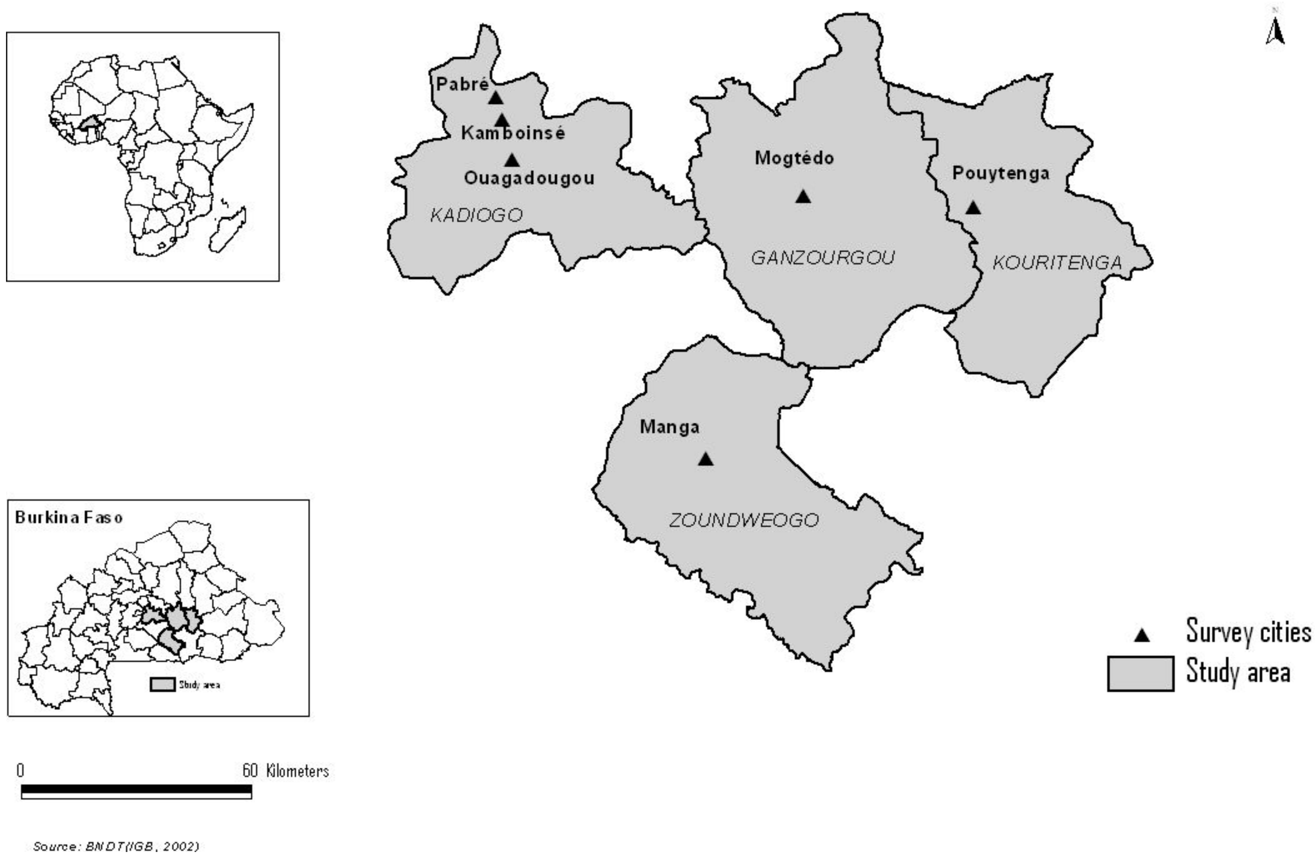

Figure 1.2 Map of Burkina Faso showing the survey area (the provinces of Kadiogo, Ganzourgou, Kouritenga and Zoundwéogo) and the survey sites (CTIG/INERA, 2009).

Source: Remote Sensing and Geographical Information Unit (CTIG)/ Institute of Environment and Agriculture Researches (INERA), 2009. Ouagadougou, Burkina Faso: CTIG/INERA.

1.3 GENERAL OBJECTIVE AND THESIS OUTLINE

1.3.1. Overall objective

The use of grain sorghum in dolo production requires a constant supply of high quality grain available at a reasonable price through better cropping systems to develop and maintain the supply chain. Although much is known about the importance of *dolo* production, a lot remains to be done in terms of cropping systems to optimize grain yields while maintaining malting and brewing qualities. Previous research at the Food and Technology Laboratory of the National Centre for Science and Technology Research (CNRST) on sorghum processing for malting and brewing helped identify the sorghum varieties IRAT9 and ICSV1001 (Framida) as the most suitable varieties for *dolo* production (Bougouma, 2002).

The objective of this study was to identify the best cropping practice (water management + fertilizer application) and parameters affecting quality and assess the economic profit of malt and dolo processing to quantitatively and qualitativily optimize sorghum grain for *dolo* production. Meeting this objective would increase the potential of the crop to be an economical grain crop for Burkina Faso and other West African countries.

1.3.2. Specific objectives

Specific objectives to achieve were:

- To evaluate the influence of water and fertilizer on yield and yield components of two red grain sorghum varieties for *dolo* production.
- To evaluate the influence of water and fertilizer on physicochemical properties of raw grain and malt quality of two red grain sorghum varieties for *dolo* production.
- To assess factors affecting the quality of *dolo* and ways to improve production and chain in Burkina Faso.
- To participate in developing a system to increase the use of grain sorghum in the agro-based companies.
- To transfer and promote sustainable technologies of sorghum based cropping systems to farmers and seed producers, improved *dolo* processing technologies to *dolo* producers.

1.3.3. THESIS OUTLINE

Following the present introductive chapter, Chapter 2 presents the literature review. Chapter 3 presents the influence of water and fertilizer on yield of grain sorghum varieties for traditional beer (*dolo*) production. The influence of water and fertilizer on sorghum grain quality for traditional beer (*dolo*) production is discussed in Chapter 4. Chapter 5 deals with the quality assessment of sorghum malt and traditional beer (*dolo*). Chapter 6 presents the economic assessment of malt and traditional beer *(dolo*) and ways to improve the *dolo* chain. Chapter 7 summarizes the main conclusions on quantitative and qualitative sorghum grain production for traditional beer (*dolo*) production in Burkina Faso.

REFERENCES

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

Bramel-Cox, P.J., Kumar, K.A., Hancock, J.D. and Andrews, D.J. 1995. Sorghum and millets for forage and feed. *In* D.A.V. Dendy (eds.). Sorghum and Millets: Chemistry and Technology. American Association of Cereal Chemists, Inc., St. Paul, Minnesota, USA, pp. 325-364.

DSA-BF. 2001. Production du Sorgho (Sorghum production). MAHRH, DGPSA, DSA, BF

INSD-BF. 1996. Recensement de la population du Burkina Faso 1996 (Census of the population of Burkina Faso 1996). MAT, DGSD, INSD, BF.

Maunder, A. B. 2002. Sorghum worldwide. *In* J. F. Leslie (eds.). Sorghum and Millet Diseases. Iowa State Press, Ames, IA, USA. pp. 11-17.

Sanders, J. H. 1999. Availability and adoption of improved technologies in the semi-arid and sub-humid zones of West Africa. *In* S.K. Debrah & W.G. Koster (eds.). Linking soil fertility management to agricultural input and output market development: the key to sustainable agriculture in West Africa. *Miscellaneous Fertilizer Studies* 16: 61-72. IFDC - Africa, Lomé, Togo.

Sanders, J.H., Shapiro, B.I and Ramaswamy, S. 1996. The economics of agricultural technology in semi-arid sub-Saharan Africa. Johns Hopkins Univ. Press, Baltimore, MD. p. 328.

LITERATURE REVIEW

2.1 INTRODUCTION

In Burkina Faso, especially in the Central Plateau Region, grain sorghum is the major cereal crop used in traditional beer (*dolo*) production and the most used varieties are red grain varieties, though in some places (Western and South-Western Burkina Faso) white grain varieties may also be used. Traditional beer production has mainly been an economical activity of women for decades, but men have also started to become interested in this activity particularly in cities, where dolo production has become one of the most profitable agro-based activities (INSD-BF, 1996). The following review focuses on (1) productions, utilizations and economic importance of grain sorghum, (2) cropping systems and correlations and (3) grain physicochemical properties, quality assessment and processing.

2.2 GRAIN SORGHUM: PRODUCTIONS, UTILIZATIONS AND ECONOMIC IMPORTANCE

Grain sorghum ranks fifth in world cereal production after wheat (*Triticum aestivum L.*), maize (*Zea mays L.*), pearl millet [(*Pennisetum glaucum (L.) R. Br.*)] and rice (*Oryza sativa L.*) (Feldmann, 2002). According to FAO statistics, the world production of sorghum in 2001 was 57.36 million tons for a total of 41.57 million hectares. From 1995 to 2000, annual grain sorghum production in Burkina Faso averaged 825 000 metric tons for white-grain varieties and 291 000 metric tons for red grain varieties (DSA-BF, 2001). Sorghum constitutes the most common cereal grain in Burkina Faso (Chantereau and Nicou, 1991). From 1995 to 2000, annual grain sorghum production in Burkina Faso averaged 825 000 metric tons for white-grain varieties and 291 000 metric tons for red grain varieties (DSA-BF, 2001).

Grain sorghum constitutes, along with pearl millet, 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 livestock (swine, poultry and cattle) feed in the western hemisphere (Bramel-Cox *et al.*, 1995). More than 35% of sorghum production is used for human consumption and the rest is used for animal feed mainly in the western hemisphere (Bramel-Cox *et al.*, 1995; Awika and Rooney, 2004), alcohol production and industrial products (Awika and Rooney, 2004). Over 30% of the total grain sorghum production in Burkina Faso is used in *dolo* production (DSA-BF, 2001.). Grain sorghum is used in the preparation of *tô*, porridges, breads, biscuits, doughnuts and couscous. Porridges are fluid end-products prepared with flour from malted and non-malted grains, useful for the formulation of weaning foods for infants because of their low energy density (Traoré *et al.*, 2004). *Tô* is a thick paste prepared by cooking slurry sorghum grain flour and is eaten with special sauces. Couscous is a steamed and granulated traditional food originated in North Africa. Sorghum grain has the ability to produce high malt activity and is the raw material for the preparation of soft drinks (*zoom-koom* in Burkina Faso), alcoholic beverages such as traditional beer or *dolo* in many countries of West Africa and starch (in industries). Sorghum stems are also used as source for energy for cooking, building materials (sheds and fences) and for making mats and woven objects and musical instruments such as flutes.

Grain sorghum is a source of income of house-hold in Africa (Anglani, 1998) and McCall (2001) indicated that, although the financial returns to labor in household-scale brewing are usually poor, brewing constitutes the third-highest household income source in Burkina Faso (after farm produce sales and wage labor). Malt and *dolo* production is primarily a female enterprise and their economic well being and reputation is greatly influenced by the quality of the beer they produce (Murty & Kumar, 1995; Saul, 1981). This generates significant profits, particularly for large-scale processors, thus benefiting females, an under-represented segment of the society in Burkina Faso. In Burkina Faso, although *dolo* production has mainly been an economic activity of women for decades, the production has become one of the most profitable agro-based activities (INSD-BF, 1996). However, the production is mainly hampered by lack of capital particularly for young or small-scale brewers and retailers who cannot produce their own *dolo* and thus have to buy it from processors and retail with reduced profit (Saul, 1981). Saul (1981) indicated that malt and *dolo* prices vary depending on daily supply and demand which is influenced by the fact that it is not easy to store sorghum beer.

2.3 GRAIN SORGHUM: CROPPING SYSTEMS AND CORRELATIONS

Grain sorghum is usually grown in stressful environments with high temperatures, lack of predictable water supply, fragile soils with low nutrient status, and limited growing season length. Lack of water is usually the most critical environmental factor controlling growth and limiting yield in Africa. Sorghum is well suited to heavy soils commonly found in the tropics and is particularly adapted to drought prone areas: hot, semi-arid tropical environments with 400-600 mm rainfall-areas that are too dry for other cereals. In West Africa, sorghum is grown mainly in rainy season, often associated with other crops such as pearl millet and cowpea *(Vigna unguiculata*).

The use of grain sorghum for human consumption and particularly *dolo* production requires a constant supply of high quality grain and this can only be achieved through better cropping practices. Earlier findings emphasized the importance of soil nutrient availability and water availability and their management to improve efficiency and increase crop biomass production along with grain yields (Nagy *et al.*, 1990; Nyakatawa, 1996; Zaongo *et al.*, 1997; Ayuk & Bationo, 1999; Sanders, 1999; Breman & Debrah, 2003; Woyessa *et al.*, 2006). Improving the African agricultural resource base by increasing either nutrient availability or water availability can increase the efficiency of external inputs and make them an attractive option for African farmers (Breman and Debrah, 2004).

Sanders (1999) indicated that the diffusion of new agricultural production technologies into the semiarid region is a critical issue and the principal constraint to this diffusion is insufficient water to enhance the beneficial effects of fertilizer application, and once there is sufficient available water, soil fertility becomes the primary constraint. Bekunda *et al.* (1997) and Ofori (1999) mentioned that the two most limiting nutrients to food production in Africa are nitrogen (N) and phosphorus (P) and Zaongo *et al.* (1997) reported the importance of N in increasing water use efficiency (WUE) of sorghum genotypes produced under rainfed conditions. Bationo and Mokwunye (1991) indicated that a modest annual application of 15 to 20 kg P ha^{-1} is usually adequate for sandy soils with a low P sorption. Muehlig-Versen *et al.* (2003) tested the effects of small quantities of P, placed in or close to the planting hill on growth of pearl millet grown under rainfed conditions and found that placed applications of 3, 5 and 7 kg P ha^{-1} led to 72%, 81% and 88% respectively, of the grain yield produced by broadcasting 13 kg P ha^{-1}. The study also showed that with P application, the addition of N resulted in an 80% grain yield increase. Taonda (2005) and Bagayoko *et al.* (2011) evaluated the effect of different fertilization rates, based on a microdose application (4 g per hill at planting of a complex NPK fertilizer equivalent of 19 kg N ha^{-1}, 19 kg P ha^{-1} and 19 kg K ha^{-1}) on pearl millet production in the Central Plateau of Burkina Faso (Taonda, 2005). Results from this study showed higher grain yields resulting from the use of microdose with addition of 20 kg P ha^{-1} as triple super phosphate at planting and 30 kg N ha^{-1} as urea applied 45 days after planting. Pearl millet grain yield increases were 404 kg ha^{-1} and 543 kg ha^{-1} at the farm and research station, respectively. This indicated that the use of microdose fertilization alone was not sufficient to cover the pearl millet mineral nutrient needs.

Sanders et al. (1990) conducted research on sorghum on 223 farms in Burkina Faso and found that tied ridges increased grain yield by 156 kg ha^{-1} (40% increase), fertilizer by 289 kg ha^{-1} (75% increase) and the combination of tied ridges and fertilizer by 511 kg ha^{-1} (132% increase). Results from farmer-managed trials conducted in Burkina

Faso showed higher sorghum grain yields with the combination of fertilizer and tied-ridges than with either fertilizer or tied-ridges alone (Nagy *et al.*, 1990). From a study conducted in Zimbabwe, Nyakatawa (1996) reported sorghum yield increases from 118 to 388 kg ha^{-1} when 1.5-m tied-ridges were used and increases to 1071 kg ha^{-1} when 50 kg N ha^{-1} was applied to the tied-ridges in years of limited rainfall. Utzurrum *et al.* (1998) reported that late application of N on sorghum plants reduced leaf senescence which then resulted in increased grain yield, even under water limiting conditions. Previous studies reported that tied-ridges improve soil water availability by reducing surface runoff and delaying water depletion, thus improving food production (Nyakatawa, 1996; Ayuk and Bationo, 1999; Taonda, 1999; Gusha, 2002; Howll, 2002; Brhane *et al.*, 2006; Brhane and Wortmann, 2008). Taonda (1999) in Burkina Faso, compared the effects of scarifying and tied-ridges on pearl millet grain yield and reported yield increases due to tied ridges of 112 kg ha^{-1} in years of sufficient rainfall (931 mm), 88 kg ha^{-1} in years of medium to intermediate rainfall (760 mm) and 474 kg ha^{-1} in years of low rainfall (621 mm).

The zaï system is a traditional system used in Burkina Faso. Small pits 20 to 30 cm in diameter and 10 to 20 cm deep are dug and in the bottom of the pit organic matter (manure, compost) is placed and seeds planted (Fatondji et al. 2001; Palé et al. 2009). This system combines the effects of tillage, micro-catchments to capture water and supply nutrient to increase plant growth and yield. Ouattara et al. (1999) reported a 35 to 220% yield increase from use of zaï. Recently animal traction systems to simulate the zaï have been developed in Burkina Faso, producing equal yields to the traditional zaï while reducing the human labor required (Mason, 2007). On land left under grassland, Woyessa *et al.* (2006) compared runoff stored in dams and used downstream for irrigation, with the infield rain-water harvesting (IRWH) technique used to capture and convert runoff to stored water in a microbasin for crop production. Results showed that the IRWH technique, coupled with appropriate farming practices, increased maize production six times more than the downstream irrigation strategy. Barro *et al.*, (2005) reported that the combination of zaï with application of compost increases yields of grain sorghum.

Yield component studies with grain sorghum have shown the number of panicles per square meter and kernel mass to be positively associated with non-uniform stand reductions (Larson & Vanderlip, 1994) and N application (Rajewski *et al.*, 1991). Maman *et al.* (2004) reported a positive correlation of grain yield with kernel mass (r^2 = 0.51; p = 0.05 or less) and panicles per square meter (r^2 = 0.80; p = 0.05 or less) for grain sorghum.

2.4 GRAIN SORGHUM: GRAIN PHYSICOCHEMICAL PROPERTIES, QUALITY ASSESSMENT AND PROCESSING

The successful growth of *dolo* brewing depends on the presence of adequate infrastructure, skilled personnel, consistent quality of raw materials (clean, mature sorghum grain with low moisture content free of breakage and stress cracks, and insect damage), development of efficient brewing processes (Novellie & Taylor, 1993), and economic profitability. Murty and Kumar (1995) indicated that high quality grain will improve the brewing processes, and thus *dolo* quality, since a commercialized traditional product has a greater chance of being popular and culturally acceptable than an exotic or novel product. Many studies have been carried out to improve sorghum grain performance based on agronomic characteristics, mainly high yield and tolerance to drought and pests (Badu-Apraku *et al*., 1995) and the utilization of sorghum in beer brewing (EtokAkpan & Palmer, 1990; Ogbonna *et al.*, 2003). Literature showed that these studies were limited to morphology and ultra-structure (Aisien *et al*., 1983; Glennie *et al.*, 1983; Glennie, 1984), enzyme development and extraction (Dyer & Novellie, 1966; Okon & Uwaifo, 1985; EtokAkpan & Palmer, 1990; Ogbonna *et al.*, 2003), malting and malt quality (Taylor and Dewar, 2000; Morrall *et al.*, 1986; Subramanian *et al.*, 1992; Beta *et al.*, 1995; Hagir *et al.*, 1999;) as well as mashing features (Taylor & Boyd, 1986; Aisien & Muts, 1987; Palmer,

1989) and criteria for assessing *dolo* quality and parameters affecting quality (Kayode *et al.*, 2005)., but little research on grain quality for specific end uses was done.

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 (Mason and D'Croz-Mason, 2002; Calderón-Chinchilla *et al.*, 2008; Griess *et al.*, 2010). 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). 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. Many studies reported higher grain protein concentration 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). 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. Waniska and Rooney (2000) indicated that production of sorghum grain under ample soil water conditions increases grain starch synthesis while decreases protein concentration. Water-by-nitrogen interaction influences sorghum grain protein concentration (Kamoshita *et al.*, 1998).

The primary quality criterion of selection of sorghum varieties for traditional beer is their potential to produce malt with high diastatic activities (*alpha*- and *beta*-amylase activities) (Taylor and Dewar, 2001). 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). Germination of grains is an essential part of the malting process. Kayode et al. (2005) reported that processors' choice of sorghum for beer processing is mainly based on the ability of the grain to germinate quickly (germinative power), size and color of the grain, storage period, wort quantity and quality (mainly sugar content), and the origin of the grain. Ungerminated grains may be ready sources of microbial infection during malting that will affect the dolo quality (Agu and Palmer, 1998). Chavan *et al.* (1981) suggested that tannins are responsible for retarding the seedling growth by decreasing the rate of starch and protein degradation in tannin rich seeds.

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). 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. 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. Red sorghum grain generally has higher amylase activities than white grain which likely explains the preference of red grain sorghums for *dolo* production (Dicko *et al.*, 2006). 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 total malting losses. 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 traditional beer, commonly called *dolo* in Burkina Faso, is obtained by brewing starch from sorghum, millet and maize. *Dolo* is commonly filtered, but is still cloudy, and has a combination of sweet and sour taste, fruity aroma, and contains one to five percent v/v alcohol (Demuyakor & Ohta, 1993; Murty & Kumar 1995). In Burkina Faso, especially in the Central Plateau Region, grain sorghum is the major cereal crop used in *dolo* production and the traditional preparation of *dolo* involves malting of red sorghum grain followed by crushing, mashing-in, cooking, lactic fermentation, filtration, boiling and alcoholic fermentation of the wort as summarized in Figure 2.1 (Murty and Kumar, 1995). During the *dolo* production, separation of the insoluble components is facilitated by addition of mucilaginous substances (mucilage) such as crushed okra stems (Demuyakor & Ohta, 1991), or baobab or okra bark (Murty & Kumar, 1995). Taylor and Dewar (2000) indicated that the quality of the yeast used to carry out alcoholic fermentation and the timing of wort inoculation influence *dolo* quality. For example during Harmattan [hot and dry wind from Sahara blowing in dry season (November to March) in West Africa] period, inoculation is initiated early while the wort is still a little warm to allow good alcoholic fermentation (Kayode *et al.*, 2005).

CONCLUSIONS

This review summarized results on research on grain sorghum production practices , utilizations and economic importance, correlations among yield and yield components, grain physicochemical properties and processing. Yet it is apparent that improvement of the quantity and quality of grain sorghum for traditional beer (*dolo*) to improve the *dolo* supply chain in Burkina Faso still remains a big challenge for farmers, processors and policy-makers. Future studies need to be conducted to identify the best cropping practice to optimize grain sorghum yields and grain quality for *dolo* production, evaluate sorghum malt and *dolo* quality criteria and parameters affecting quality and to assess costs and profits of malt and *dolo* processing. The new research findings, processor and consumer knowledge and new information once integrated into training packages will help develop and maintain the supply chain, thus increasing the potential of grain sorghum to be an economical grain crop for Burkina Faso and other West African countries.

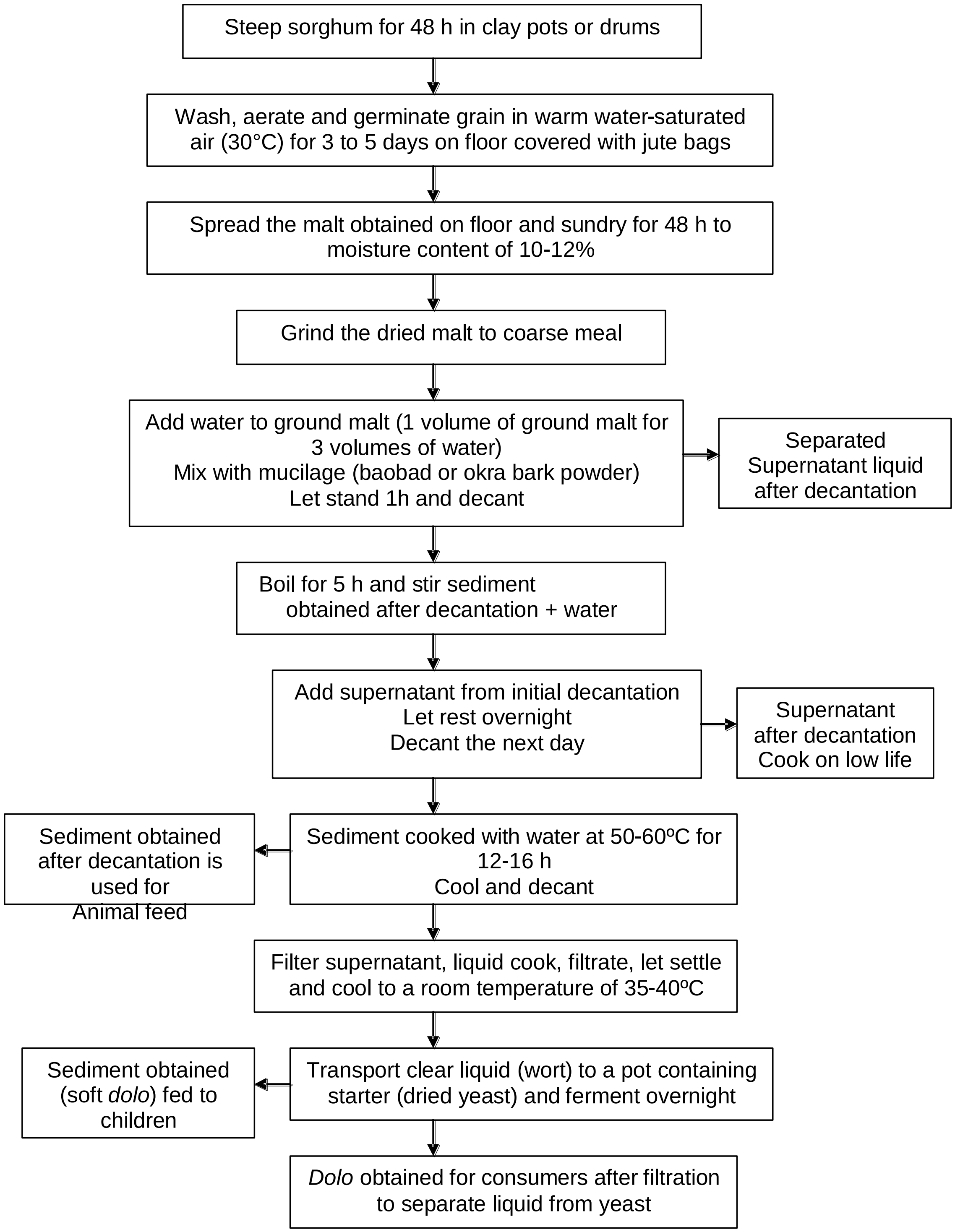

Figure 2.1 Traditional production of *dolo* in Burkina Faso (Murty and Kumar, 1995)

REFERENCES

Agu, R.C. and Palmer, G.H. 1998. A reassessment of sorghum for lager-beer brewing. *Bioresource Technology* 66: 253-261.

Aisien, A.O. and Muts, G.C.J. 1987. Micro-scale malting and brewing studies of some sorghum varieties. *Journal of the Institute of Brewing* 93: 328-331.

Aisien, A.O., Palmer, G.H. and Stark, J.R. 1983. The development of enzymes during germination and seedling growth in Nigerian sorghum. *Starch-Stärke* 9: 316-320.

Anglani, C. 1998. Sorghum for human food: a review. *Plant Foods for Human Nutrition* 52: 85-89.

Awika, J.M. and Rooney, L.W. 2004. Sorghum phytochemicals and their potential aspects on human health. *Phytochemistry* 65:1199-1221.

Ayuk, E.T. and Bationo, A. 1999. Socioeconomic assessment of soil fertility technology options in the Sahel. *In*: S.K. Debrah & W.G. Koster (eds.). Linking soil fertility management to agricultural input and output market development: the key to sustainable agriculture in West Africa. *Miscellaneous Fertilizer Studies* 16: 52-60. IFDC-Africa, Lomé, Togo.

Badu-Apraku, B., Okoruwa, A.E., Kling, J.G. and Kim, S.K. 1995. Improvement of maize genotypes with appropriate quality characteristics for industrial processing and use. *In* J.M. Menyonga, B. Taye, C.C. Nwasike, P.M. Sedego and E. Tenkouanoeds (eds.). Processing and industrial utilization of sorghum and related cereals in Africa. OAU/STRC-SAFGRAID, Ouagadougou, Burkina Faso. pp. 247-272.

Bagayoko, M., Maman, N., Palé, S., Sirifi, S., Taonda, S.J.B., Traoré, S. and Mason, S.C. 2011. Microdose and N and P fertilizer application rates for pearl millet in West Africa. *African Journal of Agricultural Science* 6:1141-1150.

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

Bationo, A. and Mokwunye, A.U. 1991. Alleviating soil fertility constraints to increased crop production in West Africa: The experience in the Sahel. *Fertilizer Research* 29: 95-115.

Bekunda, A.M., Bationo, A. and Ssali, H. 1997. Soil fertility management in Africa: a review of selected research trials. *In*: R.J. Brush, P.A. Sanchez and F. Calhoun (eds.). Replenishing soil fertility in Africa. SSSA, Special Publication No.. *Soil Science Society of America* 51, 63-80.

Beta, T., Rooney, L.W. and Waniska, R.D. 1995. Malting characteristics of sorghum cultivars. *Cereal Chemistry* 72: 533-538.

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.

Bramel-Cox, P.J., Kumar, K.A., Hancock, J.D. and Andrews, D.J. 1995. Sorghum and millets for forage and feed. *In* D.A.V. Dendy (eds.). Sorghum and Millets: Chemistry and Technology. American Association of Cereal Chemists, Inc., St. Paul, Minnesota, USA. pp. 325-364.

Breman, H. and Debrah, S.K. 2003. Improving African Food Security. *SAIS Review* 23: 153 – 170.

Brhane, G.T. and Wortmann, C.S. 2008. Tie-ridge tillage for high altitude pulse production in Northern Ethiopia. *Agronomy Journal* 100: 2447-453.

Brhane, G.T., Wortmann, C.S., Mamo, M., Gebrekidan, H. and Belay, A. 2006. Micro-basin tillage for grain sorghum production in semi-arid areas of Northern Ethiopia. *Agronomy Journal* 98: 124-128.

Calderón-Chinchilla, V.R., Hernández-Valle, M., Mason, S.C. and Rooney, L.W. 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. and Nicou, R. 1991. Le sorgho (sorghum). *In* Maisonneuve et Larose (eds.). Le technicien d'agriculture tropicale (The technology of tropical agriculture). Paris, France. p.159.

Chavan, J.K., Kadam, S.S. and Salunkhe, D.K. 1981. Changes in tannin, free amino acids, reducing sugars, and starch during seed germination of low and high tannin cultivars of sorghum. *Journal of Food Science* 46: 638-639.

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

Demuyakor, B. and Ohta, Y. 1991. Characteristics of pito yeasts from Ghana. *Food Microbiology* 8: 183-193.

Demuyakor, B. and Ohta, Y. 1993. Characteristics of single and mixed culture fermentation of pito beer. *Journal of the Science of Food and Agriculture* 62: 401-408.

Dicko, M.H., Gruppen, H., Traoré, A.S., van Berkel, W.J.H. and Voragen, A.G.J. 2006. Sorghum grain as human food in Africa: relevance of content of starch and amylase activities. *African Journal of Biotechnology* 5: 384-395.

DSA-BF. 2001. Production du Sorgho (Sorghum production). MAHRH, DGPSA, DSA, BF.

Dyer, T.A. and Novellie, L. 1966. Kaffircorn malting and brewing studies XVI - The distribution and activity of α and β-amylases in germinating kaffircorn. *Journal of the Science of Food and Agriculture* 17: 449-456.

EtokAkpan, O.U. and Palmer, G.H. 1990. Comparative studies of the endosperm-degrading enzymes in malting sorghum and barley. *World Journal of Microbiology and Biotechnology* 6: 408-417.

FAO-UNESCO. 2001. Rapport sur les ressources en sols du monde 60, FAO, Rome.

Fatondji, D., Martius, C. and Vlek P. 2001. Zaï - A traditional technique for land rehabilitation in Niger. *ZEFnews* 8: 1 – 2.

Feldmann, P. 2002. Les céréales dans les systèmes de culture des régions semi-arides d'Afrique de l'Ouest. *In* Le futur des céréales photopériodiques pour une production durable en Afrique Tropicale semi-aride. SIA / CIRAD. Montpellier, France. pp. 163-174.

Glennie, C.W. 1984. Endosperm cell wall modification in sorghum grain during germination. *Cereal Chemistry* 61: 285-289.

Glennie, C.W., Harris, J. and Liedenberg, N.V.D.W. 1983. Endosperm modification in germinating sorghum grain. *Cereal Chemistry* 60: 27-31.

Griess, J.K., Mason, S.C., Jackson, D.S., Galusha, T.D., Yaseen, M. and Pedersen, J.F. 2010. Environment and hybrid influences on food-grade sorghum grain yield and hardness. *Crop Science* 50: 1480-1489.

Gusha, A.C. 2002. Effects of tillage on soil microrelief, surface depression storage and soil water storage. *Soil Tillage Research* 76 : 105–114.

Hagir, B.E., Babiker, E.E. and Abdullahi El Tinay, H. 1999. Changes in chemical composition, grain malting, starch and tannin contents and protein digestibility during germination of *sorghum cultivars. Food Chemistry* 64: 331-336*.*

Howell, T.A., Schneider, A.D. and Dusek, D.A. 2002. Effects of furrow diking on corn response to limited and full sprinkler irrigation. *Soil Science Society of America* 66: 222–227.

INSD-BF, 1996. Recensement de la population du Burkina Faso 1996 (Census of the population of Burkina Faso 1996). INSD, Ouagadougou, Burkina Faso.

Kamoshita, A., Fukai, S., Muchow, R.C. and Cooper, M. 1998. Genotypic variation for grain yield and grain nitrogen concentration among sorghum hybrids under different levels of nitrogen fertilizer and water supply. *Australian Journal of Agricultural Research* 49: 737-747.

Kaye, N.M., Mason, S.C., Jackson, D.S. and Galusha, T.D. 2007. Crop rotation and soil amendment alters sorghum grain quality. *Crop Science* 47: 722-729.

Kayode, P.A.P., Adegbidi, A., Hounhouigan, D.J., Linnemann, R.A. and Nout, M.J.R. 2005. Quality of farmers' varieties of sorghum and derived foods as perceived by consumers in Benin. *Ecology of Food and Nutrition* 44: 271-294.

Kondombo, C. 2004. Programme mil – maïs - sorgho: Rapport analytique. Amélioration des sorghos précoces et à moyen cycle. INERA, Saria, Burkina Faso. pp.36.

Larson, E.J. and Vanderlip, R.L. 1994. Grain sorghum yield response to non-uniform stand reductions. *Agronomy Journal* 86: 475-477.

Maman, N., Mason, S.C., Lyon, D.J. and Dhungana, P. 2004. Yield components of pearl millet and grain sorghum across environments in the Central Great Plains. *Crop Science* 44 : 2138-2145.

Mason, S.C. and D'Croz-Mason, N.E. 2002. Agronomic practices influence maize grain quality. *Journal of Crop Production* 5: 75 – 91.

Mason, S.C. 2007. Cropping systems to optimize yield, water and nutrient use efficiency of pearl millet and grain sorghum. INTSORMIL, Lincoln, Nebraska. Annual Report. pp 31 -38

Maunder, A.B. 2002. Sorghum worldwide. *In* J.F. Leslie (Ed.). Sorghum and millet diseases. Iowa State Press, Ames, Iowa, USA. pp. 11-17.

McCall, M. 2001. Brewing rural beer should be a hotter issue. *Boiling Point* 47: 23-25.

Morrall, P., Boyd, H.K., Taylor, J.R.N. and van der Walt, W.H. 1986. Effect of germination time, temperature and moisture on malting of sorghum. *Journal of the Institute of Brewing,* 92, 439-445.

Muehlig-Versen, B., Buerkert, A., Bationo, A. and Roemheld, V. 2003. Phosphorus placement on acid arenosols of the West African Sahel. *Experimental Agriculture* 39: 307–325.

Murty, D.S. and Kumar, K.A. 1995. Traditional uses of sorghum and millets. *In* D.A.V. Dendy (eds.). Sorghum and Millets: Chemistry and Technology. American Association of Cereal Chemists, Inc., St. Paul, Minnesota, USA, pp. 185-221.

Nagy, J.G., Ohm, H.W. and Sawadogo, S. 1990. Farmer-researcher collaboration in developing cropping practices that involve the complementary use of mechanical tied ridge and fertilizer technology for sorghum in Burkina Faso. *Experimental Agriculture* 26 : 161-169.

Novellie, L. and Taylor, J.R.N. 1993. Beverages from sorghum and millet. *In* R. Macrae, R.K. Robinson, and M.J. Sadler (Eds.). Encyclopedia of Food Science, Food Technology and Nutrition. Academic Press, London. pp. 1781-1786.

Novellie, L. 1962. Kaffircorn malting and brewing studies XII. Effect of malting conditions on malting losses and total amylases activity. *Journal of the Science of Food and Agriculture* 13: 121-123.

Nyakatawa, E.Z. 1996. Rain water and soil fertility management for sustainable cropping on sandy soils in semi-arid South-East Lowveld of Zimbabwe. *Journal of Sustainable Agriculture* 7: 19-34.

Ofori, S.C. 1999. The need for an integrated approach to soil fertility management in West Africa. *In*: S.K. Debrah & W.G. Koster (eds.). Linking soil fertility management to agricultural input and output market development: The key to sustainable agriculture in West Africa. *Miscellaneous Fertilizer Studies* 16: 17-30.

Ogbonna, A.C., Obi, S.K.C. and Okolo, B.N. 2003. Modifications of the methods for the extraction of carboxypeptidase and proteinase activities from sorghum malts. *Journal of the Institute of Brewing* 109: 51-56.

Okon, E.U. and Uwaifo, A.O. 1985. Evaluation of malting sorghums 1. The malting potential of Nigerian varieties of sorghum. *Brewers Digest* 12: 24-29.

Ouattara, B., Hien, V. and Lompo, F. 1999. Development of water management technologies for rainfed crops in Burkina Faso. *In* Pala, M., Studer, C. & Bielders, M.

(eds.). Efficient Soil Water Use: The Key to Sustainable Crop Production in the Dry Areas of West Asiak and North and Sub-Saharan Africa. ICRISAT, Patancheru, India. pp. 265 – 281

Owuama, C.I. and Asheno, I. 1994. Studies on malting conditions for sorghum. *Food Chemistry*, 49: 257-260.

Palé, S., Mason, S.C. and Taonda, S.J.B. 2009. Water and fertilizer influence on yield of grain sorghum varieties produced in Burkina Faso. *South African Journal of Plant and Soil* 26: 91-97.

Palmer, G.H. 1989. Cereals in malting and brewing. *In* G.H. Palmer (eds.). Cereal science and technology. Aberdeen University Press, Aberdeen. pp. 167-168.

Rajewski, J., Francis, C.A. and Eastin, J.D. 1991. Differential response to defoliation of grain sorghum yield components and yield related traits. *Crop Science* 31 : 561-567.

Sanders, J.H., Nagy, J.G. and Ramaswamy, S. 1990. Developing new agricultural technologies for the Sahelian countries: The Burkina Faso case. *Economic Development and Cultural Change* 39:1-22.

Sanders, J. H. 1999. Availability and adoption of improved technologies in the semi-arid and sub-humid zones of West Africa. *In* S. K. Debrah & W. G. Koster (eds.). Linking soil fertility management to agricultural input and output market development: the key to sustainable agriculture in West Africa. *Miscellaneous fertilizer studies* 16: 61-72. IFDC - Africa, Lomé, Togo.

Saul, M. 1981. Beer, Sorghum and Women: Production for the market in rural Upper Volta. *Journal of the International African Institute* 51: 746-764.

Subramanian, V., Murty, D.S., Rao, N.S. and Jambunathan, R. 1992. Chemical changes and diastatic activity in grains of sorghum (*Sorghum bicolor*) cultivars during germination. *Journal of the Science of Food and Agriculture* 58: 35-40.

Taonda, S.J.B. 2005. Microdose fertilizer study on pearl millet in Burkina Faso. In: S.C. Mason. Optimizing grain yield and nutrient water use efficiency of pearl millet and grain sorghum. Project UNL-213 INTSORMIL, 2005 Annual Report, 49-50. INTSORMIL, Lincoln, NE.

Taonda, S.J.B. 1999. Amélioration des systèmes de culture à base de mil (Improving pearl millet based cropping systems). Rapport d'Activités dans le cadre du Projet P4, ROCAFREMI, Burkina Faso.

Taylor, J.R.N. and Dewar, J. 2001. Developments in sorghum food technologies. *In* S. L. Taylor (eds.), Advances in Food and Nutrition. Research Vol. 43; Academic Press, San Diego, CA, USA.

Taylor, J. and Dewar, J. 2000. Fermented products: Beverages and porridges. *In* C.W. Smith (eds.). Sorghum: Origin, History, Technology, and Production. John Wiley and Sons, Inc., New York. pp. 751-795.

Taylor, J.R.N. and Boyd, H.K. 1986. Free α-amino nitrogen in sorghum beer mashing. *Journal of the Institute of Brewing* 37: 1109-1117.

Traoré, T., Mouquet, C., Icard-Verniere, C., Traore, A.S. and Treche, S. 2004. Changes in nutrient composition, phytate and cyanide contents and alpha-amylase activity during cereal malting in small production units in Ouagadougou (Burkina Faso). *Food Chemistry* 88: 105-114.

Utzurrum, Jr, S.B., Fukai, S. and Foale, M.A. 1998. Effect of later nitrogen application on growth and nitrogen balance of two cultivars of water stressed grain sorghum. *Australian Journal of Agricultural Research* 49: 687-694.

Waniska, R.D. and Rooney, L.W. 2000. Structure and chemistry of the sorghum caryopsis. *In* Smith, C.W. (eds.), Sorghum: Origin, History, Technology, and Production. John Wiley and Sons, Inc., New York. pp. 649-688.

Woyessa, Y.E., Pretorius, E., Hensley, M., van Rensburg, L.D. and van Heerden, P.S. 2006. Up-scaling of rain-water harvesting for crop production in the communal lands of the Modder River basin in South Africa: Comparing upstream and downstream scenarios. *Water S. A.* 32: 223-228.

Zaongo, C.G.L., Wendt, C.W., Lascano, R.J. and Juo, A.S.R. 1997. Interaction of water, mulch and nitrogen on sorghum in Niger. *Plant Soil* 197: 119-126.

WATER AND FERTILIZER INFLUENCE ON YIELD OF GRAIN SORGHUM VARIETIES PRODUCED IN BURKINA FASO

PALE, S.C. MASON AND S.J.B. TAONDA. 2009. Water and fertilizer influence on yield of grain sorghum varieties produced in Burkina Faso. *South African Journal of Plant and Soil*, 26: 91-97.

ABSTRACT

Grain sorghum [*Sorghum bicolor* (L.) Moench] is the major cereal crop used in the Central Plateau of Burkina Faso to produce the traditional beer called “dolo”. Experiments combining five water management techniques (WMT) and four fertilizer treatments (FT) in a randomized complete block design with a split-plot arrangement of treatments were conducted from 2003 to 2005. Water management techniques were allocated to main plots and FT to subplots. The objective was to determine the best cropping practice to optimize yields for two red grain sorghum varieties, IRAT9 and ICSV1001 (Framida), commonly used for dolo production. Results indicated that water conservation using tied-ridges produced higher grain yields. The highest yield benefit was 241 kg ha^{-1} for Framida. In the IRAT9 field, the highest yield benefit of 395 kg ha^{-1}occurred in the lowest rainfall year (736 mm) of 2005. In all years, microdose consisting of application of 19 kg N ha^{-1}, 19 kg P ha^{-1} and 19 kg K ha^{-1} as complex fertilizer NPK at planting, 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 (microdose + 20 kg P ha^{-1} + 30 kg N ha^{-1}) produced the highest grain yield increases from 420 to 756 kg ha^{-1} for Framida and from 812 to 1346 kg ha^{-1} for IRAT9. In the IRAT9 field, microdose + 20 kg P ha^{-1} + 30 kg N ha^{-1} produced the highest grain yield in all WM treatments, with yield increases from 518 to 1327 kg ha^{-1} depending on the WMT. Correlations indicated that the number of panicles harvested ha^{-1} were associated with grain yield for the two varieties. The best cropping system to optimize grain yield of Framida and IRAT9 was the use of tied-ridges and application of microdose + 20 kg P ha^{-1} + 30 kg N ha^{-1}.

Keywords: microdose, reversible tool IR12, tied-ridges, traditional beer, zaï

3.1. INTRODUCTION

In Burkina Faso, especially in the Central Plateau Region, where its 21-yr average grain yield is 700 kg ha^{-1}, grain sorghum is the major cereal crop used to produce the traditional beer, commonly called "*dolo*" and over 30% of the total grain sorghum production is devoted to *dolo* production (DSA-BF, 2001 and 2005). The use of grain sorghum in dolo production requires a constant supply of high quality grain and this can only be achieved through better cropping practices. Previous research on grain sorghum processing for malting and brewing helped to identify two red grain sorghum varieties IRAT9 and ICSV1001 (Framida) as the most suitable varieties for dolo production (Bougouma, 2002).

Grain sorghum is usually grown in stressful environments with high temperatures, lack of predictable water supply, fragile soils with low nutrient status, and limited growing season length. Bekunda *et al.* (1997) and Ofori (1999) indicated that the two most limiting nutrients to food production in Africa are nitrogen (N) and phosphorus (P). Breman and Debrah (2003) indicated that improving the African agricultural resource base by increasing either nutrient availability or water availability can increase the efficiency of external inputs and make them an attractive option for African farmers. Ayuk and Bationo (1999) emphasized the primary role that soil and water management play in ensuring successful growth of agricultural productivity in the Sahel. Zaongo *et al.* (1997) indicated that N is important to increase water use efficiency (WUE) of sorghum genotypes produced under rainfed conditions.

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. These holes will also trap other organic matter transported by the wind and water (Roose *et al.*, 1993). Sowing is done in the holes. Bationo and Mokwunye (1991) indicated that a modest annual application of 15 to 20 kg P ha^{-1} is usually adequate for sandy soils with a low P sorption.

One critical issue for the expansion of fertilizer use into the semi-arid regions is insufficient water (Sanders, 1999) to enhance the beneficial effects of fertilizer application. Utzurrum *et al.* (1998) reported that late application of N on sorghum plants reduced leaf senescence which then resulted in increased grain yield, even under water limiting conditions. Results from farmer-managed trials conducted in Burkina Faso showed higher sorghum grain yields with the combination of fertilizer and tied-ridges than with either fertilizer or tied-ridges alone (Nagy *et al.*, 1990). From a study conducted in Zimbabwe, Nyakatawa (1996) reported sorghum yield increases from 118 to 388 kg ha^{-1} when 1.5-m tied-ridges were used and increases to 1071 kg ha^{-1} when 50 kg N ha^{-1} was applied to the tied-ridges in years of limited rainfall. On land left under grassland, Woyessa *et al.* (2006) compared runoff stored in dams and used downstream for irrigation, with the infield rain-water harvesting (IRWH) technique used to capture and convert runoff to stored water in a microbasin for crop production. Results showed that the IRWH technique, coupled with appropriate farming practices, increased maize production six times more than the downstream irrigation strategy. Taonda (1999) in Burkina Faso, compared the effects of scarifying and tied-ridges on pearl millet grain yield and reported yield increases due to tied ridges of 112 kg ha^{-1} in years of sufficient rainfall (931 mm), 88 kg ha^{-1} in years of medium to intermediate rainfall (760 mm) and 474 kg ha^{-1} in years of low rainfall (621 mm). The effectiveness of tie-ridging at or after planting in reducing surface runoff, improving soil water availability, delaying water depletion and increasing yields had been reported by Gusha (2002), Howell (2002), Brhane *et al.* (2006) and Brhane and Wortmann (2008). Muehlig-Versen *et al.* (2003) tested the effects of small quantities of P, placed in or close to the planting hill, on growth of pearl millet grown under rainfed conditions and found that placed applications of 3, 5 and 7 kg P ha^{-1} led to 72%, 81% and 88% respectively, of the grain yield produced by broadcasting 13 kg P ha^{-1}. The study also showed that with P application, the addition of N resulted in an 80% grain yield increase. A four year study (2001 to 2004) evaluated the effect of different fertilization rates, based on a microdose application (4 g per hill at planting of a complex NPK fertilizer equivalent of 19 kg N ha^{-1}, 19 kg P ha^{-1} and 19 kg K ha^{-1}) on pearl millet production in the Central Plateau of Burkina Faso (Taonda, 2005). Results from this study showed higher grain yields resulting from the use of microdose with addition of 20 kg P ha^{-1} as triple super phosphate at planting and 30 kg N ha^{-1} as urea applied 45 days after planting. Pearl millet grain yield increases were 404 kg ha^{-1} and 543 kg ha^{-1} at the farm and research station, respectively. This indicated that the use of microdose fertilization alone was not sufficient to cover the pearl millet mineral nutrient needs.

Yield component studies with grain sorghum have shown the number of panicles per square meter to be positively associated with non-uniform stand reductions (Larson & Vanderlip, 1994) and N application (Rajewski *et al.*, 1991). Maman *et al.* (2004) reported a positive correlation of grain yield with kernel mass ($r^2 = 0.51$; p = 0.05 or less) and panicles per square meter ($r^2 = 0.80$; p = 0.05 or less) for grain sorghum.

The objective of this study was to identify the best cropping (water management and fertilizer application) practice to optimize grain sorghum yields. Meeting this objective would increase the potential of the crop to be an economical grain crop for Burkina Faso and other West African countries.

3.2. MATERIALS AND METHODS

The Central Plateau of Burkina Faso is a semi-arid, low yield potential area typical of the Sudanian belt of Sahelian West Africa (Figure 1.1). 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 cropping systems based on low yields of sorghum and pearl millet (Sanders *et al.*, 1996).

To optimize sorghum grain yield for traditional beer production, experiments combining different soil water management techniques and fertilizer treatments were conducted from 2003 to 2005 at the Saria Agricultural Research Station (12^o 16’ N lat; 2^o 09’ W long) located in the Central Plateau of Burkina Faso (Figure 1.1). Experiments were conducted under rainfed conditions and on separate fields (one for Framida and one for IRAT9), thus no statistical comparison between the sorghum varieties was possible. The soil type at the Saria Agricultural Research Station was a Ferric Lixisol (FAO-UNESCO, 1994). Soil analyses indicated that the soil in the Framida field is 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 field 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 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 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 of iron limited the two fields at a depth of 0.40 m for the Framida field and 0.60 m for the IRAT9 field. The average water holding capacity to these depths was 24 mm for the Framida field and 77 mm for the IRAT9 field. 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.

The Framida field had previously been fallowed for 4 years and the IRAT9 field for 10 years. The grain sorghum variety ICSV1001 (Framida) has a vegetative cycle of 120 days and IRAT9 has a vegetative cycle of 100-110 days.

The total seasonal precipitation was lower than the 26-year average (778 mm), with highest rainfall that occurred from June to September, with a peak in August, except in 2004 when the peak occurred in July. Minima for the air temperature (13 to 25^{O}C) were generally slightly lower than the 26-year averages (21 to 23^{O}C). In 2003, maxima for the air temperature (26 to 46^{O}C) were generally lower than the 26-year averages (37 to 45^{O}C). Maxima for the air temperature in 2004 (41 to 47^{O}C) and 2005 (33 to 52^{O}C) were generally higher than the 26-year averages.

Two factors were evaluated: (1) soil water management techniques and (2) fertilizer treatments. A randomized complete block design with a split-plot arrangement of treatments was used with four replications. The main plot was soil water management technique and the sub-plot was fertilizer treatment. The treatments were applied to the same experimental units each year.

Five soil water management techniques (WMT) were 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 3.1). 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.

Figure 3.1. Tie-ridging technique (Ridge : made along the planting rows ; Tie : made at 1 m distance and tying ridges).

3. Manual zaï (Figure 3.2) 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.

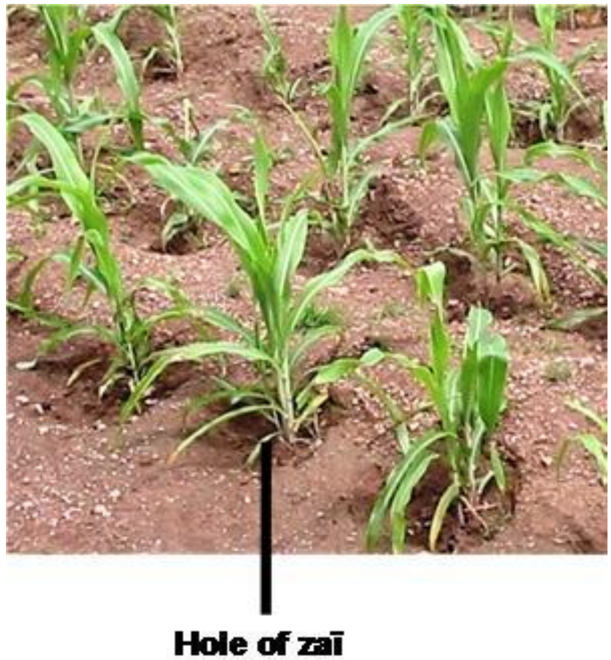

Figure 3.2. Zaï technique (Hole of zaï : sorghum plants are in the holes of the zaï).

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.

In the present study, the treatments named "manual zaï" and "mechanized zaï" are modified conventional zaï methods that did not contain compost (organic fertilizer) 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 DST technique, the planting rows are not crossed as in the mechanized zaï.

Four fertilizer treatments (FT) 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, 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 24 for Framida and July 25 for IRAT9 in 2003. In 2004, planting date was July 19 for both varieties. In 2005, planting date was July 12 for Framida and July 14 for IRAT9. Weed control was done by hand hoeing as needed.

In all three 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. In 2003, 1 L ha^{-1} of Decis® 12 EC containing deltamethrine as active ingredient was mixed with 50 L of water ha^{-1} and sprayed on the fields to control spittle bug [*Poophilus costalis* Walter] that attacked the crops 33 days after planting at the panicle initiation stage.

Grain yield, number of panicles harvested ha^{-1} and 1000-kernel mass from the plots were analyzed by combining years, using standard analysis of variance and pair-wised comparisons by the General Linear Model Procedure on the software SAS/STAT®, version 9.1. Results were considered significant when p = 0.05 or less. Pearson correlations among yield and yield components were calculated using data from 2003 and 2005.

3.3. RESULTS AND DISCUSSION

The analysis of variance showed that grain yield of Framida was due to year x fertilizer interaction effects and WMT main effects, but the number of panicles harvested and 1000-kernel mass were due to year x water management interaction effects (Table 3.1).

Table 3.1 ANOVA pro yields and yield components for grain sorghum varieties Framida and IRAT9 produced at Saria Agricultural Research Station, Burkina Faso, from 2003 through 2005.

	Degree of Freedom				
	Grain yields & panicles Harvested	1000 kernel mass	Grain yield	Number of panicles harvested	1000-Kernel mass
			Framida		
Year	2	1	<0.01	<0.01	<0.01
Water management	4	4	<0.01	<0.01	<0.01
Year x water management	8	4	0.37	0.01	0.01
Fertilizer	3	3	<0.01	<0.01	<0.01
Year x fertilizer	6	3	0.02	0.34	0.60
Water management x fertilizer	12	12	0.37	0.5	0.26
Year x water management x fertilizer	24	12	0.98	0.78	0.45
			IRAT9		
Year	2	1	<0.01	<0.01	<0.01
Water management	4	4	<0.01	<0.01	<0.01
Year x water management	8	4	<0.01	<0.01	<0.01
Fertilizer	3	3	<0.01	<0.01	<0.01
Year x fertilizer	6	3	<0.01	<0.01	0.46
Water management x fertilizer	12	12	<0.01	<0.01	0.01
Year x water management x fertilizer	24	12	<0.01	<0.01	0.28

Year x water management x fertilizer interaction effects for grain yield and number of panicles of IRAT9 were observed (Table 3.1). These year x water management x fertilizer interactions has little biological meaning, thus only the two-way interactions are discussed. For IRAT9, grain yield and yield components were affected by year x water management, year x fertilizer and water management x fertilizer interactions. Grain yield differences for both varieties were due to higher panicle number and/or kernel mass, found to be positively correlated with the grain yields as reported by Rajewski *et al.* (1991), Larson and Vanderlip (1994) and Maman *et al.* (2004).

3.3.1. Year x soil water management technique interaction and water management main effects on grain yields

In all three years and for both varieties, tied ridges produced the highest yields, although similar to scarifying and dry soil tillage for IRAT9 in 2003 and mechanized zaï in 2005 (Table 3.2, Appendix 1).

Table 3.2 Year x soil water management interaction effects on grain yield for grain sorghum variety IRAT9 and water management main effects on grain yield for grain sorghum variety Framida produced at Saria Agricultural Research Station, Burkina Faso, from 2003 through 2005.

	IRAT9				Framida
Water management	2003	2004	2005	Mean	Mean
	---------------------------------- kg ha^{-1} --------------------				
Scarifying	785 a	789 c d	997 b	857	494 b
Tied ridges	881 a	1148 a	1392 a	1140	735 a
Manual zaï	588 b	730 d	1038 b	785	340 c
Mechanized zaï	665 b	879 b c	1318 a	954	589 b
Dry soil tillage with IR12	848 a	919 b	1038 b	935	477 b
[a] Seasonal rainfall (mm)	767	742	736	748	748

Note: Values followed by the same letter in a column are not significantly different at p = 0.05 or less.

[a] Source: *Saria Meteorological Station*

Manual zaï produced the lowest yields, although similar to scarifying for IRAT9 in 2004 and 2005 and dry soil tillage in 2005. Data clearly showed that water conservation using tied ridges always produced higher grain yields, with the highest yield benefits of 241 kg ha^{-1} in the lighter textured soil with Framida in the lowest rainfall year of 2005 and 395 kg ha^{-1} for IRAT9 produced in the soil with higher clay content (Table 3.2).

Results from the present study confirmed the effectiveness of tied-ridges in improving soil water availability and food production previously reported by Nyakatawa (1996), Ayuk and Bationo (1999), Taonda, (1999), Gusha (2002), Howell (2002), Brhane *et al.* (2006) and Brhane and Wortmann (2008). The manual zaï did not improve grain yields for the two varieties compared to tied-ridges (Table 3.2), although previous studies showed that in combination with application of compost, zaï has increased yields (Barro *et al.*, 2005).

3.3.2. Year x fertilizer treatment interactions and fertilizer main effects on grain yields

In all three years, the year x fertilizer interaction effects were significant for both varieties (Table 3.1). These year x fertilizer interaction effects might be due to the irregular total seasonal rainfall during the study (Table 3.3, Appendix 2) that probably affected the fertilizer use efficiencies (FUE).

Table 3.3 Year x fertilizer treatment interaction effects on grain yields for grain sorghum varieties Framida and IRAT9 produced at Saria Agricultural Research Station, Burkina Faso, from 2003 through 2005.

	Framida				IRAT9			
Fertilizer	2003	2004	2005	Mean	2003	2004	2005	Mean
	------------------------------------- kg ha^{-1} ---------------------------------------							
Zero fertilizer	273 c	202 c	254 c	243	257 d	461 d	534 d	417
Microdose	547 b	528 a b	671 b	582	710 b	1042 b	1208 b	986
Recommended fertilizer rate	597 b	376 b c	332 c	435	444 c	797 c	1022 c	755
Microdose + 20P ha^{-1} + 30N ha^{-1}	1029 a	622 a	892 a	848	1603 a	1273 a	1862 a	1579
[a] Seasonal rainfall (mm)	767	742	736	748	767	742	736	748

Note: Values followed by the same letter in a column are not significantly different at $p = 0.05$ or less.

[a] Source: *Saria Meteorological Station*

More seasonal water stress, possibly due to the shallower depth, was observed in the Framida field, suggesting that fertilizers were less efficiently used in this field, leading to low grain yields. Although these year x fertilizer interaction effects were significant for the two varieties, microdose + 20 kg P ha^{-1} + 30 kg N ha^{-1} produced the highest grain yield increases from 420 to 756 kg ha^{-1} in all three years in the lighter textured soil with Framida, and from 812 to 1346 kg ha^{-1} in the higher clay content soil with IRAT9 and the control the lowest (Table 3.3). These results supported the important role that N and P play in food production reported by Bationo and Mokwunye (1991), Bekunda *et al.* (1997), Zaongo *et al.* (1997), Utzurrum *et al.* (1998) and Ofori (1999), Muehlig-Versen *et al.* (2003), and the necessary addition of more N and P to microdose (Taonda, 2005) to allow pearl millet plants to meet their mineral nutrient requirements.

Microdose increased grain yields over the recommended fertilizer rate in the soil with IRAT9 in all three years and in the Framida soil in 2005. These data indicated that microdose + 20 kg P ha^{-1} + 30 kg N ha^{-1} should be used to maximize yield, while microdose might be recommended when fertilizer availability is limited or the cost of fertilizers is high relative to grain price.

3.3.3. Soil water management x fertilizer interaction effects on grain yields

The water management x fertilizer interaction effects only occurred in the less sandy loam soil with IRAT9 (Table 3.1). The water holding capacities of this field with more clay content, and the consequences of its soil depth, probably enhanced soil storage of water in each WMT, especially in the tied-ridge plots. The soil water status probably affected the FUE and thus led to the water management x fertilizer interaction effects. Similar to the results for the fertilizer x year interaction effects (Table 3.3), microdose + 20 kg P ha^{-1} + 30 kg N ha^{-1} produced the highest yields in all WMT and zero fertilizer the lowest (Table 3.4, Appendix 3).

Table 3.4 Soil water management x fertilizer treatment interaction effects on grain yields for grain sorghum variety IRAT9 produced at Saria Agricultural Research Station, Burkina Faso, from 2003 through 2005.

Fertilizer	Scarifying	Tied ridges	Manual zaï	Mechanized zaï	Dry soil Tillage
	---------- kg ha^{-1} ----------				
Zero fertilizer	410 d	545 c	334 d	448 d	350 d
Microdose	944 b	1110 b	855 b	939 b	1085 b
Recommended Rate	757 c	1034 b	581 c	781 c	621 c
Microdose + 20P ha^{-1} + 30N ha^{-1}	1319 a	1872 a	1373 a	1649 a	1685 a

Note: Values followed by the same letter in a column are not significantly different at p = 0.05 or less.

The highest grain yields due to this fertilizer treatment occurred with the use of the tied-ridge technique. Compared to zero fertilizer treatment, yield increases due to microdose + 20 kg P ha^{-1} + 30 kg N ha^{-1} application were 518 to 1327 kg ha^{-1} depending upon the WMT. Earlier findings emphasized the importance of soil nutrient availability and water availability and their management to improve efficiency and increase crop biomass production along with grain yields (Nagy *et al.*, 1990; Nyakatawa, 1996; Zaongo *et al.*, 1997; Ayuk & Bationo, 1999; Sanders, 1999; Breman & Debrah, 2003; Woyessa *et al.*, 2006).

Application of microdose fertilizer produced higher yield than the recommended fertilizer rate in all WMT, except for the tied-ridge treatment where yields were similar. Although not measured, the tied-ridge technique should have stored more soil water from seasonal rainfall and, with lower soil water available, the microdose was superior to the recommended fertilizer rate.

3.4. CONCLUSIONS

Although the two grain sorghum varieties, Framida and IRAT9, were slightly different genetically (Bougouma, 2002) and were produced on soils of different depths and available water holding capacities, their responses to water management and fertilizers were similar. The highest grain yields for the two varieties were obtained with the use of tied ridges as a field water management technique and microdose to which were added 20 kg of P ha^{-1} and 30 kg of N ha^{-1} as fertilizer treatment. Microdose increased grain yields over the recommended fertilizer rate in the Framida field in 2005 and in the IRAT9 field in all three years and for all WMT, except for the tied-ridge technique where yields were similar. Based on the results, recommendations for the grain sorghum varieties Framida and IRAT9 grain yield maximization would be the use of tied ridges and microdose + 20 kg P ha^{-1} + 30 kg N ha^{-1} in the Central Plateau of Burkina Faso. Application of microdose alone might be recommended when fertilizer availability is limited or the cost of fertilizers is high relative to the grain price.

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REFERENCES

Ayuk, E.T. and Bationo, A. 1999. Socioeconomic assessment of soil fertility technology options in the Sahel. *In* S.K. Debrah & W.G. Koster (eds.). Linking soil fertility management to agricultural input and output market development: the key to sustainable agriculture in West Africa. *Miscellaneous Fertilizer Studies* 16: 52-60.

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

Bationo, A. and Mokwunye, A.U. 1991. Alleviating soil fertility constraints to increased crop production in West Africa: The experience in the Sahel. *Fertilizer Research* 29: 95-115.

Bekunda, A.M., Bationo, A. and Ssali, H. 1997. Soil fertility management in Africa: a review of selected research trials. *In* R.J. Brush, P.A. Sanchez and F. Calhoun (eds.). Replenishing soil fertility in Africa. SSSA, Special Publication No. 51, 63-80. Soil Science Society of America, Madison, Wisconsin.

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

Brhane, G., Wortmann, C.S., Mamo, M., Gebrekidan, H. and Belay, A. 2006. Micro-basin tillage for grain sorghum production in semi-arid areas of Northern Ethiopia. *Agronomy Journal* 98: 124-128.

Brhane, G.T. and Wortmann, C.S. 2008. Tie-ridge tillage for high altitude pulse production in Northern Ethiopia. *Agronomy Journal* 100: 2447-453.

Breman, H. and Debrah, S.K. 2003. Improving African Food Security. *SAIS Review* 23: 153 – 170.

DSA-BF. 2005. Evolution des rendements du sorgho par région et par province de 1984 à 2004 (Grain sorghum grain yield trends by region and province from 1984 to 2004). MAHRH, DGPSA, DSA, Ouagadougou, Burkina Faso.

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.

Gusha, A.C. 2002. Effects of tillage on soil microrelief, surface depression storage and soil water storage. *Soil & Tillage Research* 76: 105–114.

Hillel, D. 1980. Applications of Soil Physics. Academic Press, New York, pp. 771.

Howell, T.A., Schneider, A.D. and Dusek, D.A. 2002. Effects of furrow diking on corn response to limited and full sprinkler irrigation. *Soil Science Society Of America* 66: 222–227.

Larson, E.J. and Vanderlip, R.L., 1994. Grain sorghum yield response to non-uniform stand reductions. *Agronomy Journal* 86: 475-477.

Maman, N., Mason, S.C., Lyon, D.J. and Dhungana, P. 2004. Yield components of pearl millet and grain sorghum across environments in the Central Great Plains. *Crop Science* 44: 2138-2145.

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

Maunder, A.B. 2002. Sorghum worldwide, p. 11-17. *In* J.F. Leslie (eds.). Sorghum and millet diseases. Iowa State Press, Ames, IA, USA.

Muehlig-Versen, B., Buerkert, A., Bationo, A. and Roemheld, V. 2003. Phosphorus placement on acid arenosols of the West African Sahel. *Experimental Agriculture* 39: 307–325.

Nagy, J.G., Ohm, H.W. and Sawadogo, S. 1990. Farmer-researcher collaboration in developing cropping practices that involve the complementary use of mechanical tied ridge and fertilizer technology for sorghum in Burkina Faso. *Experimental Agriculture* 26: 161-169.

Nyakatawa, E.Z. 1996. Rain water and soil fertility management for sustainable cropping on sandy soils in semi-arid South-East Lowveld of Zimbabwe. *Journal of Sustainable Agriculture* 7: 19-34.

Ofori, S.C. 1999. The need for an integrated approach to soil fertility management in West Africa. *In* S.K. Debrah & W.G. Koster (eds.). Linking soil fertility management to agricultural input and output market development: The key to sustainable agriculture in West Africa. *Miscellaneous fertilizer studies* 16: 17-30. IFDC-Africa, Lomé, Togo.

Rajewski, J., Francis, C.A. and Eastin, J.D. 1991. Differential response to defoliation of grain sorghum yield components and yield related traits. *Crop Science* 31 : 561-567.

Roose, E., Kaboré, V. and Guenat, C. 1993. Le zaï: fonctionnement, limites et amélioration d'une pratique traditionnellle africaine de réhabilitation de la végétation et de restauration de la productivité des terres dégradées de la région soudano-sahelienne (The zaï : function, limitations and improvment of an African traditional practice to reclaim and restore soil productivity of degraded lands in the Sudano-Sahelian region). *Cahiers ORSTOM série Pédologie* 28: 159-174.

Sanders, J.H. 1999. Availability and adoption of improved technologies in the semi-arid and sub-humid zones of West Africa. *In*: S.K. Debrah & W.G. Koster (eds.). Linking soil fertility management to agricultural input and output market development: the key to sustainable agriculture in West Africa. *Miscellaneous fertilizer studies* 16: 61-72. IFDC - Africa, Lomé, Togo.

Sanders, J.H., Shapiro, B.I and Ramaswamy, S. 1996. The economics of agricultural technology in semi-arid sub-Saharan Africa. Johns Hopkins Univ. Press, Baltimore, Maryland. p. 328.

Taonda, S.J.B. 1999. Amélioration des systèmes de culture à base de mil (Improving pearl millet based cropping systems). Rapport d'Activités dans le cadre du Projet P4, ROCAFREMI, Burkina Faso.

Taonda, S.J.B. 2005. Microdose fertilizer study on pearl millet in Burkina Faso. *In*: S.C. Mason. Optimizing grain yield and nutrient water use efficiency of pearl millet and grain sorghum. Project UNL-213 INTSORMIL, 2005 Annual Report, pp. 49-50. INTSORMIL, Lincoln, NE.

Utzurrum Jr, S.B., Fukai, S. and Foale, M.A. 1998. Effect of later nitrogen application on growth and nitrogen balance of two cultivars of water stressed grain sorghum. *Australian Journal of Agricultural Research* 49: 687-694.

Wang, X. and Benson, C.H. 2004. Leak-free pressure plate extractor for measuring the soil water characteristic curve. *Geotechnical Testing Journal* 27: 1–10.

Woyessa, Y.E., Pretorius, E., Hensley, M., van Rensburg, L.D. and van Heerden, P.S. 2006. Up-scaling of rain-water harvesting for crop production in the communal lands of the Modder River basin in South Africa: Comparing upstream and downstream scenarios. *Water S A* 32: 223-228.

Zaongo, C.G.L., Wendt, C.W., Lascano, R.J. and Juo, A.S.R. 1997. Interaction of water, mulch and nitrogen on sorghum in Niger. *Plant Soil* 197: 119-126.

WATER AND FERTILIZER INFLUENCE ON SORGHUM GRAIN QUALITY FOR TRADITIONAL BEER (*DOLO*) PRODUCTION IN BURKINA FASO

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ABSTRACT

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.

4.1. INTRODUCTION

In the Central Plateau Region of Burkina Faso, where grain sorghum 21-yr average grain yield is 700 kg ha^{-1}, this crop constitutes the major cereal crop used to produce the traditional beer, commonly called "*dolo*". Previous studies indicated that 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* 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 *dolo*. 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 *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).

4.2. MATERIALS AND METHODS

4.2.1. 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 1.1). 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).

4.2.2. 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 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 3.1). 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 3.2) 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.

4.2.3 LABORATORY ANALYSIS

4.2.3.1. 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 (Braize, 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 xZ,

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.

4.2.3.2. 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.

4.2.3.2.1. 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.

4.2.3.2.2. 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 molecularly disperse the starch. The dispersed starch was then centrifuged at 1000 rpm for 2 min to remove all residues in suspension. Samples of the dispersed 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 concentrations, amylose and amylopectin concentrations (expressed in % in the starch) were determined using wheat standard starch and amylose.

4.2.3.2.3. Diastatic power and malting losses

i. 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 were 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.

ii. 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) (Novellie, 1962; Bougouma 2002):

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

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.

iii. 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 (Bougouma, 2002):

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

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 = 0.05 or less.

4.3. RESULTS AND DISCUSSION

4.3.1. 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.

4.3.2. 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 at p = 0.05 or less. 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.

4.3.2.1. Protein and starch

4.3.2.1.1. Year-by-water management interactions

In contrast to previous studies that have shown correlations between grain yield and starch concentration, and protein and starch concentrations (Griess et al., 2010), no significant correlations were present between grain yield and starch and between protein and starch in both experiments (Table 4.1).

Table 4.1. 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

Note: Values significant at p = 0.05 or less (N = 40).

These non-significant correlations ($p = 0.05$ or less) 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 4.1). 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 4.2, Appendix 4) and in 2004 in the Framida experiment (Table 4.3, Appendix 5).

Table 4.2. 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 IRAT9 produced for *dolo* at Saria Agricultural Research Station, Burkina Faso, from 2004 to 2005.

	Protein concentration [a]		**Tannin concentration** [a]		**Diastatic Power** [b]	
Water management	**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

Note: [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 4.3. Year x water management and Year x fertilizer interaction 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.

	Protein concentration [a]		**Tannin Concentration** [a]		**Diastatic Power** [b]		**Starch concentration** [a]	
Water management	**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		

Note: [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.

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 4.2) 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 4.2). 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 4.3). In this Framida field, the use of mechanized zaï in 2004 and manual zaï in 2005 increased the grain protein concentrations (Table 4.3). 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 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 4.3); the grain starch concentration for the mechanized zaï was higher than for the manual zaï in 2004 (Table 4.3).

4.3.2.1.2. Year-by-fertilizer interactions

Fertilizer applications generally increased the grain protein concentrations (Tables 4.2 and 4.3), 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 4.2 and 4.3). 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.

4.3.2.1.3. 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 (Table 4.4, Appendix 6; Table 4.5, Appendix 7).

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 4.4 and 4.5), 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 4.4 and 4.5) 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 and Belton, 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.

Table 4.4 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.

	Scarifying	Tied Ridges	Manual Zaï	Mechanized Zaï	Dry soil Tillage
Fertilizer treatment	**Total protein concentration (% of dry matter weight)**				
Zero fertilizer	13.4b	13.5a	13.3c	11.8d	13.3b
Microdose	13.8a	11.9c	13.4c	14.3a	13c
Recommended Rate	12.7c	12.8b	15.2a	12.5c	14.5a
Microdose + 20 P + 30 N	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
Microdose	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 + 30 N	0.97c	1.15b	1.25d	1.28c	1.12d
	Diastatic power *				
Zero fertilizer	81d	77d	83bc	108b	102b
Microdose	107b	94b	83c	108b	97c
Recommended Rate	86c	80c	85b	103c	82d
Microdose + 20 P + 30 N	112a	113a	112a	113a	109a

Note: * 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 4.5. 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.

	Scarifying	Tied Ridges	Manual Zaï	Mechanized Zaï	Dry soil Tillage
Fertilizer treatment	**Total protein concentration (% of dry matter weight)**				
Zero fertilizer	10.2c	9.4b	10.1c	10.4a	10.9b
Microdose	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 + 30 N	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
Microdose	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 + 30 N	0.81a	0.69c	0.69d	0.71c	0.70d
	Diastatic power *				
Zero fertilizer	39d	38c	47c	25d	54b
Microdose	59b	44b	62a	53c	61a
Recommended Rate	42c	62a	59b	69a	61a
Microdose + 20 P + 30 N	79a	43b	59b	57b	53b

Note: * 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.

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 ha^{-1} that generally increases grain protein concentrations (Tables 4.4 and 4.5) 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.

4.3.2.2. Tannin

4.3.2.2.1. Year-by-water interactions

Water management influence on grain tannin concentration varied with different water management treatments across years in both experiments (Tables 4.2 and 4.3). 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 4.2). 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 4.3). 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.

4.3.2.2.2. 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 4.2 and 4.3). Previous studies reported high levels of phenolics that were associated with nutrient poor soils and slow growth rates of plants (Bryant 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 4.2).

4.3.2.2.3. 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 4.4 and 4.5). 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 4.4 and 4.5). Increases in tannin concentration occurred in mechanized zaï plots with application of microdose in Framida experiment (Table 4.4) and in scarified plots with application of microdose + 20 kg P ha^{-1} and 30 kg N ha^{-1} in IRAT9 experiment (Table 4.5). 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 4.1).

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 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.

4.3.2.3. Diastatic power and malting losses

4.3.2.3.1. 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 4.2 and 4.3). 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 4.2). 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 4.3). 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. The analysis of variance indicated that malting loss levels were quite variable, thus no differences in malting losses related to year-by-water interaction effects were observed in either experiment.

4.3.2.3.2. 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 analyses (Table 4.1) indicated a positive relationship between the grain protein concentration and 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 4.2 and 4.3) was also expected. Results showed lower diastatic power in plots where recommended fertilizer was applied in 2004 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 4.1). 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.

4.3.2.3.3. Water management-by-fertilizer interactions

Water management-by-fertilizer interaction affected malted grain diastatic power in both experiments (Tables 4.4 and 4.5). 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 4.5). 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 4.4). The analysis of variance indicated that 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. 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.

4.4. CONCLUSIONS

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 g 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 4.2). Results from these studies indicate that for Framida the combination of water management techniques such as scarifying, tie-ridging, manual zai, mechanized zai or dry soil tillage with application of microdose + additional 20 kg P ha^{-1} and 30 kg N ha^{-1} produced a sorghum malt with higher diastatic power than the commercially acceptable one (Table 4.4) which may explain the greater use of Framida in *dolo* production than IRAT9. For IRAT9, this targeted diastatic power is only achieved in an agronomic practice combining scarifying and microdose + additional 20 kg P ha^{-1} and 30 kg N ha^{-1} (Table 4.5).

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. Pearson correlation data indicated that grain yield was rarely correlated with the physicochemical properties of raw grain and malt quality parameters in both Framida and IRAT9 fields, indicating that the quality of the grain is independent from lower or higher grain yields. 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 ensured ample soil water in combination with fertilizer that provides sufficient nutrients and particularly nitrogen to the crops.

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REFERENCES

Agu, R.C. and Palmer, G.H. 1998. A reassessment of sorghum for lager-beer brewing. *Bioresource Technology* 66: 253-261.

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

Beta, T., Rooney, L.W. and Waniska, R.D. 1995. Malting characteristics of sorghum cultivars. *Cereal Chem*istry 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, J.P., Clausen, T.P., Reichardt, P.B., McCarthy, M.C. and Werner, R.A. 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, V.R., Hernández-Valle, M., Mason, S.C. and Rooney, L.W. 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. and Nicou, R. 1991. Le sorgho (Sorghum). *In* Maisonneuve et Larose (eds.). Le technicien d'agriculture tropicale (The technology of tropical agriculture). Paris, France. p.159.

Chavan, J.K., Kadam, S.S. and Salunkhe, D.K. 1981. Changes in tannin, free amino acids, reducing sugars, and starch during seed germination of low and high tannin cultivars of sorghum. *Journal of Food Science* 46: 638-639.

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

Dicko, M.H., Gruppen, H., Traoré, A.S., van Berkel, W.J.H. and Voragen, A.G.J. 2006. Sorghum grain as human food in Africa: relevance of content of starch and amylase activities. *African Journal of Biotechnology* 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, J.K., Mason, S.C., Jackson, D.S., Galusha, T.D., Yaseen, M. and Pedersen, J.F. 2010. Environment and hybrid influences on food-grade sorghum grain yield and hardness. *Crop Science* 50: 1480-1489.

Hillel, D. 1980. Applications of soil physics. Academic Press, New York, pp. 771.

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, C.E. and Walker, J.R.L. 1993. Simultaneous, rapid spectrophotometric determination of total starch, amylose and amylopectin. *Journal of the Science of Food and Agriculture* 63: 53-57.

Kamoshita, A., Fukai, S., Muchow, R.C. and Cooper, M. 1998. Genotypic variation for grain yield and grain nitrogen concentration among sorghum hybrids under different levels of nitrogen fertilizer and water supply. *Australian Journal of Agricultural Research* 49: 737-747.

Kaye, N.M., Mason, S.C., Jackson, D.S. and Galusha, T.D. 2007. Crop rotation and soil amendment alters sorghum grain quality. *Crop Science* 47: 722-729.

Mason, S.C. and D'Croz-Mason, N.E. 2002. Agronomic practices influence maize grain quality. *Journal of Crop Production* 5: 75 – 91.

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

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

Murty, D.S. and Kumar, K.A. 1995. Traditional uses of sorghum and millets. *In* D.A.V. Dendy (eds.). Sorghum and Millets: Chemistry and Technology. American Association of Cereal Chemists, Inc., St. Paul, Minnesota, USA, 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. *Journal of the Science of Food and Agriculture* 13: 121-123.

Novozamsky, I., Houba, V.J.G., Temminghoff, E. and Van der Lee, J.J. 1984. Determination of total N and total P in a single soil digest. *Netherlands Journal of Agricultural Science* 32: 322-324.

Owuama, C.I. and Asheno, I. 1994. Studies on malting conditions for sorghum. *Food Chemistry* 49: 257-260.

Palé, S., Mason, S.C. and Taonda, S.J.B. 2009. Water and fertilizer influence on yield of grain sorghum varieties produced in Burkina Faso. *South African Journal of Plant and Soil* 26: 91-97.

Palé, S., Taonda, S.J.B., Bougouma, B. and Mason, S.C. 2010. Sorghum malt and traditional beer (*dolo*) quality assessment in Burkina Faso. *Ecology of Food and Nutrition* 49: 129-141.

Sanders, J.H., Shapiro, B.I. and Ramaswamy, S. 1996. The economics of agricultural technology in semi-arid sub-Saharan Africa. Johns Hopkins Univ. Press, Baltimore, Maryland. p. 328.

Subramanian, V., Murty, D.S., Rao, N.S. and Jambunathan, R. 1992. Chemical changes and diastatic activity in grains of sorghum (*Sorghum bicolor*) cultivars during germination. *Journal of the Science of Food and Agriculture* 58: 35-40.

Taylor, J.R.N. and Dewar, J. 2001. Developments in sorghum food technologies. *In* S. L. Taylor (ed.), Advances in Food and Nutrition Research Vol. 43; Academic Press San Diego, CA, USA.

Taylor, J.R.N. and Belton, P.S. 2002. Sorghum. *In* Belton, P.S, and Taylor, J.R.N.(eds.), Pseudocereals and less common cereals. Springer, Berlin. pp. 25-91.

Walkley, A. and Black, I.A. 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 Science* 63: 251-263.

Wang, X. and Benson, C.H. 2004. Leak-free pressure plate extractor for measuring the soil water characteristic curve. *Geotechnical Testing Journal* 27: 1–10.

Waniska, R.D. and Rooney, L.W. 2000. Structure and chemistry of the sorghum caryopsis. *In* Smith, C.W. (eds.), Sorghum: Origin, History, Technology, and Production. John Wiley and Sons, Inc., New York. pp. 649-688.

SORGHUM MALT AND TRADITIONAL BEER (*DOLO*) QUALITY ASSESSMENT IN BURKINA FASO

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ABSTRACT

Sorghum malt and *dolo* quality evaluation criteria and parameters affecting quality were surveyed in six cities in Burkina Faso through questionnaires addressed to malt processors, *dolo* processors, retailers and consumers. The major quality criteria for malt quality assessment were perceived to be taste and presence/absence of roots in the malt. Taste, alcohol content and wort sufficiently cooked were perceived as major criteria for the *dolo* quality assessment. The major parameters affecting malt quality were perceived to be malt production period, proportions of grain and the amount of water entering malting, presence of pesticide residues in the malting grains and age of grain. Processing method, yeast source, proportions of the components (crushed grain, water, mucilage, yeast) entering *dolo* production, malt quality, wort temperature at time of inoculation, amount of energy available for cooking, wort and sediment boiling time, quality of mucilage, malt with non-sweet taste, presence/absence of roots in the malt and ease of filtering crushed malt were perceived as major parameters affecting the *dolo* quality. These results will further be integrated into training programs for malt and *dolo* processors for efficient malt production and *dolo* brewing that will improve the *dolo* chain in Burkina Faso.

Keywords: consumers, retailers, processors, local foods, brewing processes

5.1. INTRODUCTION

The traditional beer obtained from malt of grain sorghum and commonly called *dolo* in Burkina Faso is a product filtered, but still cloudy, and has a combination of sweet and sour taste, fruity aroma, and contains one to five percent v/v alcohol (Demuyakor and Ohta, 1993; Murty and Kumar 1995). Traditionally, the preparation of *dolo* involves malting of red sorghum grain followed by crushing, mashing-in, cooking, lactic fermentation, filtration, boiling and alcoholic fermentation of the wort. The colors of sorghum grain and flour play an important role in its acceptance by consumers (Waniska and Rooney, 2000).

The successful industrialization of *dolo* brewing depends on adequate infrastructure, skilled personnel, consistent quality of raw materials (clean, mature sorghum grain with low moisture content free of breakage and stress cracks, and insect damage) and the development of efficient brewing processes (Novellie and Taylor, 1993). Most breeding programs conducted in Africa tend to improve food crop performance based on agronomic characteristics, mainly high yield and tolerance to drought and pests (Badu-Apraku *et al*., 1995). Many studies have been carried out to improve the utilization of sorghum in beer brewing, but these studies were limited to morphology and ultra-structure (Aisien *et al*., 1983; Glennie *et al.*, 1983; Glennie, 1984), enzyme development and extraction (Dyer and Novellie, 1966; Okon and Uwaifo, 1985; EtokAkpan and Palmer, 1990; Ogbonna *et al.*, 2003), malting and malt quality (Morrall *et al.*, 1986; Subramanian *et al.*, 1992; Beta *et al.*, 1995; Hagir *et al.*, 1999; Taylor and Dewar, 2000) as well as mashing features (Taylor and Boyd, 1986; Aisien and Muts, 1987; Palmer, 1989). To date, research to determine malt and *dolo* quality, parameters affecting quality as perceived by processors and consumers has not been documented in Burkina Faso. The objective of this study was to identify the major criteria for assessing traditional beer (*dolo*) and malt (Figure 5.1) quality, and parameters affecting *dolo* and malt quality as perceived by processors and consumers. Results will help in the improvement of the *dolo* supply chain in Burkina Faso by providing more reliable information for training programs for efficient *dolo* brewing processes, development of best cropping practices to improve grain quality, and providing better selection criteria for sorghum breeding programs.

5.2. MATERIALS AND METHODS

The questionnaires used to conduct the survey were prepared by the senior author with assistance of survey professionals at the Institute of Environment and Agricultural Research (INERA) and the Department of Food Technology at the Institute of Applied Sciences and Technology Research (DTA/IRSAT), and were approved by the two institutions and the participating authors. The survey was conducted in six cities in the Central Plateau of Burkina Faso: Ouagadougou (capital of Burkina Faso), Manga, Pouytenga, Mogtédo, Pabré and Kamboinsé (Figure 1.2).

These cities were chosen for the survey since they are located in major red sorghum production zones where malt and *dolo* production and consumption is widespread. Two hundred forty randomly chosen individuals including malt processors (45 people), *dolo* processors (65 people), retailers (30 people) and consumers (100 people) participated in the survey (Figure 5.2). Traditional production of beer is a commercial activity usually practiced by women in Burkina Faso, and their economic well being and reputation is greatly influenced by the quality of the beer they produce (Murty and Kumar, 1995). The survey indicated that all the malt processors, *dolo* processors and retailers were female, while the consumers were either male or female. The questionnaires included questions addressing the following issues:

- Perceptions of high quality malt criteria: defined by *dolo* processors;
- Perceptions of parameters that influence malt quality, defined by malt processors;
- Perceptions of high *dolo* quality criteria, defined by *dolo* processors, retailers and consumers;

- Perceptions of parameters that influence *dolo* quality, defined by *dolo* processors and consumers.

Data were analyzed using SAS version 9.12 software. Criteria and parameters mentioned by at least 50% of the respondents were judged as major criteria for quality assessment or major parameters affecting quality; this will guide training program designers in the determination of parameters on which emphasis should be put when designing training programs for processors to improve the *dolo* production chain. Chi-square tests were performed for the major criteria for quality assessment and major parameters affecting quality for among group comparisons and results were considered significant when p = 0.05 or less.

5.3. RESULTS AND DISCUSSION

5.3.1. QUALITY EVALUATION CRITERIA

5.3.1.1. Malt quality assessment criteria according to malt processors

A summary of survey responses on criteria used by processors to assess malt quality are listed in Table 5.1. Results indicated that the surveyed malt processors had from 1 to 43 years experience in malt production. The major criteria used by these malt processors to assess malt quality (percent of respondents) were the taste of the malt (82%), and the presence/absence of roots in the malt (76%) (Table 5.1). The presence of roots in the malt which is related to the grain germinative power and the sweet taste of the malt are criteria for high quality malt assessment. Though red sorghum is the most used for *dolo* production in the study area, the color of the malt was not perceived to be an important criterion in malt quality assessment and was mentioned by only 46% of the malt processors (Table 5.1). A small number of malt processors indicated that malt weight (heavy malt is desired), conservation ability of malt influenced by the malt moisture content after drying and the storage conditions, and malt moisture content were criteria used to assess malt quality.

Table 5.1 Sorghum malt and *dolo* quality assessment criteria used by malt processors (N = 45) and *dolo* consumers (N = 165)

Malt quality assessment criteria by malt processors	Frequency (%)	*Dolo* quality assessment criteria By *dolo* consumers	Frequency (%)
Sweet taste	**82**	**Taste**	**82**
Presence/Absence of roots	**76**	not very acidic	32
Color	**46**	half acidic half sweet	26
Red	38	Sweet	24
dark red	4	**Alcohol content**	**73**
Yellow	4	Alcoholic	56
Smell	**34**	very alcoholic	10
Presence/absence of shoots	**24**	less alcohol	7
Presence	13	**Wort sufficiently cooked**	**63**
Absence	11	**Texture**	**43**
Absence of mold	**24**	Heavy	29
Cleanliness of the malt	**20**	Medium	8
Malt appearance	**13**	Light	6
Malt moisture content	**9**	**Hygiene**	**43**
very low	7	Cleanliness of utensils	37*
Low	2	Cleanliness of water for sale	36*
Capacity for conservation	**9**	Cleanliness of the place of sale	35*
Malt weight	**4**	cleanliness of the place of conservation	31*
		Cleanliness of the person selling the *dolo*	5*
		Cleanliness of the *dolo*	5*
		Color	**33**
		Presence/Absence of toxic substances in the *dolo*	**26**
		Smell	**19**
		Presence of froth on top of *dolo*	**12**
		Capacity for conservation	**5**

Note: N, number of interviewed people. All criteria in bold are main criteria. *Sum > 43 because several answers were possible.

5.3.1.2. Dolo quality assessment criteria according to consumers

A summary of survey responses on criteria used by consumers to assess *dolo* quality are listed in Table 5.1. Results indicated that the surveyed *dolo* consumers had consumed *dolo* for the past 2 to 60 years. Respondents indicated that taste (82%) was the most important criteria to assess *dolo* quality, followed by alcohol content related to the alcoholic fermentation phase (*dolo* still fermenting or fully fermented) (73%) and the wort being sufficiently cooked (63%) (Table 5.1). The survey indicated that consumers prefer *dolo* with a high alcohol content, non-acidic taste and heavy texture. Kayode *et al.* (2005) indicated that high alcohol content, opaque appearance with an appreciable solid content, pink or red color, effervescent, sour, and alcoholic beer taste and smell as being major quality criteria used by consumers to determine a high quality *tchoukoutou*, another sorghum opaque beer from Benin. Consumers are attracted to *dolo* that has been conserved and sold in clean containers and which is fully fermented. Color of the *dolo*, presence of froth, and the age (*dolo* should be consumed within one day following alcoholic fermentation to avoid losses) were perceived as minor *dolo* quality attributes.

The chi-square tests for major criteria for *dolo* quality assessment indicated that all three groups agreed on the importance of taste and wort sufficiently cooked to insure a good fermentation of *dolo* for quality assessment (Table 5.2). Texture and wort sufficiently cooked to insure a good fermentation of *dolo* were more important to *dolo* processors than other two groups, while alcohol content and hygiene were of more importance to consumers than to *dolo* processors and retailers.

Table 5.2 Percent of respondents per survey group for each major *dolo* quality criterion and chi-squares for Group Comparisons

	Group				
Criterion	*Dolo* Consumers	*Dolo* Producers	*Dolo* Resellers	Chi-square Value	Chi-square Probability
Taste	86	75	83	3.0538	0.2172
Texture	28	60	53	18.1827	0.0001
Alcohol content	85	54	73	19.3225	< 0.0001
Hygiene	52	29	43	8.3300	0.0155
Wort sufficiently cooked	63	66	57	0.7938	0.6724

Note: Sample size = 195

5.3.2. Parameters affecting quality

5.3.2.1. Parameters affecting malt quality according to malt processors

A summary of survey responses on parameters affecting malt quality according to malt processors are listed in Table 5.3. Malt processors perceived that major parameters affecting malt quality were the malt production period (100%), particularly when malting is done during the cold season; the proportions of grain and water (used for washing, steeping, watering) entering malting (100%); the presence of grain storage pesticide residues on grain (62%) that affects the viability of grain used for malting; and the grain age (64%) (Table 5.3). Kayode *et al.* (2005) indicated that processors' choice of sorghum for beer processing is mainly based on the ability of the grain to germinate quickly (germinative power), size and color of the grain, storage period, wort quantity and quality (mainly sugar content), and the origin of the grain. Unfortunately malting grain germinative power, mostly affected by the presence of wrinkled, insect bitten, broken and cracked grain, was not perceived during the survey to be a major parameter affecting malt quality.

Red grain sorghum varieties are the most used for dolo production in the Central Plateau of Burkina Faso, but results indicated that grain color was not perceived as being a major parameter affecting malt quality, in contrast to being a major factor that guides processors' choice when purchasing grain for *dolo* production (Table 5.3).

Table 5.3 Parameters affecting quality as perceived by malt processors (N = 45) and *dolo* processors (N = 65).

Parameters affecting malt quality according to malt Processors	Frequency (%)	Parameters affecting *dolo* quality according to *dolo* Processors	Frequency (%)
Proportion of grain and amount of water entering malting	**100**	**Processing method skills**	**100**
Malt production period	**100**	**Yeast source**	**100**
cold season	84	**Proportion of components entering the preparation of *dolo***	**97**
any season	11	**Wort temperature at time of inoculation**	**96**
hot season	5	Warm whatever the season	45
Presence of pesticide residues in the malting grain	**62**	Completely cooled whatever the season	37
Age of the grain	**56**	Completely cooled in hot season and warm in cold season	14
Malting grain containing wrinkled, insect bitten, broken or cracked grains	**45**	**Sediment and wort boiling time**	**92**
Ability of the grain to germinate quickly	**40**	**Quality of mucilage**	**78**
Amount of time needed for malt drying	**40**	**Taste**	**75**
Grain germinative power	**38**	Non-sweet	*72*
Quality of water entering malting	**33**	Sour	*3*
Grain color	**31**	**Presence/absence of roots in the malt**	**73**
bright red	29	Absence	*48*
dark red	2	Presence	*25*
Type of material used for malt packaging and conservation	**29**	**Ease of filtering crushed malt**	**64**
Malt storage place	**29**	**Malt smell**	**39**
Moldy grain	**24**	**Malt color**	**34**
Presence of impurities in the stock	**24**	Red	*31*
		Bright red	*3*

(Continued)

Table 5.3 (Continued)

Parameters affecting malt quality according to malt Processors	Frequency	Parameters affecting *dolo* quality according to *dolo* Processors	Frequency
Grain size	**20**	**Malt ability to chewing**	**34**
large grain	11	**Presence of mold in the malt**	**30**
small grain	7	**Age of malt**	**28**
Medium grain	2	**Presence of impurities in the malt**	**27**
Grain hardness	**18**	***Dolo* ability to be conserved**	**25**
hard grain	9	**Time required for alcoholic fermentation**	**23**
soft grain	9		
Time required for soaking	**16**		
Cleanliness of malting equipment	**13**		
Grain maturity state	**11**		
Origin of grain	**11**		
Grain taste	**9**		
Grain weight	**8**		
Addition of ashes during soaking	**7**		
Contact of malting grains with sesame (*Sesamum indicum*)	**2**		
Ghost next to the malting area during malting	**2**		

Note: N, number of people interviewed; all criteria in bold are main criteria

5.3.2.2. Parameters affecting dolo quality according to dolo processors

A summary of survey responses on parameters affecting *dolo* quality according to dolo processors are listed in Table 5.3. *Dolo* processors surveyed had 4 to 60 years experience. They perceived the type of yeast (Figure 5.3) used for alcoholic fermentation (100%), processing method (100%), proportions of crushed malt, water, yeast, mucilage entering the *dolo* preparation (97%) and malt quality (97%) to be important parameters that affect *dolo* quality (Table 5.3). The quality of the yeast used to carry out alcoholic fermentation and the timing of wort inoculation influence *dolo* quality (Taylor and Dewar, 2000). For example, during Harmattan [hot and dry wind from Sahara blowing in dry season (November to March) in West Africa] period, inoculation is initiated early while the wort is still a little warm to allow good alcoholic fermentation (Kayode *et al.*, 2005). The Mossi (an ethnic group) yeast, which is the most used to inoculate wort (89%), is usually produced locally, either directly by the *dolo* producer or is obtained from other local *dolo* producers. Ninety-six percent of the *dolo* processors indicated that the wort temperature at time of yeast inoculation has an influence on the quality of the *dolo*, and most of these processors mentioned the best time for inoculation to be when the wort is warm (30 ^{O}C) in both cold and hot seasons (Table 5.3). Other parameters that may adversely affect *dolo* quality were the length of time for wort and sediment to boil- which varies depending on fuel source (crop stems vs. wood) and amount of energy available (92%), the quality of mucilage (78%), the malt taste (75%) and principally when the malt has a non-sweet taste, the presence/absence of roots in the malt (73%) and the ease of filtering crushed malt (64%). During the *dolo* production, separation of the insoluble components is facilitated by addition of mucilaginous substances (mucilage) such as crushed okra stems (Demuyakor and Ohta, 1991), or baobab or okra bark (Murty and Kumar, 1995). The survey indicated that white raisin (*Grewia bicolor*) bark or leaf fibers (locally obtained) were the most substances often used as mucilage in the Central Plateau of Burkina Faso. Since the shelf live of the *dolo* is so short, processors indicated that the *dolo* should be consumed the day following alcoholic fermentation to avoid spoilage, thus the storage capacity for *dolo* was not perceived as major parameters affecting quality.

The chi-square tests indicated that *dolo* consumers and processors did not agree on the importance of malt quality and processing method/skills in producing high quality *dolo* (Table 5.4). *Dolo* processors being more knowledgeable on the product and its process emphasized on these quality parameters more than consumers did.

Table 5.4 *Dolo* quality perception by processors and consumers.

	Group			
Criterion	*Dolo* Processors (% respondents)	*Dolo* Consumers (% respondents)	Chi-square Value	Chi-square probability
Malt quality	97	42	51.3531	<.0001
Processing method skills	100	82	13.1327	0.0003

Note: Sample size = 165

5.3.2.3. Parameters affecting dolo quality according to dolo consumers

A summary of survey responses on parameters affecting *dolo* quality according to *dolo* consumers are listed in Table 5.5. Consumers perceived that the processing method (82%) and the source and amount of energy for cooking (63%) were the most important parameters that alter *dolo* quality (Table 5.5). A few consumers (< 10% of respondents for each parameter) indicated that the quality of water used in *dolo* preparation, addition of sugar or liquor to the fermenting wort and wort temperature at time of inoculation affect the *dolo* quality.

Table 5.5 Parameters affecting *dolo* quality as perceived by consumers (N = 100).

Parameters affecting *dolo* quality according to consumers	Frequency (%)
Processing method skills	82
Source and amount of energy for cooking	63
Addition to *dolo* of toxic substances	44
Malt quality	42
Nature and cleanliness of production equipment	30
Contact of *dolo* with products such as sesame (*Sesamum indicum*) seeds, monkey cutlass tree (*Parkia biglobosa*) flour, and baobab (*Adansonia digitata*)flour	24
Quantity and quality of yeast	21
Dilution of *dolo* by addition of water to fermented *dolo*	16
Quality of water entering *dolo* preparation	7
Addition of sugar or liquor in fermenting wort	6
Wort temperature at time of inoculation (or addition of yeast)	5
Presence of crushed malt in the wort or in the fermented *dolo*	4
Passage of a ghost next to the fermenting *dolo*	3
Experience of the *dolo* processor	3
Mixture of filtrate and wort	2
Mucilage quality	1
Mixture of *dolo* of different sources	1

Note: N, number of people interviewed

In summary, the survey showed that the major quality criteria for malt quality assessment were perceived to be taste and presence/absence of roots in the malt. Taste, alcohol content and wort sufficiently cooked were perceived as major criteria for the *dolo* quality assessment. The major parameters affecting malt quality were perceived to be malt production period, proportions of grain and the amount of water entering malting, presence of pesticide residues in the malting grains and age of grain. Processing method, yeast source, proportions of the components (crushed grain, water, mucilage, yeast) entering *dolo* production, malt quality, wort temperature at time of inoculation, amount of energy available for cooking, wort and sediment boiling time, quality of mucilage, malt with non-sweet taste, presence/absence of roots in the malt and ease of filtering crushed malt were perceived as major parameters affecting the *dolo* quality.

5.4. CONCLUSIONS

Results from these studies showed various criteria used by processors and consumers to assess product (malt, *dolo*) quality, and parameters that influence quality. The study results also indicated that interviewed processors were knowledgeable about the main malting and brewing procedures and conditions and parameters that can affect malt and *dolo* quality. Unfortunately, these interviewed processors who did not receive any training in improved malting and brewing procedures, did not perceive the following aspects as parameters affecting quality. Determination of the grain germinative power before malting, washing and treatment of grain to remove pesticide residues and fungal attacks to ensure grain viability and its good germination, steeping conditions, conditions for good germination (temperature, watering), malting time length, malt drying conditions that determine the moisture content and malt conservation methods to ensure longer malt shelf-life were not emphasized by processors as major parameters influencing malt quality. *Dolo* distribution and conservation methods using adapted equipment to avoid direct contact of the *dolo* and the *dolo* retailer and ensure adequate hygiene, and also to allow a longer conservation time of the *dolo* were not highlighted by the people interviewed in this study. Suitable training programs should be developed and addressed to processors and others in the *dolo* supply chain in Burkina Faso to inform them about the importance of those parameters and improve processing method skills and quality. In addition to food performance based on agronomic characteristics (mainly high yield and tolerance to drought and pests) previously indicated by Badu-Apraku *et al*. (1995), the above criteria for quality assessment and parameters affecting quality must be integrated into suitable breeding programs to improve quality. Further research will be conducted to investigate the economic aspects of the malt production, *dolo* production and *dolo* retail marketing to help design regulations and strategies to improve the *dolo* production and marketing chain.

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REFERENCES

Aisien, A.O. and Muts, G.C.J. 1987. Micro-scale malting and brewing studies of some sorghum varieties. *Journal of the Institute of Brewing* 93: 328-331.

Aisien, A.O., Palmer, G.H. and Stark, J.R. 1983. The development of enzymes during germination and seedling growth in Nigerian sorghum. *Starch-Stärke* 9: 316-320.

Badu-Apraku, B., Okoruwa, A.E., Kling, J.G. and Kim, S.K. 1995. Improvement of maize genotypes with appropriate quality characteristics for industrial processing and use. *In* J.M. Menyonga, B. Taye, C.C. Nwasike, P.M. Sedego and E. Tenkouanoeds (eds.). Processing and industrial utilization of sorghum and related cereals in Africa. OAU/STRC-SAFGRAID, Ouagadougou, Burkina Faso. pp. 247-272.

Beta, T., Rooney, L.W. and Waniska, R.D. 1995. Malting characteristics of sorghum cultivars. *Cereal Chemistry* 72: 533-538.

Demuyakor, B. and Ohta, Y. 1991. Characteristics of pito yeasts from Ghana. *Food Microbiology* 8: 183-193.

Demuyakor, B.and Ohta, Y. 1993. Characteristics of single and mixed culture fermentation of pito beer. *Journal of the Science of Food and Agriculture* 62; 401-408.

Dyer, T.A. and Novellie, L. 1966. Kaffircorn malting and brewing studies XVI - The distribution and activity of α and β-amylases in germinating kaffircorn. *Journal of the Science of Food and Agriculture* 17: 449-456.

EtokAkpan, O.U. and Palmer, G.H. 1990. Comparative studies of the endosperm-degrading enzymes in malting sorghum and barley. *World Journal of Microbiology and Biotechnology* 6; 408-417.

Glennie, C.W. 1984. Endosperm cell wall modification in sorghum grain during germination. *Cereal Chemistry* 61; 285-289.

Glennie, C.W., Harris, J. and Liedenberg, N.V.D.W. 1983. Endosperm modification in germinating sorghum grain. *Cereal Chemistry* 60: 27-31.

Hagir, B.E., Babiker, E.E., and Abdullahi El Tinay, H. 1999. Changes in chemical composition, grain malting, starch and tannin contents and protein digestibility during germination of sorghum cultivars. *Food Chemistry 64:331-336.*

Kayode, P.A.P., Adegbidi, A., Hounhouigan, D.J., Linnemann, R.A. and Nout M.J.R. 2005. Quality of farmers' varieties of sorghum and derived foods as perceived by consumers in Benin. *Ecology of Food and Nutrition* 44: 271-294

Maunder, A.B. 2002. Sorghum worldwide. *In* J.F. Leslie (eds.). Sorghum and millet diseases. Iowa State Press, Ames, IA, USA. pp. 11-17.

Morrall, P., Boyd, H.K., Taylor, J.R.N. and van der Walt, W.H. 1986. Effect of germination time, temperature and moisture on malting of sorghum. *Journal of the Institute of Brewing* 92: 439-445.

Murty, D.S., and Kumar, K.A. 1995. Traditional uses of sorghum and millets. *In* D.A.V. Dendy (eds.). Sorghum and Millets: Chemistry and Technology. American Association of Cereal Chemists, Inc., St. Paul, MN, USA. pp. 185-221.

Novellie, L., and Taylor, J.R.N. 1993. Beverages from sorghum and millet. *In* R. Macrae, R.K. Robinson, and M.J. Sadler (eds.). Encyclopedia of Food Science, Food Technology and Nutrition. Academic Press, London. pp. 1781-1786.

Ogbonna, A.C., Obi, S.K.C. and Okolo, B.N. 2003. Modifications of the methods for the extraction of carboxypeptidase and proteinase activities from sorghum malts. *Journal of the Institute of Brewing* 109: 51-56.

Okon, E.U. and Uwaifo, A.O. 1985. Evaluation of malting sorghums 1. The malting potential of Nigerian varieties of sorghum. *Brewers Digest* 12: 24-29.

Palmer, G.H. 1989. Cereals in malting and brewing. *In* G.H. Palmer (eds.). Cereal Science and Technology. Aberdeen University Press, Aberdeen. pp. 167-168.

Subramanian, V., Murty, D.S., Rao, N.S. and Jambunathan, R. 1992. Chemical changes and diastatic activity in grains of sorghum (*Sorghum bicolor*) cultivars during germination. *Journal of the Science of Food and Agriculture* 58: 35-40

Taylor, J. and Dewar, J. 2000. Fermented products: Beverages and porridges. *In* C.W. Smith (eds.). Sorghum: Origin, History, Technology, and Production. John Wiley and Sons, Inc., New York, pp. 751-795.

Taylor, J.R.N. and Boyd, H.K. 1986. Free α-amino nitrogen in sorghum beer mashing. *Journal of the Institute of Brewing* 37: 1109-1117.

Waniska, R.D. and Rooney, L.W. 2000. Structure and chemistry of the sorghum caryopsis. *In* C.W. Smith (eds.). Sorghum: Origin, History, Technology, and Production. John Wiley and Sons, Inc., New York. pp. 649-688.

Figure 5.1 Malt being dried on floor

Figure 5.2 Women participating in the survey

Figure 5.3 Yeast being dried on sacks laid on floor

ECONOMIC ASSESSMENT OF MALT AND TRADITIONAL BEER (*DOLO*) PRODUCTION IN BURKINA FASO

PALE S, KABORE DP, TAONDA SJB, BOUGOUMA B AND MASON SC (2011). Economic assessment of malt and traditional beer (dolo) production and ways to improve the *dolo* chain in Burkina Faso. *Journal of Development and Agricultural Economics* 3: 689-694.

ABSTRACT

Costs and profits in malt processing, *dolo* brewing and *dolo* retail sales and ways to improve the *dolo* supply chain were surveyed in six cities in Burkina Faso, through questionnaires administered to malt processors, *dolo* processors, *dolo* retailers and *dolo* consumers. The highest costs were reported for *dolo* processing and the lowest profits for *dolo* retail sales. Large malt and *dolo* processors and dolo retailers had higher costs which were compensated for by greater profits than for medium and small processors/retailers. Comparisons of profits per unit cost indicated that malt processing in medium category, *dolo* processing in small category and *dolo* retail sales in large category often generate more profit per unit cost. The profit made by each member of the supply chain was higher than the Inter-professional minimum guaranteed salary (IMGS) in Burkina Faso. It appeared in this study that the improvement of the *dolo* supply chain would require that (1) credit be available and accessible for farmers to produce quality sorghum grain and women processors to purchase equipment needed for malt and *dolo* processing, conservation and distribution, and (2) malt and *dolo* production and marketing systems to the benefit of all members of the supply chain be organized through improvement of the partnership between members, increase profit of all supply chain members and training to improve all supply chain members production skills.

Keywords: costs, *dolo*, malt, processors, retailers, profits

6.1 INTRODUCTION

Dolo is obtained by brewing starch from grain sorghum, millet and maize and is commonly filtered but still cloudy. It has a combination of sweet and sour taste, fruity aroma, and contains 1 to 5% v/v alcohol (Demuyakor and Ohta, 1993; Murty and Kumar 1995). In Burkina Faso, the traditional preparation of *dolo* involves malting of red sorghum grain followed by crushing, mashing-in, cooking, lactic fermentation, filtration, boiling and alcoholic fermentation of the wort. *Dolo* should be consumed within one day following alcoholic fermentation to avoid losses. Malting in *dolo* production involves steeping of 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 for brewing (Beta *et al.*, 1995; Taylor and Dewar, 2000).

Previous studies indicated that the majority of red sorghum grain is sold in the capital (Ouagadougou) or exported to neighboring countries in the form of malt. An important part of the grain is transformed into traditional beer (*dolo*) for local consumption. Malt and *dolo* production is primarily a female enterprise and their economic well being and reputation is greatly influenced by the quality of the beer they produce (Murty & Kumar, 1995; Saul, 1981). This generates significant profits, particularly for large-scale processors, thus benefiting females, an under-represented segment of the society in Burkina Faso. Unfortunately, an economic assessment of the traditional beer production that would result in a better understanding of key problems that need to be solved in order to improve the *dolo* supply chain and thus increase the economic potential of grain sorghum in Burkina Faso and neighboring countries remains an issue. Murty and Kumar (1995) indicated that a commercialized traditional product has a greater chance of being popular and culturally acceptable than an exotic or novel product.

The successful growth of *dolo* brewing depends on the presence of adequate infrastructure, skilled personnel, consistent quality of raw materials (clean, mature sorghum grain with low moisture content free of breakage and stress cracks, and insect damage), development of efficient brewing processes (Novellie & Taylor, 1993) and economic profitability. Most breeding programs conducted in Africa tend to focus on grain yield, not on grain quality for specific end uses and economic profitability. Many studies have been carried out to improve sorghum grain-based food performance based on agronomic characteristics, mainly high yield and tolerance to drought and pests (Badu-Apraku *et al*., 1995). The utilization of sorghum in beer brewing (EtokAkpan & Palmer, 1990; Ogbonna *et al.*, 2003), malting and malt quality (Subramanian *et al.*, 1992; Beta *et al.*, 1995; Hagir *et al.*, 1999; Taylor &. Dewar, 2000) as well as mashing features (Taylor & Boyd, 1986; Aisien & Muts, 1987; Palmer, 1989), and criteria for assessing *dolo* quality and parameters affecting quality (Kayode *et al.*, 2005; Palé *et al.*, 2010) have been studied. To date, research to assess the economic profitability of *dolo* production and to determine ways to improve the *dolo* supply chain has not been documented in Burkina Faso. The objective of this study was to assess the cost and benefit of malt and *dolo* production, and *dolo* retail sales. Results will help design programs to improve the *dolo* supply chain.

6.2 MATERIALS AND METHODS

The survey questionnaires used in the study were prepared by the senior author with assistance of survey professionals at the Institute of Environment and Agricultural Research (INERA) and the Department of Food Technology at the Institute of Applied Sciences and Technology Research (DTA/IRSAT). Questionnaires were approved by the two institutions and the participating authors. The survey was conducted using these questionnaires, from December, 2006 through January, 2007, in six cities in the Central Plateau of Burkina Faso: Ouagadougou (capital of Burkina Faso), Manga, Pouytenga, Mogtédo, Pabré and Kamboinsé (Figure 1.2).

These cities were chosen for the survey since they are located in major red sorghum production zones where malt and *dolo* production and consumption is widespread. Two hundred and thirty four (234) randomly chosen individuals including 40 malt processors, 64 *dolo* processors, 30 retailers and 100 consumers participated in the survey. Unfortunately, some of the economic data were unusable, thus reducing the number of malt processors to 37 and *dolo* processors to 32. The survey indicated that all the malt processors, *dolo* processors and retailers were female, while the consumers were either male or female; supporting the widely recognized fact that *dolo* commercial activity is primarily practiced by women in Burkina Faso (Murty & Kumar, 1995). The questionnaires included questions addressing the following issues:

Production and distribution costs, sales and profit in malt and *dolo* production, and retail sales;

Ways to improve the *dolo* chain as perceived by all individuals who participated in the survey.

Mean sales, mean costs, mean profits, profit per unit cost and coefficients of variation for profits were calculated from the survey data using the following equations:

$$\text{Mean Sales (MS)} = \frac{\sum_{i=1}^{N} Si}{N} \qquad \text{(Eq 1)}$$

$$\text{Mean Cost (MC)} = \frac{\sum_{i=1}^{N} Ci}{N} \qquad \text{(Eq 2)}$$

$$\text{Mean Profit (MP)} = \frac{\sum_{i=1}^{N} Pi}{N} = MS - MC \qquad \text{(Eq 3)}$$

$$\text{Profit per Unit Cost (PUC)} = \frac{MP}{MC} \qquad \text{(Eq 4)}$$

$$\text{Coefficient of Variation (VC)} = \frac{\text{Standard deviation}}{\text{Mean}} \times 100 \qquad \text{(Eq 5)}$$

where Si, is the monthly sales for each individual; Ci, is the monthly cost (variable costs + fixed costs) for each individual; Pi, is the monthly profit for each individual; and N, is the number of observations (individuals).

Malt and *dolo* processors, and retail sellers were classified as large, medium or small based on monthly sales (Table 6.1). Data were analyzed using Microsoft Excel and Genstat version 14. An analysis of variance (ANOVA) was preformed to compare sales, costs and profits for (1) chain members: groups of malt processors, *dolo* processors, and *dolo* retailers and (2) categories within these groups. Sales, costs and profits were considered significantly different when p = 0.10 or less. Ways to improve the *dolo* chain mentioned by at least 50% of the survey respondents were judged to be of great importance. Coefficients of variation, used to assess levels of risk incurred by each category of malt processors, *dolo* processors and dolo retailers, were calculated to compare the categories within each group.

Table 6.1 Categories of malt and *dolo* processors and retailers, defined based on monthly sales, Burkina Faso, from November, 2006 through December, 2007.

Category	Malt processors	N	*Dolo* processors	N	*Dolo* retailers	N
Small	≤ 200 000	23	≤ 250 000	18	≤ 150 000	10
Medium	]200 000 – 400 000[	7	]250 000 – 500 000 [	7	]150 000 – 300 000[	18
Large	≥ 400 000	7	≥ 500 000	5	≥ 300 000	2

Note: N, number of people interviewed. Values for category classification are in FCFA.

6. 3 RESULTS AND DISCUSSION

6.3.1 PRODUCTS SOLD AND MAJOR COSTS

The main products sold are malt for malt processors; *dolo*, sediment (animal feed), yeast and charcoal for *dolo* processors; and d*olo* and yeast for *dolo* retailers. The survey indicated that the major costs were:

1) Costs for malt processors include (a) acquisition of raw material (grain, water), (b) building, production and distribution equipment (areas for malting and drying, warehouses, pots, bowls, buckets, drums or barrels (Figure 6.1), cans, jars (Figure 6.2), calabashes, baskets), (c) labor, (d) transport, and (e) taxes and fees.
2) Costs for *dolo* processors include (a) acquisition of raw material (grain or malt, water, yeast, mucilage, etc.), (b) houses and production and distribution equipment ["improved stoves" (Figure 6.3) for *dolo* preparation, warehouses, pots, bowls, buckets, drums, cans, jars, calabashes, baskets, filters (Figure 6.4 A, B and C), cabinets, benches, tables, soap, energy (wood particularly), etc.], (c) labor, (d) transport, and (e) taxes and fees.
3) Costs for *dolo* retailers include (a) purchase of *dolo* from processors, (b) acquisition of water and soap, (c) places for selling *dolo*, bowls, buckets, drums, cans, jars, calabashes, baskets, cabinets, benches, tables, soap, etc.), and (d) taxes and fees.

The survey also indicated that malt and *dolo* prices vary depending on daily supply and demand (Saul, 1981), which is influenced by the fact that, it is not easy to store sorghum beer (Palé et al., 2010; Saul, 1981).

6.3.2 SALES, COST AND PROFIT

Given that the categories of malt processors, *dolo* processors and retailers were defined, based on their monthly sales, only costs, profits and profits per unit cost are presented and discussed. The ANOVA showed results that are largely influenced by natural variation and the number of respondents in each category.

6.3.2.1 Chain members

Costs in malt processing and *dolo* retail were similar while *dolo* processors who usually used more labor than the other groups had approximately 33% higher costs (Table 6.2). Economic profits for *dolo* and malt processing were similar, while retail sales had lower profit potential as they had to purchase *dolo* to sell. The production of *dolo* is mainly hampered by lack of capital particularly for young or small-scale brewers and for retailers who buy *dolo* from brewers and retail it with reduced profit (Saul, 1981). In addition, consumers ask to taste the product before they buy thereby reducing the quantity of *dolo* being sold and profit made. Comparison of the profits per unit cost showed that, although *dolo* processors had higher economic profits, malt processing generated greater profit per unit cost, but risk in this latter activity is greater than in others (Table 6.2). In Burkina Faso, a salary of 30 684 FCFA is considered as the Inter-professional minimum guaranteed salary (IMGS) (Ministry of Budget and Finances, 2006). Results from this survey indicated that the profit made by each member of the supply chain was higher than the IMGS in Burkina Faso (Table 6.2).

Table 6.2 Monthly sales, costs, profits, profits per unit cost and variation coefficients for all chain members, Burkina Faso, from November, 2006 through December, 2007.

Group	N	Sales	Cost	Profit	PUC	VC
		-------------------------	-FCFA-	-------------------------		
Dolo processors	37	297 726	195 758	101 968	0.52	64
Malt processors	30	214 219	129 788	84 431	0.65	99
Dolo retailers	30	189 295	130 851	58 444	0.45	80
p-value		0.02	0.03	0.05	-	
l.s.d.		66 527	45 844	27 883	-	

Note: N, number of people interviewed. PUC, profit per unit cost. VC, variation coefficient. l.s.d., least significant difference of means; 1 Euro = 656 FCFA.

6.3.2.2 Malt processors

Large malt producers had higher costs and higher profits due to higher labor requirement which was compensated for by greater sales than for medium and small processors who produced less malt (Table 6.3). Costs for medium and small malt processors were 54 and 81% less than for large malt processors, but large malt processors had 99 and 620% greater profit. Comparison of the profits per unit cost showed that, although large malt processors had higher economic profits, malt processing in medium category generated greater profit per unit cost with lower risk (Table 6.3). All three malt processor classes made greater profits than the IMGS in Burkina Faso which is particularly important since all were females.

Tables 6.3 Monthly costs, profits, profits per unit cost and variation coefficients for malt processors, *dolo* processors and *dolo* retailers, Burkina Faso, from November, 2006 through December, 2007.

	Malt processors				Dolo processors				Dolo retailers			
Category	Cost	Profit	PUC	VC	Cost	Profit	PUC	VC	Cost	Profit	PUC	VC
					FCFA							
Large	331 238	227 781	0.69	30	440 535	160 745	0.36	53	331 320	175 368	0.53	22
Medium	152 620	114 618	0.75	17	237 007	137 014	0.58	49	126 885	62 480	0.49	61
Small	61 528	31 616	0.51	59	111 722	72 012	0.64	52	97 896	27 795	0.28	39
p-value	< 0.01	< 0.01	-		< 0.01	< 0.01	-		< 0.01	< 0.01	-	
l.s.d	50 711	24 578	-		41 063	46 806	-		46 018	40 115	-	

Note: PUC, profit per unit cost. VC, variation coefficient. l.s.d., least significant difference of means. 1 Euro, 656 FCFA.

6.3.2.3 Dolo processors

Large *dolo* producers had higher costs compared to medium and low processors due to the volume of *dolo* produced being greater (Table 6.3). Medium *dolo* processors had higher costs than small processors. Large and medium *dolo* processors had similar profit, while small processors had -55% profit. Costs for medium and small *dolo* processors were 46 and 75% less than those for large malt processors. Comparison of the profits per unit cost showed that, although large and medium *dolo* processors had higher economic profits, *dolo* brewing in small category generated greater profit per unit cost, while brewing in medium category had greater risk (Table 6.3).

Two of the *dolo* processors were found to be outliers with profits ranging from 1 000 000 to nearly 1 500 000 FCFA and profits per unit cost of 2.56 and 2.84. These two outliers with modern equipment for processing and distribution were found in the capital (Ouagadougou) and were the biggest suppliers of *dolo* for retail sellers in this city. All three *dolo* processor classes made profits higher than the IMGS in Burkina Faso (Table 6.3). The study also showed that household-scale brewing that is an economic activity of women is one of the few income-generating activities available to females in sub-Saharan Africa. McCall (2001) indicated that, although the financial returns to labor in household-scale brewing are usually poor, brewing constitutes the third-highest household income source in Burkina Faso (after farm produce sales and wage labor).

6.3.2.4 Dolo retailers

Large retailers had higher costs of 62 to 70% and higher profits of 64 to 84% compared to medium and small retailers (Table 6.3). *Dolo* retail sales in large category generated greater profit per unit cost with lower risk than the two other categories (Table 6.3). Results of this study indicated that small *dolo* retailer categories made profits less than the IMGS in Burkina Faso, in contrast to large and medium *dolo* retailers.

6.3.3 IMPROVING THE *DOLO* SUPPLY CHAIN

Malt and *dolo* processors and retailers who participated in the survey mentioned that the principal supply source for their production, conservation and distribution equipment, and the raw material for malt and *dolo* production (sorghum grain, mucilage, yeast) was local suppliers (data not presented). A few surveyed individuals also purchased equipment and/or raw material in other provinces in Burkina Faso or in neighboring countries. Equipment and raw materials were indicated to be readily available throughout the year, but their high cost limited accessibility and acquisition. To improve the *dolo* supply chain, the participants in the survey proposed diverse strategies (Table 6.4). Among these strategies, the most frequently mentioned were: (1) access to credit (mentioned by all members of the supply chain) for farmers to produce quality sorghum grain and women processors to purchase equipment needed for malt and *dolo* processing, conservation and distribution, (2) organization of malt and *dolo* production, and marketing systems to the benefit of all members of the supply chain, increase profit of all supply chain members, and provide training to improve all supply chain members production skills. Further investigations are also needed to assess the economics of the sorghum grain production by farmers and the pasteurization possibilities for *dolo* to give the product a longer shelf life.

Table 6.4 Ways to the *dolo* chain improvement according to participants in the survey (in % of N respondents), Burkina Faso, from November, 2006 through December, 2007.

Propositions	*Dolo* Producers	Malt Producers	*Dolo* consumers	*Dolo* retailers
N=	64	40	100	30
Information, consciousness-raising and training on processing, conservation and distribution skills and on good hygienic practices	18	16	44	7
Access to credit	63	51	71	77
Organization of the production and marketing systems	48	56	38	57
Fight against the use of prohibited products such as toxic chemicals and drugs to consumers	2	4	25	0
Reduction of the quantities of industrially produced beer or increase of their prices	5	7	3	0
Reduction of taxes and fees	8	0	0	0

Note: N, number of people interviewed.

6.4 CONCLUSIONS

Results from this economic study showed differences in costs, sales and profits in the *dolo* chain from one group of members to another and from one category to another within each group. The study also indicated that, although equipment and raw materials were readily available throughout the year, their high cost limited accessibility and acquisition. Actions should be undertaken by policymakers and developers to make credit available for farmers to produce quality sorghum grain and women processors to purchase equipment needed for malt and *dolo* processing, conservation and distribution, thus increasing profits. Other important aspects to consider when designing programs to improve the *dolo* supply chain are the organization of malt and *dolo* production, marketing systems and suitable training programs to the benefit of all members to improve production skills and increase profit per unit cost in all *dolo* activities. The study provided a better understanding of key problems that need to be solved in order to improve the *dolo* supply chain and thus, increase the economic potential of grain sorghum in Burkina Faso and neighboring countries. Murty and Kumar (1995) indicated that a commercialized traditional product has a greater chance of being popular and culturally acceptable than an exotic or novel product.

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REFERENCES

Aisien AO and Muts GCJ (1987). Micro-scale malting and brewing studies of some sorghum varieties. *J. Inst. Brew.* 93: 328-331.

Badu-Apraku B, Okoruwa AE, Kling JG and Kim SK (1995). Improvement of maize genotypes with appropriate quality characteristics for industrial processing and use. *In* J.M. Menyonga, B. Taye, C.C. Nwasike, P.M. Sedego and E. Tenkouanoeds (eds.). Processing and industrial utilization of sorghum and related cereals in Africa. OAU/STRC-SAFGRAID, Ouagadougou, Burkina Faso, pp. 247-272.

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

Bramel-Cox PJ, Kumar KA, Hancock JD and Andrews DJ (1995). Sorghum and millets for forage and feed. *In* D.A.V. Dendy (eds.). Sorghum and Millets: Chemistry and Technology. American Association of Cereal Chemists, Inc., St. Paul, Minnesota, USA, pp. 325-364.

Demuyakor B and Ohta Y (1993). Characteristics of single and mixed culture fermentation of pito beer. *J. Sci. Food Agric.* 62: 401-408.

EtokAkpan OU and Palmer GH (1990). Comparative studies of the endosperm-degrading enzymes in malting sorghum and barley. *World J. Microbiol. and Biotechnol.* 6: 408-417.

Hagir BE, Babiker EE, and Abdullahi El Tinay H (1999). Changes in chemical composition, grain malting, starch and tannin contents and protein digestibility during germination of sorghum cultivars. *Food Chem.* 64:331-336.

Kayode PAP, Adegbidi A, Hounhouigan DJ, Linnemann RA, and Nout MJR (2005). Quality of farmers' varieties of sorghum and derived foods as perceived by consumers in Benin. *Ecol. Food Nutr*. 44: 271-294

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

McCall M (2001). Brewing rural beer should be a hotter issue. *Boiling Point* 47: 23-25.

Ministry of Budget and Finances (2006). Decree N° 2006-655/PRES/PM/MTSS/MFB, December 29, 2006 defining the Inter-professional minimum guaranteed salaries. Ministry of Budget and Finances, Ouagadougou, Burkina Faso, pp.1.

Murty DS and Kumar KA (1995). Traditional uses of sorghum and millets. *In* D.A.V. Dendy (eds.). Sorghum and Millets: Chemistry and Technology. American Association of Cereal Chemists, Inc., St. Paul, Minnesota, USA, pp. 185-221.

Novellie L and Taylor JRN (1993). Beverages from sorghum and millet. *In* R. Macrae, R.K. Robinson, and M.J. Sadler (eds.). Encyclopedia of Food Science, Food Technology and Nutrition. Academic Press, London, pp. 1781-1786.

Ogbonna AC, Obi SKC and Okolo BN (2003). Modifications of the methods for the extraction of carboxypeptidase and proteinase activities from sorghum malts. *J. Inst. Brew.* 109: 51-56.

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

Palmer GH (1989). Cereals in malting and brewing. *In* G.H. Palmer (eds.). Cereal Science and Technology. Aberdeen University Press, Aberdeen, pp. 167-168.

Saul M (1981). Beer, Sorghum and Women: Production for the market in rural Upper Volta. *J. Int. Afr. Inst.* 51: 746-764.

Subramanian V, Murty DS, Rao NS and 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 J and Dewar J (2000). Fermented products: Beverages and porridges. *In* C.W. Smith (eds.). Sorghum: Origin, History, Technology, and Production. John Wiley and Sons, Inc., New York, pp. 751-795.

Taylor JRN and Boyd HK (1986). Free α-amino nitrogen in sorghum beer mashing. *J. Inst. Brew.* 37: 1109-1117.

Figure 6.1 Plastic barrels for dolo conservation and other uses

Figure 6.2 Traditional clay jar for dolo conservation and other uses

Figure 6.3 Improved stove using wood as energy source

Figure 6.4 A

Figure 6.4 B

Figure 6.4 C

Photo 6.4 DIFFERENT FILTERS USED IN *DOLO* PRODUCTION (A, B and C)

SYNTHESIS AND CONCLUSIONS

Quantitative and qualitative studies on grain sorghum for traditional beer (*dolo*) production in Burkina Faso

7.1 INTRODUCTION

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*. Improvement of the *dolo* chain supply that requires quantity and quality grain for *dolo* and ways to improve the supply chain constitutes a big challenge for processors and policy-makers. To that end, studies were conducted (1) to determine the best cropping practice to optimize grain yields and grain quality for IRAT9 and Framida (two red grain sorghum varieties) for *dolo* production, through experiments combining water management techniques and fertilizer treatments and conducted from 2003 to 2005, (2) to evaluate sorghum malt and *dolo* quality criteria and parameters affecting quality and (3) to assess costs and profits of malt and traditional beer (*dolo*) production through surveys conducted from December 2006 through January 2007. It was hypothesized that improvement of the *dolo* chain could be achieved through water and fertilizer management to improve quality and quantity of the sorghum grain and integration of quality criteria and parameters affecting quality into breeding programs..

7.2 SYNERGY OF WATER AND FERTILIZER MANAGEMENT ON GRAIN YIELD AND QUALITY

Chapters 3 and 4 showed that the combination of water management techniques and fertilizer treatments largely influenced grain yield production and grain quality of the grain sorghum varieties produced for traditional beer production. These chapters indicated that 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 application with additional phosphorus and nitrogen to provide sufficient nutrients and particularly nitrogen to the crop.

7.3 CRITERIA FOR QUALITY ASSESSMENT AND PARAMETERS AFFECTING QUALITY

The malt and traditional beer (*dolo*) quality assessment study (Chapter 5) indicated that the major quality criteria for malt quality assessment were perceived to be taste and presence/absence of roots in the malt. Taste, alcohol content and wort sufficiently cooked were perceived as major criteria for the *dolo* quality assessment. The major parameters affecting malt quality were perceived to be malt production period, proportions of grain and the amount of water entering malting, presence of pesticide residues in the malting grains and age of grain. Processing method, yeast source, proportions of the components (crushed grain, water, mucilage, yeast) entering *dolo* production, malt quality, wort temperature at time of inoculation, amount of energy available for cooking, wort and sediment boiling time, quality of mucilage, malt with non-sweet taste, presence/absence of roots in the malt and ease of filtering crushed malt were perceived as major parameters affecting the *dolo* quality.

7.4 ECONOMICS OF SORGHUM GRAIN PROCESSING

The economic study (chapter 6) showed differences in costs, sales and profits in the dolo chain from one group of members to another and from one category to another within each group. The study also indicated that, though equipment and raw materials were readily available throughout the year, their high cost limited accessibility and acquisition, thus limiting production.

7.5 CONCLUSIONS AND RECOMMENDATIONS

Improving sorghum grain yield and quality for traditional beer (*dolo*) production in the Central Plateau of Burkina Faso is a big challenge. This study contributed to the knowledge of the synergistic effect of water and mineral fertility management on sorghum grain yield and quality for *dolo* production, quality and parameters affecting assessment and costs and profits in grain processing in the Central Plateau of Burkina Faso. The results reported in this thesis indicate that high sorghum grain yield and malt with needed characteristics for high *dolo* quality could be achieved with the use of water management techniques that sufficiently improve soil water conditions in combination with a microdose application with additional phosphorus and nitrogen to provide sufficient nutrients and particularly nitrogen to the crop. The study also presented the various criteria used for malt and traditional beer (*dolo*) quality assessment and the parameters affecting quality.

Economic assessment indicated that, though equipment and raw materials were readily available throughout the year, their high cost limited accessibility and acquisition, thus limiting dolo production. These results impose that actions be undertaken by policy-makers and developers to make credit and inputs (fertilizers and seeds) and equipment available and accessible for farmers to produce quality sorghum grain and credit available for women processors to purchase equipment needed for malt and *dolo* processing, conservation and distribution, thus increasing profits. Other important aspects to consider, when designing programs to improve the *dolo* supply chain are the organization of malt and *dolo* production and marketing systems, and suitable training programs to the benefit of all members in the *dolo* supply chain in Burkina Faso to improve production skills and increase profits per unit cost in all *dolo* activities. Another important action to consider is the integration of criteria used by processors and consumers to assess quality and parameters affecting quality into suitable breeding programs to improve quality.

Quantitative and qualitative studies on grain sorghum for traditional beer (*dolo*) production in Burkina Faso

Appendix 1 Year x soil water management interaction effects on grain yield for grain sorghum variety IRAT9 and water management main effects on grain yield for grain sorghum variety Framida produced at Saria Agricultural Research Station, Burkina Faso, from 2003 through 2005.

Water management	IRAT9				Framida
	2003	2004	2005	Mean	Mean
	---------------------------------- kg ha^{-1} --------------------				
Scarifying	785	789	997	857	494
Tied ridges	881	1148	1392	1140	735
Manual zaï	588	730	1038	785	340
Mechanized zaï	665	879	1318	954	589
Dry soil tillage with IR12	848	919	1038	935	477
Standard error			35.88		45.58

Appendix 2 Year x fertilizer treatment interaction effects on grain yields for grain sorghum varieties Framida and IRAT9 produced at Saria Agricultural Research Station, Burkina Faso, from 2003 through 2005.

	Framida				IRAT9			
Fertilizer	2003	2004	2005	Mean	2003	2004	2005	Mean
	---------- kg ha^{-1} ----------							
Zero fertilizer	273	202	254	243	257	461	534	417
Microdose	547	528	671	582	710	1042	1208	986
Recommended fertilizer rate	597	376	332	435	444	797	1022	755
Microdose + 20P ha^{-1} + 30N ha^{-1}	1029	622	892	848	1603	1273	1862	1579
Standard error	70.62				32.09			

Appendix 3 Soil water management x fertilizer treatment interaction effects on grain yields for grain sorghum variety IRAT9 produced at Saria Agricultural Research Station, Burkina Faso, from 2003 through 2005.

Fertilizer	Scarifying	Tied ridges	Manual zaï	Mechanized zaï	Dry soil Tillage
	kg ha^{-1}				
Zero fertilizer	410	545	334	448	350
Microdose	944	1110	855	939	1085
Recommended Rate	757	1034	581	781	621
Microdose + 20P ha^{-1} + 30N ha^{-1}	1319	1872	1373	1649	1685
Standard error			41.43		

Appendix 4 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 IRAT9 produced for *dolo* at Saria Agricultural Research Station, Burkina Faso, from 2004 to 2005.

	Protein concentration [a]		Tannin concentration [a]		Diastatic Power [b]	
Water management	**2004**	**2005**	**2004**	**2005**	**2004**	**2005**
Scarifying	11.8	10.2	0.70	0.88	71	38
Tied-ridges	10.4	8.8	0.64	0.84	54	40
Manual zaï	11.5	9.3	0.66	0.87a	78	36
Mechanized zaï	10.8	9.4	0.68	0.84	73	29
Dry soil tillage	11.9	10.0	0.66	0.86	76	38a
	0.06		0.00		0.55	
Fertilizer						
No fertilizer	11.1	9.31	0.68	0.92	52	29
Microdose	10.6	9.9	0.66	0.84	70	42
Recommended fertilizer	11	9.1	0.68	0.87	80	37
Microdose + 20 P + 30 N	12.5	9.7	0.65	0.79	79	37
Standard error	0.06		0.00		0.49	

Appendix 5 Year x water management and Year x fertilizer interaction 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.

	Protein concentration [a]		**Tannin Concentration** [a]		**Diastatic Power** [b]		**Starch concentration** [a]	
Water management	**2004**	**2005**	**2004**	**2005**	**2004**	**2005**	**2004**	**2005**
Scarifying	13.7	13.2	1.18	1.30	103	91	60	64
Tied-ridges	13.5	12.4	1.21	1.31	102	80	65	58
Manual zaï	14.4	13.5	1.56	1.31	97	85	52	64
Mechanized zaï	15.0	11.2	1.30	1.33	123	93	70	58
Dry soil tillage	14.1	12.7	1.14	1.33	119	76	65	60
Standard error	0.06		0.00		0.60		3.24	
Fertilizer								
No fertilizer	13.6	12.5	1.40	1.44	104	76.		
Microdose	13.8	12.7	1.21	1.37	115	81		
Recommended fertilizer	14.2	12.9	1.34	1.31	87	88		
Microdose + 20 P + 30 N	14.9	12.2	1.16	1.15	120	94		
Standard error	0.05		0.00		0.54			

Appendix 6 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.

	Scarifying	Tied Ridges	Manual Zaï	Mechanized Zaï	Dry soil Tillage
Fertilizer treatment	**Total protein concentration (% of dry matter weight)**				
Zero fertilizer	13.4	13.5	13.3	11.8	13.3
Microdose	13.8	11.9	13.4	14.3	13
Recommended Rate	12.7	12.8	15.2	12.5	14.5
Microdose + 20 P + 30 N	13.8	13.5	13.8	13.8	12.7
Standard error	0.09				
	Tannin concentration (% of dry matter weight)				
Zero fertilizer	1.52	1.64	1.52	1.13	1.28
Microdose	1.23	1.10	1.47	1.47	1.19
Recommended Rate	1.23	1.15	1.50	1.38	1.34
Microdose + 20 P + 30 N	0.97	1.15	1.25	1.28	1.12
Standard error	0.01				
	Diastatic power *				
Zero fertilizer	81	77	83b	108	102
Microdose	107	94	83	108	97
Recommended Rate	86	80	85	103	82
Microdose + 20 P + 30 N	112	113	112	113	109
Standard error	0.85				

Appendix 7 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.

	Scarifying	Tied Ridges	Manual Zaï	Mechanized Zaï	Dry soil Tillage
Fertilizer treatment	**Total protein concentration (% of dry matter weight)**				
Zero fertilizer	10.2	9.4	10.1	10.4	10.9
Microdose	12.3	9.4	10.4	9.6	9.5
Recommended Rate	9.8	9.5	10.3	9.8	10.8
Microdose + 20 P + 30 N	11.6	10.0	10.8	10.4	12.7
Standard error			0.09		
	Tannin concentration (% of dry matter weight)				
Zero fertilizer	0.81	0.77	0.85	0.76	0.81
Microdose	0.79	0.77	0.71	0.75	0.73
Recommended Rate	0.74	0.74	0.79	0.81	0.79
Microdose + 20 P + 30 N	0.81	0.69	0.69	0.71	0.70
Standard error			0.00		
	Diastatic power *				
Zero fertilizer	39	38	47	25	54
Microdose	59	44	62	53	61
Recommended Rate	42	62	59	69	61
Microdose + 20 P + 30 N	79	43	59	57	53
Standard error			0.78		