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Farmers' Perception of Phenotypic Variation of Different Types of Sorghum Cultivated in Burkina Faso

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Abstract

Sorghum bicolor is a multi-purpose species adapted to many agroecological zones of Burkina Faso. In the local farming system, different types of sorghum are cultivated together. Such farming conditions could increase gene flow between the different types of sorghum and contribute to the evolution of their main morphological characteristics. Understanding the effect of the farming system on the characteristics of different types of sorghum could contribute to building a strategy for the management of its genetic diversity. A survey and accessions collection was carried out in ten villages selected in two agroclimatic zones of Burkina Faso. A total of 133 accessions were collected and thirty local names were recorded. The results revealed a significant variability within sorghum characteristics based on farmers' descriptions. Four types of sorghum were identified by farmers based on their uses. These are sweet grain sorghum, grain sorghum, sweet sorghum and dyer sorghum. Most of farmers (54.6%) practised intercropping, and 28.86% of them intercropped several types of sorghum in the same or nearby fields. A high coincidence of the flowering period of the types of sorghum was observed by farmers in both agroclimatic zones. The results also showed that most of the farmers (55.7%) noted changes in the morphological characteristics of different types of sorghum. These variations included the reduction in potential yields and changes in grain taste and colour within the same type. Understanding these variations could help conserve and sustain sorghum genetic resources in Burkina Faso.

Keywords

Sorghum bicolor, Ethnobotanical Knowledge, Genetic Diversity, Burkina Faso

1. Introduction

In Burkina Faso, sorghum is one of the three main crops and, together with other cereals, constitutes the main food and source of household income [1]. Several types of sorghum are cultivated with very diverse uses. Grain sorghum is mainly used for the preparation of local dishes and for its highly prized fodder in livestock feed [2] [3]. Sweet grain sorghum is cultivated for its grains consumed fresh in a pasty stage and is usually harvested before the staple crops [4] [5]. Sweet sorghum is mainly cultivated for its sweet stem consumed as sugar cane and for its grains [6]. Dyer sorghum is cultivated exclusively for the red dye contained in its leaves, and sometimes also in the adjacent parts of the stem and for its hematopoietic value [6] [7] [8].

These four types of sorghum are generally found together in farmers' fields and are used over several years with the possibility of exchanging genetic material, as the rate of outcrossing in field-cultivated sorghum varies from 5% to 40% [9] [10] [11]. However, gene flow is a major evolutionary factor, just like selection, genetic drift or mutation [12]. Moreover, gene flow can lead to the production of new genotypes that are often not adapted to climatic conditions [13]. It is therefore necessary to examine the evolution over time of the genetic and phenotypic characteristics of these sorghum types. Previous work has highlighted farmers' management methods and genetic diversity within each type of sorghum, including grain sorghum [2] [3] [14], sweet grain sorghum [15] [16] [17] and sweet stem sorghum [6]. Other studies of genetic diversity and comparison of sorghum types at the agromorphological [18] [19] and molecular [20] [21] levels have shown the proximity to its sorghums. However, the impact of the coevolution of the different sorghum types on the organization of the diversity of these sorghums is still unknown in Burkina Faso, which could constitute a limiting factor in the management of its sorghums. Indeed, in millet, for example, gene flow has led to the formation of plants with an intermediate phenotype, ginning, which contributes to lower yields in farming areas and a shortening of the cycle of varieties [22] [23]. For [24], inter-varietal gene flow is an erosive factor of cycle diversity. Understanding the impact of gene flow between these sorghum types could help conserve and sustain sorghum genetic resources in Burkina Faso.

Regarding the importance of sorghum for the local population, it is necessary to maintain the diversity of each type and build a collection. The objective of this study is to identify farmers' perception of phenotypic variation of different types of sorghum cultivated in intercropping conditions in Burkina Faso.

2. Methodology

2.1. Description of the Study Area

The study was carried out in Burkina Faso, which has a Sudano-Sahelian climate characterized by a tropical climate with alternating seasons and high interannual and spacio-temporal variability in rainfall [25]. It covered two agroclimatic areas

(Figure 1). These are the north Sudanian area with annual rainfall ranging between 700 mm and 900 mm and the sub-Sahelian area (500 mm to 700 mm). In all, ten villages were selected based on the presence of several types of sorghum in these localities two (2) were located in the sub-Sahelian area and eight (8) in the north Sudanian area. An ethnobotanical survey was carried out in the ten villages from October to December 2020.

2.2. Ethnobotanical Survey and Accessions Collection

The ethnobotanical survey and accessions collection were carried out from October to December 2020, coinciding with sorghum maturity and harvest. The survey concerned farmers who grow several types of sorghum and farmers who have fields adjacent to those of the targeted farmers. The research tools employed were field survey, key informant interviews, followed by an observation of some morphological traits in the plot. The questionnaire captured data on demographic information, types of cultivated sorghum, uses, source of seeds,

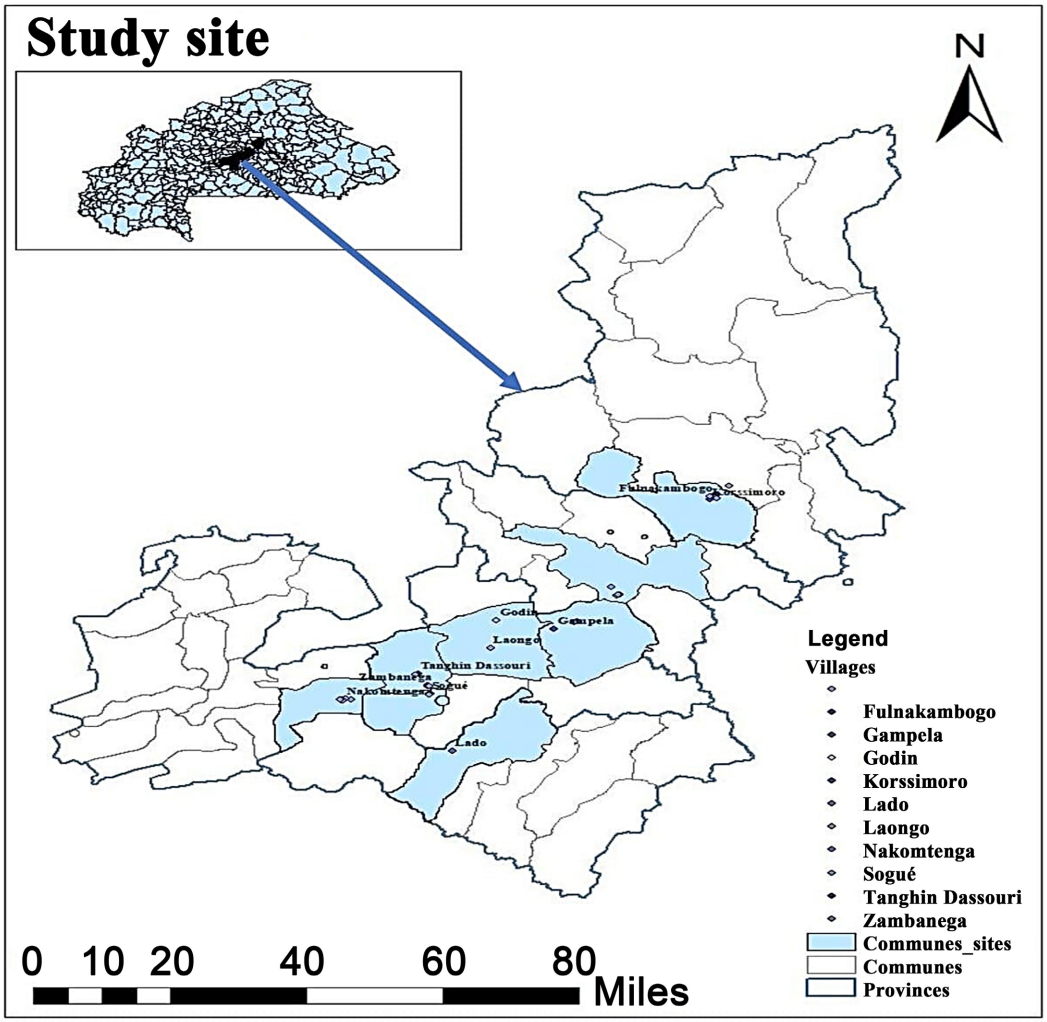

Figure 1. Location of study sites.

seeds conservation, local names, cultivar cycle, cropping methods, number of years of production, and changes observed in the sorghum characteristics in recent years. Information was also generated on some morphological characters such as panicle shape, grain colour, aristation, presence of wax, aerial tillers and leaf spot colour were also noted.

A minimum of three panicles per accession of each identified sorghum type were collected from the farmers. Each panicle collected was assigned a code indicating the province, department and village, the type of sorghum, and a number related to the number of accessions. A GPS device (GPS 60 GARMIN) was also used to record the geographical coordinates of the different sites surveyed.

2.3. Data Analysis

Microsoft Excel 2010 and SPSS (Statistical Package for the Social Sciences) 15.0 were used for data entry. Descriptive statistics involving frequencies were employed in data analysis and reporting. The frequencies were used to generate graphs using the Excel software. The graphs were generated to appreciate the distribution of accessions according to agroclimatic areas, collection sites, sorghum types, cropping systems, sorghum types, cycle, uses, parts used and findings on changes in sorghum types. Regarding the quantitative variables such as cycle, the data were first grouped by class, followed by the calculation of frequencies. The distribution of accessions collected by local names of sorghum cultivars, planting date, flowering date and maturity date according to agroclimatic areas were described.

3. Results

3.1. Criteria of Identification of Sorghum Types

The specific use of each type of sorghum is the main criterion of their discrimination. Four types of sorghum were identified in the whole study area. These types are grain sorghum, sweet grain sorghum, sweet sorghum and dyer sorghum.

Grain sorghum represented the majority of the accessions collected (57.89%). It is cultivated by all the interviewed farmers for its grains, which are highly valued for human consumption. Within this sorghum type, three cultivars were identified based on the grain colour. These are red grain sorghum used for local beer, greyish grain sorghum and white grain sorghum appreciated for their nutritional quality and used to make flour-based dough. The majority of grain sorghum have aristation grains, wax-covered leaves and red leaf spots. This sorghum also has aerial tillers and very variable panicles ranging from loose to compact (**Figure 2(A)**).

Sweet grain sorghum is observed in most of surveyed areas and represented 24.81% of the accessions collected. This sorghum type is cultivated in hut fields mainly for family self-consumption and local sale of panicles at the doughy grain

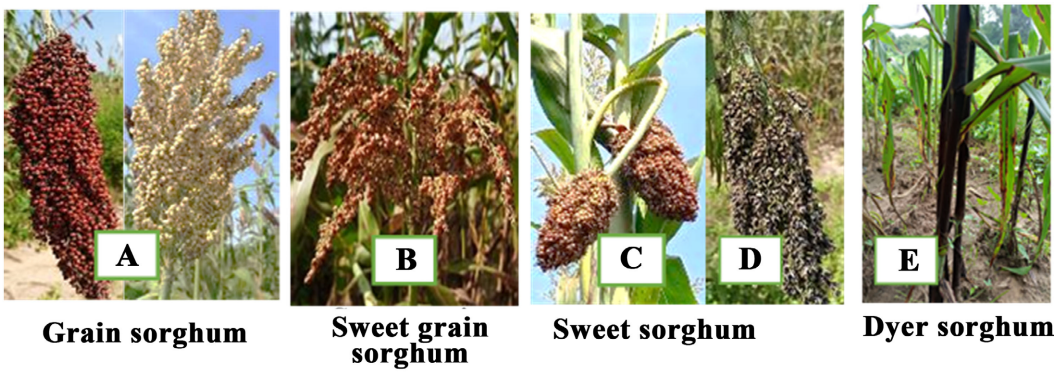

Figure 2. Photo of different types of sorghum cultivated in Burkina Faso. Legend: (A) = compact grain sorghum panicles; (B) = loose sweet grain sorghum panicle; (C) compact sweet stem sorghum panicles; (D) = semi-compact sweet stem sorghum panicle; (E) = dyer sorghum stems.

stage. The grains have a sweet flavour, an easy shelling type with generally loose panicles (Figure 2(B)). A major characteristic of this group is its earliness. The majority (86.5%) of cultivars of this sorghum have no aristation, wax and have fewer aerial tillers.

Sweet sorghum represented 11.28% of the accessions. This sorghum type is not cultivated in specific fields but, around huts or fields by very few producers for its sweet stem. It has little aristation, wax, or aerials tillers and have generally a long cycle and compact or semi-compact panicles (Figure 2(C) & Figure 2(D)).

Dyer sorghum registered the lowest rate of collected accessions (6.02%). It is produced in small quantities for use in handicrafts. The panicles are generally small and compact. The grains of this type of sorghum are not used for human consumption but only for poultry feeding. The grains are red, poorly aristed and rarely have productive aerial tillers. Their main characteristic is the colour of the leaf sheath and the general red softness (Figure 2(E)).

3.2. Distribution of Accessions According to Collection Areas

A total of 133 accessions were collected from 10 villages in two agroclimatic zones (Table 1). The highest number of samples was collected in the north Sudanian area (98) while the lowest number of accessions was collected in the sub-Sahelian area (35). The number of accessions collected per province ranged from seven (7) in Oubritenga to 42 in Boulkiemdé. At the village level, the lowest number of accessions was collected in Loango (7) and the highest was collected in Nakomtenga (42). At the household level, the number of accessions varied from one (1) to 15 with a mean of three (3). The number of accessions varied according to the type of sorghum. Grain sorghum had the highest number of accessions and was cultivated in the whole study area. It is followed by sweet grain sorghum, which is also produced by the majority of farmers (96.07%). Sweet sorghum and dyer sorghum are cultivated at the lowest level in the surveyed localities. Sweet sorghum is only present in Korsimoro and Fulnakambogo while dyer's sorghum is present in Sogué, Lado and Nakomtenga.

Table 1. Distribution of accessions according to collection sites and sorghum type.

Agroclimatic area	Provinces	Villages	Types of sorghum	Number of accessions
North sudanian	Kadiogo	Zambanega	Grain sorghum	13
			Sweet grain sorghum	9
		Sogué	Grain sorghum	4
			Sweet grain sorghum	3
			Dyer sorghum	3
		Gampela	Grain sorghum	1
			Sweet grain sorghum	2
		Godin	Grain sorghum	2
			Sweet grain sorghum	2
		Tanghin Dassouri	Grain sorghum	1
			Sweet grain sorghum	2
	Boulkièmdé	Nakomtenga	Grain sorghum	27
			Sweet grain sorghum	13
			Dyer sorghum	2
	Bazèga	Lado	Grain sorghum	4
			Dyer sorghum	3
	Oubritenga	Loango	Grain sorghum	4
			Sweet grain sorghum	3
Sub-sahelian	Sanmatenga	Korsimoro	Grain sorghum	5
			Sweet grain sorghum	2
			Sweet sorghum	9
		Fulnakambogo	Grain sorghum	10
			Sweet grain sorghum	5
			Sweet sorghum	4

3.3. Farmers' Management of Sorghum Types Cultivated in Burkina Faso

3.3.1. Mode of Seeds Collection and Conservation

Three modes of seed acquisition were identified during the survey, such self-production by mass-scale selection, purchase and donation. The majority of farmers (72.28%) acquired their seeds from mass-scale selection in their own fields. In this method, farmers harvest and store the grains of selected plants. These grains are used as seeds for the following rainy season. The second method of seed collection is donation. Up to 22.77% of the farmers used to share sorghum seeds at a local level. The less method of seed management is seed marketing. Only 4.95% of the farmers bought their seeds directly in the local markets with traders.

The seed-storing techniques observed during the survey varied. The majority of the farmers (95%) stored the whole panicle and only 5% of them removed the grains from the panicle before storing. The panicles are selected directly in the field based on some morphological characteristics such as cycle, panicle size and grain colour for grain sorghum. For sweet grain sorghum, selection is based on panicle size and grain taste. On the other hand, for sweet sorghum, seed selection is based on stem taste. For dyer sorghum, seed selection is mainly related to the colour of the leaf sheath. The collected seeds can be stored as panicles hanging from trees or roofs of houses or as grains packed in bags or put in bottles or cans.

3.3.2. Farming System of Sorghum Types in Collection Areas

The analysis of the farming system revealed that the majority of farmers (54.6%) practised intercropping. The monoculture is practiced by 45.4% of farmers. Among those who practised intercropping, 28.86% used planting several types of sorghum in the same field and 25.77% combined sorghum with other crops such as maize, millet and cowpea. These cropping patterns varied according to the area and sorghum type (Figure 3). Grain sorghum and Sweet grain sorghum are frequently planted in the same fields in the two agroclimatic regions. In the north Sudanian area, most of farmers (56.86%) used to plant sweet grain sorghum and grain sorghum in the same fields whereas only 11.76% of farmers mixed grain sorghum and dyer sorghum. Sweet sorghum is rarely observed in this agroclimatic zone. On the other hand, in the sub-Sahelian area, the association between all the types of sorghum is observed. Thus, 26.23% of the farmers combined grain sorghum and sweet grain sorghum and 22.95% combined grain sorghum and sweet sorghum. Only 11.48% of farmers combined sweet grain sorghum and sweet sorghum. Some farmers cultivated grain sorghum, sweet grain sorghum and sweet stem sorghum together in the same or very close fields (Figure 4). Monoculture is generally practised on a large scale and concerns mainly grain sorghum. It is practised by 25.5% of farmers in the north Sudanian area and 29.5% in the sub-Sahelian area.

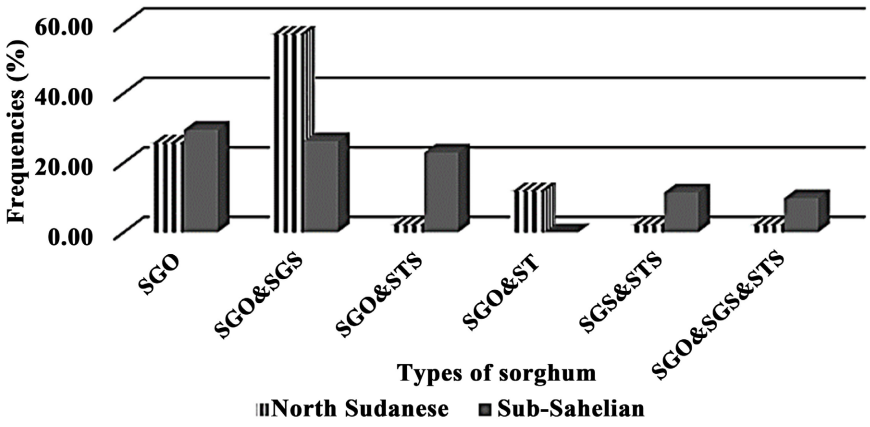

Figure 3. Variation in the frequency of sorghum cohabitation in the cultivation areas. Legend: SGO = Grain Sorghum; SGS = Sweet Grain Sorghum; STS = Sweet Sorghum; ST = Dyer Sorghum.

Figure 4. Sorghum field under intercropping in Burkina Faso. Legend: (A) grain sorghum; (B) sweet grain sorghum; (C) sweet sorghum.

3.3.3. Variation in Sowing, Flowering and Harvesting Times of Sorghum Types

Despite the different climatic contexts, farmers sowed sorghum types between May and July (Table 2). In the north Sudanian area, the majority of farmers sowed grain sorghum (59.5%), sweet grain sorghum (55.2%) and dyer sorghum (71.4%) as soon as the rains begin (end of May), with a higher rate for dyer sorghum. However, in the sub-Sahelian area, sowing dates varied according to the type of sorghum. The majority of the farmers (88.9%) sowed grain sorghum from the end of May to June while most of the farmers (62.5%) sowed sweet grain sorghum by July. Sweet sorghum is planted in June (42.9%) or July (42.9%).

Across the growing area, flowering of sorghum types occurred in September (Table 3). In the north Sudanian area, the majority of cultivars flowered in early September, *i.e.*, 59.5% for grain sorghum, 65.5% for sweet grain sorghum and 71.5% for dyer sorghum. In contrast, in the sub-Sahelian area, the earliest cultivars flowered in early September, *i.e.*, 22.2% for grain sorghum, 37.5% for sweet grain sorghum and 28.6% for sweet stem sorghum. However, the majority of cultivars flowered in mid-September with the respective proportions of 55.6%, 50.0% and 42.9% for grain sorghum, sweet grain sorghum and sweet sorghum. The latest cultivars flowered in late September, with 22.2% for grain sorghum, 12.5% for sweet grain sorghum and 28.5% for sweet sorghum.

Cultivars are harvested from mid-October to November throughout the growing area. The majority of farmers harvested sweet grain sorghum in late September and early October for consumption of fresh grains and ripe grains in late October in the two surveyed areas (75%). The other types of sorghum are in late October and early November in the North Sudanian area. In contrast, in the sub-Sahelian area, harvesting is late. The majority of farmers harvested sweet sorghum (71.4%) by the end of October, while grain sorghum was harvested from the end of October (55.6%) to November (33.3%).

Table 2. Distribution of accessions according to sowing dates.

Agroclimatic areas	Types of sorghum	Sowing dates		
		End of May	June	July
North Sudanian	Sorghum grain	59.5%	21.4%	19.0%
	Sweet grain sorghum	55.2%	27.6%	17.2%
	Dyer sorghum	71.4%	0.0%	28.6%
Sub-Sahelian	Sorghum grain	22.2%	66.7%	11.1%
	Sweet grain sorghum	12.5%	25.0%	62.5%
	Sweet sorghum	14.2%	42.9%	42.9%

Table 3. Distribution of accessions according to flowering dates.

Agroclimatic areas	Types of sorghum	Flowering period Rate		
		Early of September	Mid-September	End of September
North Sudanian	Sorghum grain	59.5%	34.3%	7.2%
	Sweet grain sorghum	65.5%	31.0%	3.4%
	Dyer sorghum	71.5%	28.5%	0.0%
Sub-Sahelian	Sorghum grain	22.2%	55.6%	22.2%
	Sweet grain sorghum	37.5%	50.0%	12.5%
	Sweet sorghum	28.6%	42.9%	28.5%

3.3.4. Cycle of Sorghum Types Cultivated in the Two Agroclimatic Areas

In general, the cycle of cultivars varied from 70 to 140 days and this variation varied according to the type of sorghum and the agroclimatic area. All the accessions collected can be structured into three groups based on the length of the maturity cycle (**Figure 5**). The first group characterized early accessions with a cycle of less than 90 days and represented 41.20% of grain sorghum cultivars, 64.9% of sweet grain sorghum, 85.7% of sweet sorghum and 50% of dyer sorghum. The second group consisted of cultivars with a medium cycle between 90 and 120 days and represented 47.10% of grain sorghum, 32.40% of sweet grain sorghum, 14.30% of sweet stem sorghum and 50% of dyer sorghum. The third group characterized the latest-cycle cultivars (≥140 days) and consisted of 11.80% of grain sorghum and 2.70% of sweet grain sorghum.

3.4. Farmers' Perception of Changes in Sorghum Types Cultivated

The results of the survey showed that most of the farmers (55.7%) noticed changes in their types of sorghum over the years. On the other hand, 44.3% of the farmers did not notice any variation in their types of sorghum. These changes included transition from one type of sorghum to another (12.37%), reduction in potential yield (8.25%), changes in the taste of grains and stem (15.46%) and changes in grain colour (19.59%) within the same type.

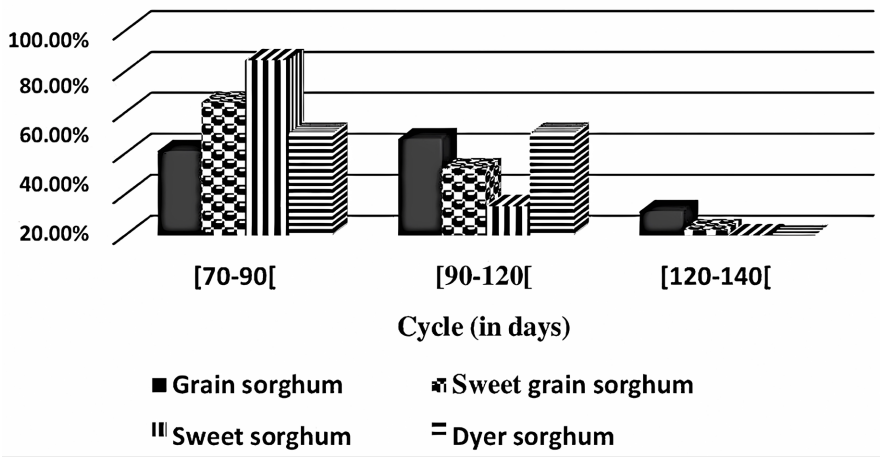

Figure 5. Cycle of accessions according to sorghum type.

During the survey, the changes observed were more frequent in grain sorghum, sweet grain sorghum and dyer. However, there are a few changes in sweet sorghum. For grain sorghum, farmers noticed that white grain sorghum becomes increasingly red when cultivated near red grain sorghum and red grain sorghum becomes increasingly white. In addition to colour, farmers reported changes in panicle shape, shrinking plant size, cycle and yield reduction (Figure 6). For sweet grain sorghum, farmers reported changes in grain colour, cycle and the sweet taste of the grains disappearing when produced in proximity to another type of sorghum. Thus, it becomes grain sorghum when produced in proximity to grain sorghum. This leads farmers to renew their seeds. The results of the survey also revealed a decrease in the sweet flavour of the stem, particularly in the sweet sorghum. For dyer sorghum, farmers noted a decrease in the intensity of the stem colour, the leaf sheath and a reduction in plant size and stem diameter. Figure 7 shows the frequency of changes according to sorghum types.

4. Discussion

The interest of farmers in different types of sorghum is justified by the different uses by the local population. Indeed, characterized by a great phenotypic variability, sorghum is mainly exploited for human consumption for their grains or the sweet juice from their stems, for animal feed, for their straw, and for the dye contained in the leaves [4] [8] [16]. Sorghum is also a source of income through the trading of its grains and derived products. According to [26] and [27], the maintenance of traditional cuisine and socio-cultural beliefs is a socio-economic issue, but also a strategic and ecological issue in the maintenance of diversity. The abundance of grain sorghum in the two agroclimatic areas surveyed suggests that the climatic conditions in these areas are more suitable for its development. This abundance could also be justified by its importance for human feeding than other types [3] [6] [28]. It is also an important source of income for local people and its fodder is highly valued for livestock feeding. However, the relatively small number of accessions of sweet grain sorghum, sweet sorghum

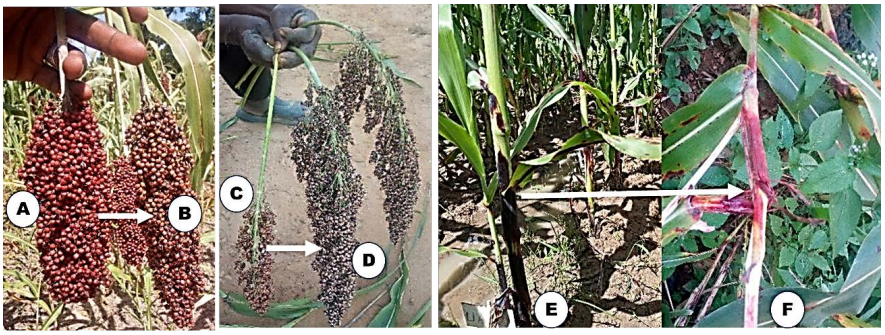

Figure 6. Photo showing some changes in grain colour, stem and panicle shape. Legend: (A) initial grain colour; (B) modified grain colour; (C) initial panicle shape; (D) modified panicle shape; (E) initial leaf sheath condition; (F) final sheath condition.

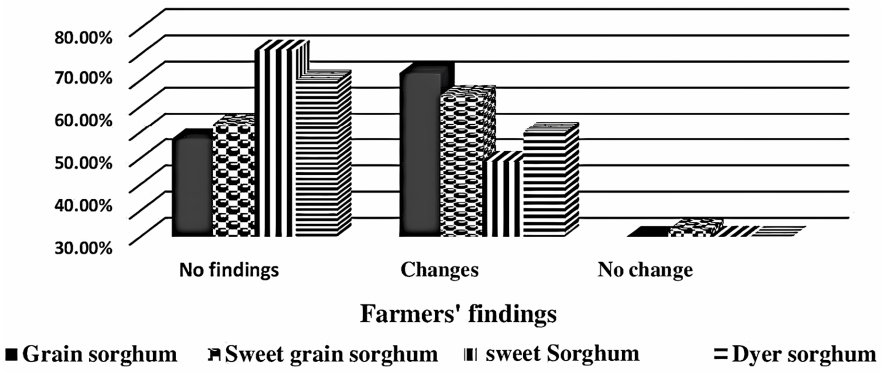

Figure 7. Frequency of changes according to sorghum types.

and dyer sorghum collected per village testifies to the marginalization of these types of sorghum. Nevertheless, the sweet grain sorghum and sweet sorghum cultivation is more common than dyer sorghum threatened with extinction. This could be explained by the other use of grain sorghum and sweet sorghum, such as the fodder aspect playing an important role in a country where livestock breeding is a major activity [5] [6] [16]. Dyer sorghum is essentially a traditional and family crop held by craftsmen and customary chiefs in some villages who use it for rituals and to dye leather, and its grains are not suitable for human feeding which limits its production [8] [29]. However, because of its richness in tannin, the use of this sorghum could help promoting handicrafts and fight anemia, hepatitis and jaundice [7]. Indeed, selection criteria based on yield, market value, variability of uses and organoleptic traits could contribute to the adoption or regression of a cultivar or variety by farmers. Similar results were observed in northwestern Benin by [30].

Farmers' seeds management practices, including conservation, seed purchase, exchanges and selection of varieties in the field, are well known practices and have already been reported for sorghum in Burkina Faso [3] [6] [16] or for other crops in the West African sub-region [31] [32] [33]. Indeed, exposing panicles to the sun is a technique used by farmers to minimize mold attacks. Most sweet sorghum has a floury texture; this makes them susceptible to mold [6] [16].

Thus, the panicles are hung on sheds or on tree branches for better protection of the grains until sowing. The association of several types of sorghum or sorghum with other crops is also a known practice in sorghum [16] [30] and could be explained by the fact that sweet grain sorghum, sweet sorghum and dyer sorghum are still marginal crops, produced in small scale at the edge of the fields for limited uses.

The variation in sowing dates could be explained by the spatio-temporal distribution of rainfall. This distribution of rainfall leads farmers to opt for early planting. Thus, the production of sorghum with a cycle between 120 and 150 days by a minority (7.2%) of farmers is justified by a selection oriented towards early cultivars. The selection oriented towards earliness and good yield could lead to a genetic erosion of the diversity of cultivated sorghum in Burkina Faso.

Despite the variation in sowing dates and cycle length of the cultivars, a high coincidence of flowering of the sorghum types was observed in the two agroclimatic areas. This could be explained by the fact that most West African sorghums are photoperiodic. The photoperiodism of these sorghums leads them to flower at the same period; this could influence the yield. The previous studies on sorghum have reported similar results in Burkina Faso on sweet grain sorghum [34] [35] and in Chad on grain sorghum [36]. These studies showed a significant effect of sowing date on most of the traits. All genotypes were sensitive to photoperiod variation by reducing their sowing-flowering cycle, size and yield at the second planting date. Indeed, late sowing will not be in favour of a good vegetative development of the plant and will at the same time favor gene flow between sorghum types when they are cultivated in the same field or nearby. Previous studies have shown the existence of gene flow between *Sorghum bicolor* cultivated in the same or nearby fields, but the extent of this situation varies according to factors including flowering timing, inflorescence morphology, distance, wind and pollen fertility [10].

The association of several types of sorghum in the same or nearby fields would be at the origin of the different phenotypic changes observed by the farmers. Indeed, despite its preferential self-pollinated mode of reproduction, sorghum has an outcrossing rate varying from 5 to more than 40%, with an average of 6% when cultivated in the field [9] [10] [11], which would favor gene flow between sorghum types. [28] also observed introgression phenomena by noting changes in glume colour of varieties or the appearance of sorghum of intermediate types between two sorghum varieties. However, the more important changes observed in grain sorghum and sweet grain sorghum could be explained by the fact that most of these sorghum types have loose panicles [5] [14] [15], unlike sweet stem sorghum and dyer sorghum [6], which generally have compact panicles. According to [9], loose panicles, such as those of the local Guinea breeds, promote cross-pollination, while very compact panicles, such as those generally found in the local Durra breeds, hinder cross-pollination. Furthermore, the modification of white grain sorghum into red grain sorghum suggests that the gene responsi-

ble for the red colour is dominant. This is also the case for sweet grains sorghum which becomes grain sorghum when produced in association with grain sorghum. According to [37] the allele controlling sweet flavour is recessive while the allele responsible for unsweet flavour is dominant.

5. Conclusion and Perspectives

Four different types were identified within sorghum genetic resources. The grain sorghum and sweet grain sorghum are widely cultivated while sweet sorghum and dyer sorghum are very minor types of sorghum.

In the local farming system, the types of sorghum are cultivated in the same fields. A coincidence of sowing and flowering dates was observed during the survey, which could contribute to gene flow between these types of sorghum. The evolution of the different types of sorghum was already observed by farmers. These included changes in grain and glume colour, panicle shape and reduction in grain flavour that can lead to evolution from one type to another. These results require further investigation through agromorphological and molecular characterization with the aim of understanding the impact of farming system on sorghum genetic diversity.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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