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Review Article

GENETIC DIVERSITY, IMPORTANCE AND PROSPECTS FOR VARIETAL IMPROVEMENT OF SWEET GRAIN SORGHUM IN BURKINA FASO

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ABSTRACT

Sweet grain sorghum is a very important cereal for urban and especially rural communities in Burkina Faso. It is mainly grown by traditional farmers. Consumed fresh in a pasty state, the grains have a huge nutritional potential and could improve the quality of the consumers' diet. In addition, the marketing of panicles harvested at the doughy grain stage offers substantial income benefits to farmers and traders. The straw of this sorghum is also an excellent fodder for the integration of agriculture with breeding. Despite the many advantages of this crop, it has long remained under-exploited due to insufficient knowledge of its potential and little research attention. However, the conservation and improvement of the quality of sweet grain sorghum is an important issue for the various stakeholders in the crop chain. Thus, based on the various research studies conducted on the crop since 2008 in Burkina Faso, this literature review highlights the importance of sweet grain sorghum, its role in crop diversification, its nutritional properties, as well as the future possibilities for selection and genetic improvement of this species.

Keywords: Sweet grain sorghum, Variability, Conservation, Selection, Neglected crop.

INTRODUCTION

Sorghum bicolor (L.) Moench] is a monocot adapted to various environmental conditions. Human selection and gene flow with wild forms have led to several morphologically and genetically different types (Chantereau and Nicou, 1991). In Burkina Faso, several types of sorghum are found. Broom sorghum, whose panicles have long branches that can be transformed into brooms after threshing (Zongo, 1991). Grain sorghum, which is the most widely cultivated, whose grains are used to prepare local dishes such as '*tô*', fritters and porridge (Zongo, 1991, Barro-Kondombo, 2010) or to produce a local beer called '*dolo*' (Zongo, 1991; Palé *et al*., 2010; Songré-Ouattara *et al*., 2016). Dye sorghum is grown exclusively for the red dye obtained after grinding and maceration of the anthocyanated stems and leaf sheaths (Balolé & Legwaila, 2006; Nandkangré, 2009). Sweet sorghums, on the other hand, accumulate sugars in the fresh stalk (sweet stalk sorghum) or in the doughy grain (sweet grain sorghum). They can be consumed by chewing the fresh stalk (Nebié *et al*., 2013) or by chewing the doughy grains (Sawadogo, 2015). Sweet grain sorghum is used in some areas of Burkina Faso as a hunger food (Nebié *et al*., 2012; Sawadogo, 2015). Although recent studies have revealed nutritional (Tondé, 2016; Sawadogo *et al*., 2017; Tiendrébéogo, 2020) and socio-economic (Nebié *et al*., 2012; Sawadogo *et al*., 2014a; Tiendrébéogo *et al*., 2018) benefits, the genetic resources of this sorghum are very little exploited and valorized on a national scale. This situation is exacerbated by the recurrent decline in rainfall (Somé, 1989; Bambara *et al*., 2016; Bougma *et al*., 2016), the intensification of economically profitable crops (cotton, maize) and the development of formal seed programs supported by national policies (MAHRH, 2006; 2010; OECD/FAO, 2016). The conservation, maintenance and expansion of minor plants such as sweet grain sorghum

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could be achieved by exploiting their potential. Thus, since 2008, the Biosciences laboratory of the Joseph KI-ZERBO University has undertaken a program to valorize this type of sorghum. This review article presents the results of research on sweet grain sorghum, including knowledge on genetic diversity, different uses, conservation and prospects for the selection and varietal improvement of this species grown in Burkina Faso.

Ethnobotanical and Genetic description

Sweet grain sorghum belongs to the species *Sorghum bicolor* (L.) Moench (2n = 20), which includes all cultivated annual sorghums (Sawadogo, 2015). Ethnobotanically, it is known by various peasant names across the different ethnic groups (Sawadogo *et al*., 2014a).These farmers' names derive from the possible provenance of the accession or from discernible agro-morphological traits (Figure 1) such as panicle shape or grain flavour (Nebié *et al*., 2012; Sawadogo *et al*., 2014a). The multiplicity of names within the same ethnic group is a good indicator of variability. Regarding genetic studies, Sawadogo (2015) on a national collection of 126 accessions of sweet grain sorghum identified the presence of a single main race namely the *caudatum* race (45.36%), and two intermediate races which are *caudatum-guinea* (48.45%) and *guinea-bicolor* (6.19%). Molecular characterization using 15 polymorphic microsatellite markers revealed a total of 49 alleles, including 6 rare alleles, an average of 3 alleles per locus and a polymorphism rate of 87%. A moderate expected heterozygosity rate (-0.474) and a high intra-population genetic differentiation (Fis) (0.934) (Sawadogo *et al*., 2018).

MORPHOLOGY AND PHYSIOLOGY

Morphology

Cultivated sorghum plants consist of a root system, stems with leaves and end in a racemose inflorescence (Lafarge, 1986). The architectural composition of cultivated sorghum differs, however, according to the nature of the parts used in each variant. In the case of sweet grain sorghum, the morphological characteristics that distinguish it from other sorghums are most noticeable in the grain and the panicle. The grain is more or less spherical in shape and slightly flattened on one side (Sawadogo, 2015). The color of the grains (Figure 2) varies from light or dark red to grey (Sawadogo, 2011; Tondé, 2020).Thereserve organ (albumen)located in the pericarp, is floury and influences the food use of the grain (Yaméogo, 2021; Sawadogo *et al*., 2022a). The panicles are compact, semi-compact, lose or very loose with some nuances (loose umbrella panicle or with drooping branches, loose bird's nest panicle or with semi-erect branches, semi-compact elliptical panicle) (Figure 3) (Sawadogo *et al*., 2014a; Tondé, 2020; Sawadogo *et al*., 2022a).

Physiology

In the process from seed sowing to harvest, the physiological cycle of sweet grain sorghum is similar to grain sorghum and is predictably characterized by three periods. The vegetative period is characterized by the predominance of leaf apparatus development (main stem, tillers and leaves) and considerable intermodal stem elongation (Tondé, 2020). This period starts with seed germination after 48 hours and emergence of the coleoptile from the soil in 3 to 4 days after sowing (jas) (Tondé, 2020; Sawadogo *et al*., 2022b).Tillering begins 10 to 15 days after sowing (jas) with a number of tillers varying from 01 to 03 (Nebié *et al*., 2012; Tiendrébéogo *et al*., 2018). The vegetative period ends with the appearance of the panicle or flag leaf formation at the end of the stem at the level of the last sheath from 48 jas (Tondé, 2020). The reproductive period is marked by the development of the panicle inside the stem or swelling that becomes active or heading following the elongation of the peduncle from 57 jas (Tondé, 2020).Flowering and heading are almost synchronous. Indeed, the gap between heading and flowering in sweet grain sorghum is on average 1 day compared to 3 days for grain sorghum and sweet stem sorghum (Sawadogo *et al*., 2022b). Sweet grain sorghum has a short cycle. Its sowing-flowering cycle is between 61 and 91 days (Sawadogo *et al*., 2014a) compared to grain sorghum whose cycle varies from 60 to 112 days (Zongo, 1991; Barro-Kondombo, 2010; Gapili, 2016). Its earliness and sensitivity to photoperiod variation gives it flexibility to adapt to end-of-cycle drought (Nebié *et al*., 2012; Tondé, 2020; Namoano, 2018).

Figure 1.Sweet grain sorghum field at grain maturation stage (Tondé, 2020).

AGRONOMIC AND BIOCHEMICAL CHARACTERISTICS

Production areas and growing conditions

In Burkina Faso, sweet grain sorghum is grown in the country's four phytogeographic zones (Sahelian, sub-Sahelian, north Sudanian, south Sudanian) (Nebié, 2009; Sawadogo, 2015). The production of this sorghum is still rainfed and, therefore, production depends on rainfall. Sowing generally takes place after the other cereals have been planted, but it is harvested very early at the doughy stage from September (Nebié *et al*., 2012; Tondé, 2020).The optimal sowing date is from 20 June to 15 July, a period that allows the plant to complete its cycle while optimising yields (Namoano, 2018; Tondé, 2020). Sweet grain sorghum is produced both as a pure crop and in association with other cereals such as ordinary grain sorghum, sweet stalk sorghum, millet and especially maize or legumes such as cowpea (Sawadogo., 2015; Namoano, 2018). It is grown even on soils of relatively low fertility and is particularly popular on sandy to sandy-clay soils. The recommended spacing is 60-90 cm between rows and 20-60 cm between bunches, and the mineral fertilisation rate to optimise grain and straw production is 100 kg/ha (Zerbo, 2017; Tiendrébéogo, 2020).

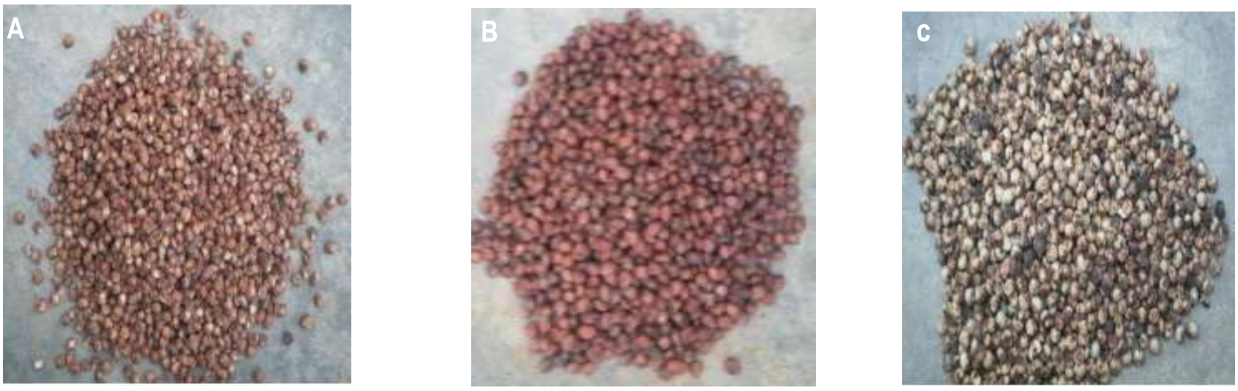

Figure 2. Different colors of sweet sorghum grains (Sawadogo., 2011). A: light red grains; B: dark red grains; C: grey grains.

Figure 3. Different shapes of sweet grain sorghum panicles (Tondé, 2020). A: Loose with drooping branches (umbrella); B: Loose with semi-erect branches (bird's nest); C: Semi-compact elliptic (bonnet); D: Very loose; E: Compact; F: Semi-compact.

Yields

National agricultural statistics on sorghum provided by the Ministry of Agriculture or the FAO do not mention sweet grain sorghum. It remains a minor crop, little valued by the structures in charge of agriculture in Burkina Faso (Sawadogo, 2015). The rare information available on yields is the work of researchers at Joseph KI-ZERBO University who are convinced of the importance of preserving agro-biodiversity and especially neglected crops. Thus, the work of Tiendrébéogo (2020) on the influence of fertilization on grain and straw productivity of sweet grain sorghum showed a non-significant variation in yields under three different doses (100 kg/ha, 125 kg/ha, 150 kg/ha). The grain yields reported were 6204.85 kg/ha, 6382.92 kg/ha and 6363.98 kg/ha and the straw yields were 9147.23 kg/ha, 8380.77 kg/ha and 8716.05 kg/ha under 100 kg/ha, 125 kg/ha and 150 kg/ha, respectively (Tiendrébéogo, 2020). A variation in productivity according to sweet grain sorghum breed is also reported by Sawadogo (2015). The sweet grain sorghum accessions of the *caudatum* race with a sowing-flowering cycle of 81 days, indeed, express the highest average performance for main panicle weight (168.29 g) and grain yield per plant (146.68 g). The accessions of the intermediate race guinea-bicolor with a shorter cycle of 70 days, have lower performances for the weight of the main panicle (118.833 g) and the grain yield per plant (88.35 g) with on the other hand a higher hundred grain weight (2.94 g). For accessions of the intermediate race *caudatum-guinea*, the average cycle was 77 days, the main panicle weight 165.62 g and the grain yield per plant 118.36 g.

Biochemical composition of grain and straw

Several studies (Tondé, 2016; Sawadogo *et al*., 2017; Tiendrébéogo, 2020) have shown important nutritional values of grain and straw of sweet sorghum. Indeed, grain is an important source of carbohydrates and proteins. The main nutritional elements found in grain are glucose (26.067 mg/g DM), fructose (30.861 mg/g DM), sucrose (2.899 mg/g DM), starch (549.047 mg/g DM) (Sawadogo *et al*., 2017) and protein (13.54%) (Tondé, 2016; Sawadogo *et al*., 2020a). Starch is the predominant carbohydrate but the sweetness of the grains is mainly due to fructose because of its higher sweetness (Sawadogo *et al*., 2017).s for the biochemical composition of the straw, Tiendrébéogo (2020) showed dry matter contents of 95.73%, organic matter of 55.01%, sugars of 7.18%), gross energy of 4204.19 kcal/kg DM, fibres such as crude cellulose of 39.27%MS, insoluble fibres in neutral detergent of 73.26%MS, insoluble fibres of 43.85%MS and insoluble lignin of 43.85%MS in acid detergent. The digestibility of straw is 32.46% for dry matter and 30.03% for organic matter.

USES OF SWEET GRAIN SORGHUM

Sweet grain sorghum is used for food, feed and various other purposes in Burkina Faso. Panicles harvested in a pasty state are dehulled (Figure 4A) and the grains are then consumed directly by chewing (Nebié *et al*., 2012; Sawadogo, 2015). The grains are also used in the preparation of local dishes such as couscous, porridge and *zoom-koom* (Figure 4B) (Tondé, 2020). The cultivation of this sorghum by farmers also responds to a strategy of climate risk management and is explained by their functional complementarity in the agrosystem (limitation of the food gap period, versus supposedly higher productivity, diversity of culinary uses, complementary places in the agricultural calendar, strategies for avoiding transhumant herds (Sawadogo, 205; Tondé, 2020). In addition to its prominent place in the human diet, sweet grain sorghum production is a source of income.The marketing of panicles harvested at the doughy grain stage (Figure 5) is one of the main income-generating activities for producers and sellers (Nebié *et al*., 2012; Sawadogo., 2015). While the grain is essential for human consumption, other parts of the plant are also used. The stems are used as fuel or for making facades or roofs and in livestock feed (Sawadogo *et al*., 2014b; Sawadogo, 2015).

PROSPECTS FOR BREEDING AND VARIETAL IMPROVEMENT

Figure 4. Different food uses of sweet grain sorghum: A: pasty grains for direct consumption; B: coucous; C: zoom-koom; D: porridge (Tondé., 2020).

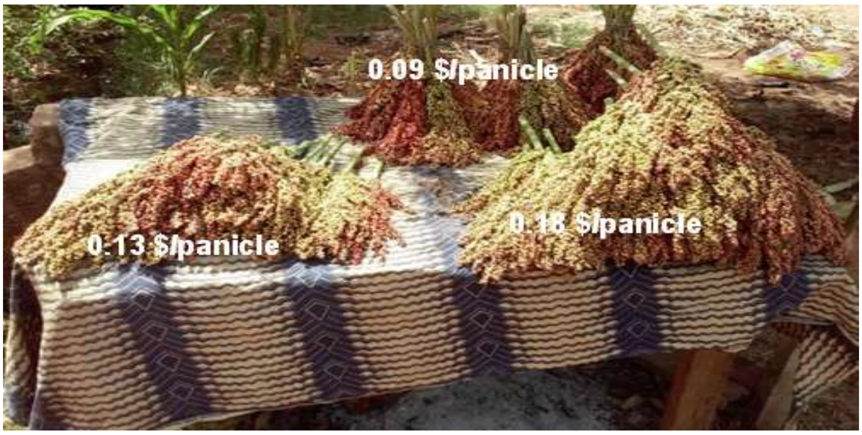

Figure 5. Sale of sweet grain sorghum panicles on the streets of Ouagadougou (Sawadogo *et al*., 2017).

Productivity and yield consistency

The development of minor crops for greater resilience is based on those that combine good productivity and, above all, a good capacity to adapt to climatic variations while generating interesting co-products to be valorized. As for all plants and in all countries, high productivity is always sought under non-limiting growing conditions (Etasse, 1977; Vaksmann *et al*., 1996). Yield is a trait that is easy to measure and assess by means of comparative yield trials. However, it is a complex trait with multiple components such as panicle characteristics, adaptation to climatic conditions, soil and parasitism. Therefore, it is difficult to select directly for yield, but the focus is rather on its components. While in the past, varieties with the best potential under optimal conditions were sought after, nowadays, it is the regularity of yield that allows for the mitigation of environmental accidents and the achievement of satisfactory production even under unfavourable conditions, especially drought, that is increasingly targeted (Vaksmann *et al*., 1996; Farooq *et al*., 2017; Gnoumou *et al*., 2017).Indeed, the various studies carried out on sweet grain sorghum have focused on its genetic diversity (Sawadogo *et al*., 2014a; Sawadogo *et al*., 2018), the biochemical composition of the grains (Sawadogo *et al*., 2017; Sawadogo *et al.,* 2020a) and straw (Tiendrébéogo, 2020), the endogenous knowledge associated with its management (Sawadogo, 2015), its grain and fodder production under the effect of fertilizers (Zerbo, 2017; Tiendrébéogo *et al.,* 2020), its genetic relationships with other cultivated sorghums (Sawadogo *et al*., 2022a; Sawadogo *et al*., 2022b; Tiendrébéogo *et al*., 2022) and its sensitivity to photoperiod variation (Namoano, 2018; Tondé, 2020). No study on the response of sweet grain sorghum to drought has yet been conducted. It is essential to evaluate the adaptation of this species to the very contrasting Sahelian climatic conditions, particularly to drought. In fact, in the tropical zone, the time of crop establishment and flowering constitute the two periods of high probability of drought that threaten annual crops in particular (Sivakumar, 1986; Bambara *et al.,* 2016; Bougma *et al*., 2016).

Molecular markers

Molecular markers are the most appropriate tools for assessing genetic diversity, as they are less influenced by environmental variation (Santoni *et al*., 1986). Genetic diversity studies conducted so far on sorghum and other species have used molecular markers (RFLP; RAPD; AFLP; SSR; SNP). Microsatellite SSRs due to their reproducibility and high level of polymorphism have been the most widely used markers in diversity studies (Sawadogo, 2015; OECD/FAO, 2016). They have thus been used in the characterization of genetic diversity in sweet grain sorghum (Sawadogo, 2015; Sawadogo *et al*., 2018).However, the results of these studies showed moderate genetic diversity despite the high agro-morphological variability obtained in several other previous studies (MAHRH, 2010; Sawadogo *et al*., 2014a; Sawadogo *et al*., 2014b). Therefore, diversity analyses based on the genome sequencing offer interesting prospects for exploiting genetic diversity. A thorough analysis of the genetic diversity expressed in a linear DNA sequence is relevant to detect genes responsible for traits of agronomic interest. SNPs have become leading markers in the characterization of genetic material. They have the advantage of accurately characterizing and describing the entire genome of a species (Santoni *et al*., 1986). The development of this type of marker on sweet grain sorghum would be very useful to further study its genetic diversity. Furthermore, they contribute to the understanding of the genetic control of quantitative traits and thus support the selection process.

Resistance to diseases and predators

Sweet grain sorghum, like other sorghums, is subject to numerous diseases and parasitic attacks that reduce its quality and productivity. The most common biotic factors encountered on sorghum are parasitic phanerogams (*Striga* *hermonthica* and *Striga gesnerioides*) (Olivier *et al*., 1992; Ohlson & Timko., 2020; Sawadogo *et al,* 2020b), stem borers (*Atherigona soccata* Rondani, *Busseola fusca* Fulle), grain (*Stenodiplosis sorghicola* Coquillett, Eurystylus spp. and Calocoris spp) and leaf (*Spodoptera* spp. and *Mythimna* spp) predators (Dakouo & Trouche, 2001) and parasitic fungi (Zida *et al*., 2010; Somda *et al*., 2012; Bonzi, 2013).The same authors also revealed that sorghum is attacked by more than 40 genera of fungi, the most important of which are *Aspergillus, Fusarium, Curvularia, Phoma, Penicillium, Colletotrichum*. However, these different studies were conducted only on grain sorghum. No study on diseases and pests of sweet grain sorghum has yet been conducted. Yet, the grains of this sugar-rich sorghum expose it more to various pest attacks (Sawadogo, 2015). Thus, it is important to identify and inventory the phytopathogenic fungi of this species.

In-situ conservation

The resilience of sub-Saharan agriculture to environmental and socio-economic disturbances is partly based on the maintenance of specific, varietal and genetic diversity within agrosystems (Naino Jika, 2016). Authors have reported gene flow and genetic introgression between sorghum varieties grown in agrosystems (Dogett, 1998; Tiendrébéogo, 2020). In sweet grain sorghum in particular, there is no data on the relationship between genetic diversity and the rate of outcrossing in the plant. It is therefore important to assess the factors acting jointly on the maintenance of the variability of agro-morphological traits and their genetic diversity, particularly the rate of outcrossing of the species. This will provide a basis for varietal creation and in-situ conservation of sweet grain sorghum.

Grain qualities

In Burkina Faso, sorghum is mainly used for human consumption with manual preparation of traditional dishes by women (Zongo, 1991; Barro-Kondombo, 2010). As a direct consequence, a certain number of characteristics are sought that are more or less imperative depending on the habits. Previous studies (Zongo, 1991; Barro-Kondombo, 2010) have also justified the large-scale production of grain sorghum, mostly belonging to the *guinea* breed, by the good vitrosity and white color of the grain, qualities required in culinary habits. As a result, the majority of popularised sorghum varieties are from the *guinea* breed despite the higher yield potential of the *caudatum* breed (Trouche *et al*., 2000; Li *et al*., 2019).Unfortunately, in sweet grain sorghum, research efforts are not yet directed towards improving grain quality. Indeed, the low use of sweet grain sorghum in Burkina Faso is linked to the floury aspect of the grain, a poor quality for traditional dishes (Nebié *et al*., 2012; Sawadogo *et al*., 2022a). Thus, for the various future varietal improvement works of sweet grain sorghum, the combined selection of good agronomic characteristics and appropriate grain quality for the different culinary uses are highly expected. Crossing between sorghum types (sweet grain sorghum x grain sorghum) (Trouche *et al*., 2000; Sawadogo *et al*., 2022a; Sawadogo *et al*., 2022b) or the use of new near-infrared spectrophotometry techniques for screening (Shahat *et al*., 2017; Li *et al*., 2019; Gnankambary-Traoré, 2019) are preferred paths to explore to really meet productivity and grain quality objectives.

Improving the straw to grain ratio

Productivity improvement is focused primarily on reducing plant height to increase the grain-to-straw ratio and matching panicle compactness and length to increase the number of grains per panicle (Trouche *et al*., 2000). Indeed, plant yield is negatively correlated with plant size and lodging (Gapili, 2016; Yamaguchi *et al*., 2016), hence the shift in selection towards shorter early varieties (Trouche *et al*., 2001; Hilley *et al*., 2016; Guindo *et al*., 2019). Moreover, sweet grain sorghum cultivars currently in cultivation have an exuberant growth habit of 199.7 cm to 398 cm (Sawadogo., 2015) and the stem bends and even breaks when the panicle is loaded with grains (Nebié *et al*., 2012; Sawadogo., 2015). This defective morphology could be improved by introgression of dwarfing genes.

CONCLUSION

Sweet grain sorghum is a minor crop with interesting food and fodder potential. It is grown in cage fields in all agro-climatic zones for food, feed and various other uses. Therefore, it is important to deepen the knowledge on this sorghum to exploit its nutritional potential and increase the economic value of the crop and thus promote the preservation of its genetic resources.

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