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Characterization of the diversity of maize (*Zea mays* L.) grown in the province of Kenedougou

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Abstract

For more than a decade, the expected yields of cultivated varieties have fallen short of stakeholders' expectations. However, little research has been done on the type and quality of seeds used by producers. This study was initiated to shed light on the issue for stakeholders by exploring the varietal diversity of cultivated maize in relation to the characterization of cobs and grains. To achieve this objective, samples were collected, and a semi-structured survey was conducted among sixty-four (64) farmers. Agromorphological measurements were then taken on the cobs and grains of the samples collected. These measurements included the average cross-sectional area and length of the cobs, the length and width of the kernels, the percentage of dented kernels, and the weight of 1,000 kernels. The results showed significant varietal diversity in the corn grown. Improved varieties accounted for 78% of the samples collected. Among these, composite varieties are the most widely grown (52.4%). In addition, varieties that mature in less than three months (early varieties) are the most popular among producers, accounting for 55.6% of the total. First-generation seeds are also the most widely used. In terms of acquisition methods, the largest supply is found in state-subsidized seeds, at 46%. In terms of cob and grain characteristics, the samples collected showed a very high variability of cobs and grains for all traits evaluated except for mean cob diameter (MED) and number of rows per cob (NR). This diversity in the varieties grown should encourage stakeholders to promote extension services, participatory selection.

Keywords: Characterization; Sample; Variety; Maize; Kenedougou

1. Introduction

In Burkina Faso, maize is the leading crop in terms of production and food supply, with a variety of forms used by humans and animals [1,2,3]. It is traded both within the country and in subregional markets [4]. Despite this potential, however, maize production has struggled to grow for more than a decade. However, INERA has developed several improved in collaboration with international institutions such as IITA and CIMMYT. These have led to the dissemination of several plant materials such as local varieties and composite varieties (Masayomba, IRAT 80, IRAT 171, Jaune Flint de Saria, Jaune de Fô, etc.) and a hybrid (IRAT 81). Subsequently, several high-yielding varieties, each adapted to specific agroecological zones and consumer needs, were developed and disseminated. These include hybrid varieties (Bondofa and Komsaya) for irrigated areas, varieties (SR21 and Espoir) for southern Sudanese areas, and varieties (Wari and Barka) for northern Sudanese areas. Today, several high-yielding simple hybrid and test-cross varieties have been created and made available to farmers to boost their agricultural production. These improved seeds are now an important component of agricultural production. However, these technologies, which have been developed over more

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than two decades, are encountering difficulties in their adoption [5] for several reasons, according to the literature, including inadequate extension services [6], insufficient financial resources for producers [7], and ecological or environmental conditions that are out of step with the developed technologies [8]. In terms of the proportion of cultivated land sown with improved varieties, the Hauts-Bassins region ranks first with 32.93%. This is followed by the Cascades region (24.44%), the Boucle du Mouhoun region (16.67%), and the Sud-Ouest region (15.52%). According to [9], grain yields are 30-40% higher for hybrid varieties and 14-25% higher for composite varieties compared than for local varieties in areas ranging from dry to favorable zones. Today, thanks to the efforts of stakeholders in the corn sector, more than 30 improved maize varieties are currently listed in the national catalogue [10]. Of these, over a dozen are maintained and cultivated by producers in agrosystems. However, it should be noted that the expected yields of these varieties have been fallen short of expectations for over a decade. Nevertheless, few studies have specifically examined the type and quality of seeds used by producers. This study aims to assess the varietal diversity of corn grown in relation to the characterization of cobs and grains in the province of Kenedougou.

2. Materials and methods

2.1. Study area

The province of Kenedougou is one of three provinces that make up the Hauts-Bassins region, now known as the Guiriko region, in western Burkina Faso. It is located between approximately 11°05' north latitude and 4°15' west longitude, with an area of 8.307 km^2 [11] in the South Sudanese climate zone [12], characterized by a rainy and dry season. Rainfall is abundant and characterized by high variability. The main forest species found are *Vitellaria paradoxa, Khaya senegalensis, Parkia biglobosa, Cassia sieberiana, Piliostigma reticulatum, Diospiros mespiliformis, Faidherbia albida*, and *Adansonia digitata*. There are also large plantations of *Mangifera indica, Anacardium occidentale, Eucalyptus camaldulensis*, and several types of citrus fruits. The soils of the province are ferralitic, leached tropical ferruginous soils, eutrophic brown soils, and hydromorphic soils suitable for growing sorghum and millet [13]. However, these soils require fertilization for maize cultivation.

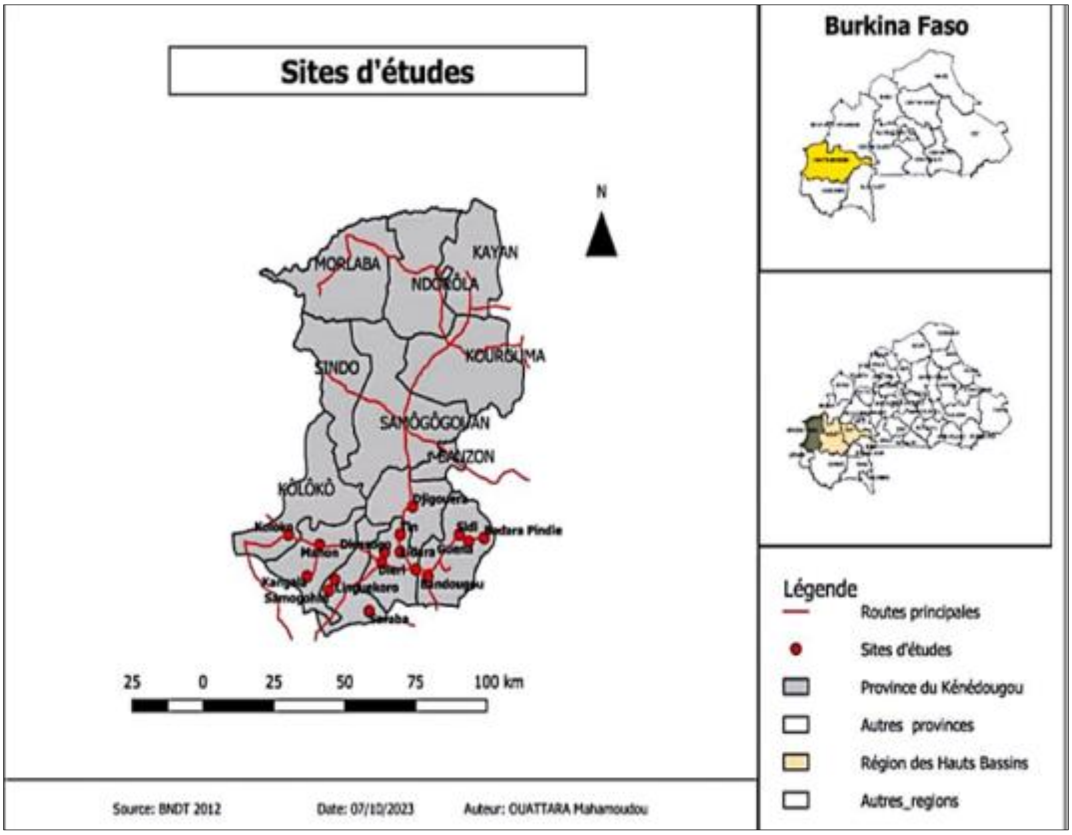

Figure 1 Map of the study area

2.2. Survey of varieties grown by producers

A qualitative approach combining semi-structured and structured individual interviews was used [14]. This involved collecting samples followed by a structured survey of sixty-four (64) farmers in the province of Kenedougou. A questionnaire was administered, and the information was recorded on a form. The questionnaire focused mainly on the variety's name, origin or method of acquisition, and how long it had been produced for. After the survey, a sample of the variety was taken from each respondent. The producer was asked to provide a minimum of five cobs from the seed lot, or three if the quantity of seed was small. Where the seed was in grain form, a minimum of 300 grams was collected [15,16]. Each sample was then labelled with the corresponding code, the name of the donor and the collection site using markers. The plant material was then packed in a plastic bag and taken to the INERA Farako-Bâ biotechnology and varietal improvement laboratory for a descriptive study.

2.3. Description of the characterization of the cobs and grains of the maize samples collected

During this laboratory study, the technical equipment used included a measuring tape, a piece of string, caliper, electronic scales and a grain counter. The plant material was divided into two groups: farmer's varieties of maize and elite varieties promoted by INERA. The first group consisted of 64 samples. The second group comprised four hybrid varieties (Bondofa, Komsaya, Kabako, and Semax6) and ten (10) composite varieties (SR21, Espoir, Wari, FBC6, Massongo, Barka, KPJ, KEJ, KEB, and KPB). Measurements of the average cross-section and length of the cobs were taken from a minimum of three cobs. Seed length and width measurements were taken on 10 batches of 10 seeds selected at random and consecutively without replacement, using a direct-reading caliper. The percentage of dented seeds and the different seed colors were determined by manually counting 100 seeds at random. To determine the 1000 grain weight, grains were selected at random and counted using a grain counter, then weighed using a precision electronic scale [17,18]. The morphological variables of the seeds and cobs considered in this evaluation were:

- cob length (LE);
- average cob cross-section (SME);
- number of rows on the cob (NR);
- number of kernels per row (NGR);
- thousand kernel weight (PMG);
- color of the grains on the cob (white (W), yellow (Y), yellow-orange (YO), red (R), purple (P));
- grain length (GL);
- and grain width (GW) [17,18].

2.4. Data analysis

The questionnaire was developed and the responses were entered using SPHINX PLUS 2.4.5 software. This software and SPSS (Statistical Package for the Social Sciences) version 26 [19] were used to analyze the citation frequencies. The data were then exported to an Excel spreadsheet for further processing analysis. Variance analysis and PCA on the data relating to cob and grain characteristics were performed using XLSTAT software, version 2016.

3. Results

3.1. Diversity of maize collected in the province of Kenedougou

3.1.1. Varietal diversity of maize collected

Figure 2 shows the percentage of different varieties in the collected sample. Analysis of Figure 2 reveals that the sample collected consisted of two types of plant material: improved and local varieties. The improved varieties accounted for 78% of the sample, while the local varieties accounted for 22%. A total of eight (08) improved varieties were used by producers. However, the proportion used varied from 28% to 2%. The most widely grown variety was Barka (28%), followed by Komsaya (20%), Massongo (11%), FBC6 (6%), Bondofa (5%), Espoir (3%), SR21 (3%), and Wari (2%).

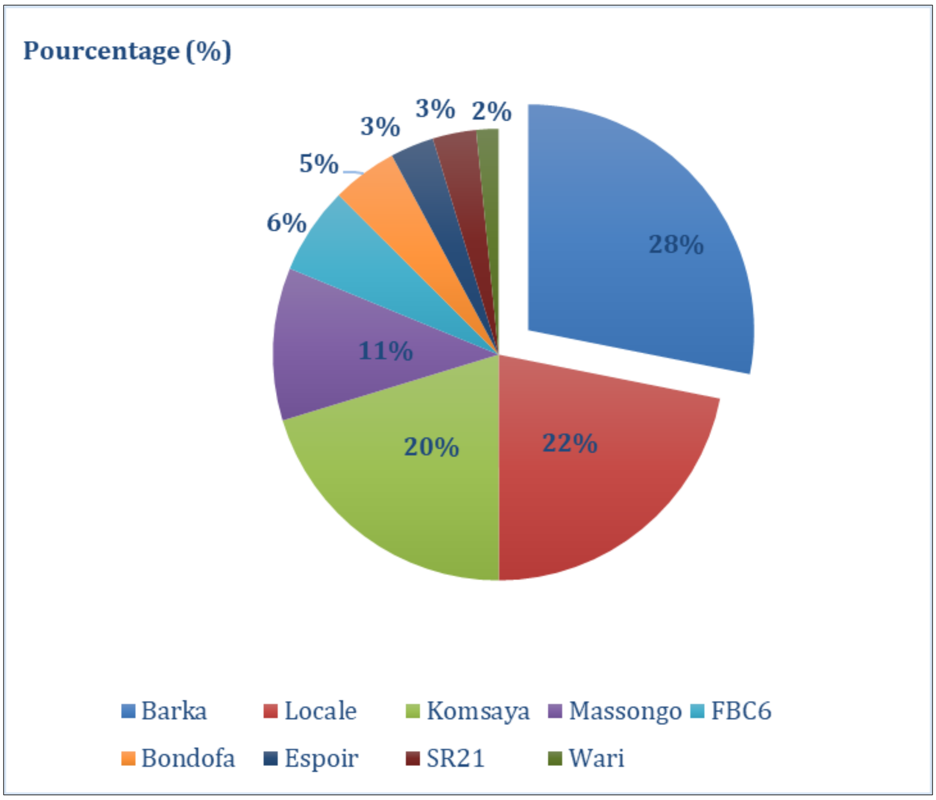

Figure 2 Rate at which varieties are used by producers

3.1.2. Different types of varieties and their vegetative cycle

Table 1 presents three types of variety according to their cycle and genetic nature: hybrid, composite, and local. However, the rate of use varied. Composite varieties were the most widely grown (52.4%), followed by hybrid varieties (25.4%) and local varieties (22.2%). In terms of the vegetative cycle, varieties with a cycle of less than three months (early) were the most popular among producers, with 55.6%, while varieties with a cycle of more than three months (intermediate) accounted for 44.4%.

Table 1 Types of varieties and their vegetative cycle cultivated by producers

Variables	Type	Frequency	Percentage (%)
Variety type	Composite	33	52.4
	Hybrid	16	25.4
	Local	14	22.2
Cycle	-3 months	35	55.6
	+3 months	28	44.4

3.1.3. Supply method and type of variety generation

With regard to the method of supplying seeds, the analysis in Table 2 shows that producers explored several sources to obtain seeds for their production. In fact, four sources of supply were explored. The largest supply was found to be government-subsidized seeds, at 46%, followed by old local seeds (inherited), at 22.2%, seeds sold at the market, at 19%, and finally seeds sold by seed companies. These seeds were divided into several generations or levels of multiplication. The most widely used were first-generation seeds (47.6%), followed by second-generation seeds (17.4%). Third-, fourth- and fifth-generation seeds were also used by producers, but at low rates of 6.4%, 4.8% and 1.6%, respectively.

Table 2 Supply method and number of seed multipliers for the varieties collected

Variables	Modality	Frequency	Percentage (%)
Origin	Inherited	14	22.2
	Market	12	19
	Seed producer	8	12.8
	Subsidy (State)	29	46
Generation	F1	9	14.3
	F2	6	9.5
	F3	1	1.6
	Unknown	14	22.2
	R1	21	33.3
	R2	5	7.9
	R3	3	4.8
	R4	3	4.8
	R5	1	1.6

3.1.4. Color, anthocyanin pigmentation, and grain texture

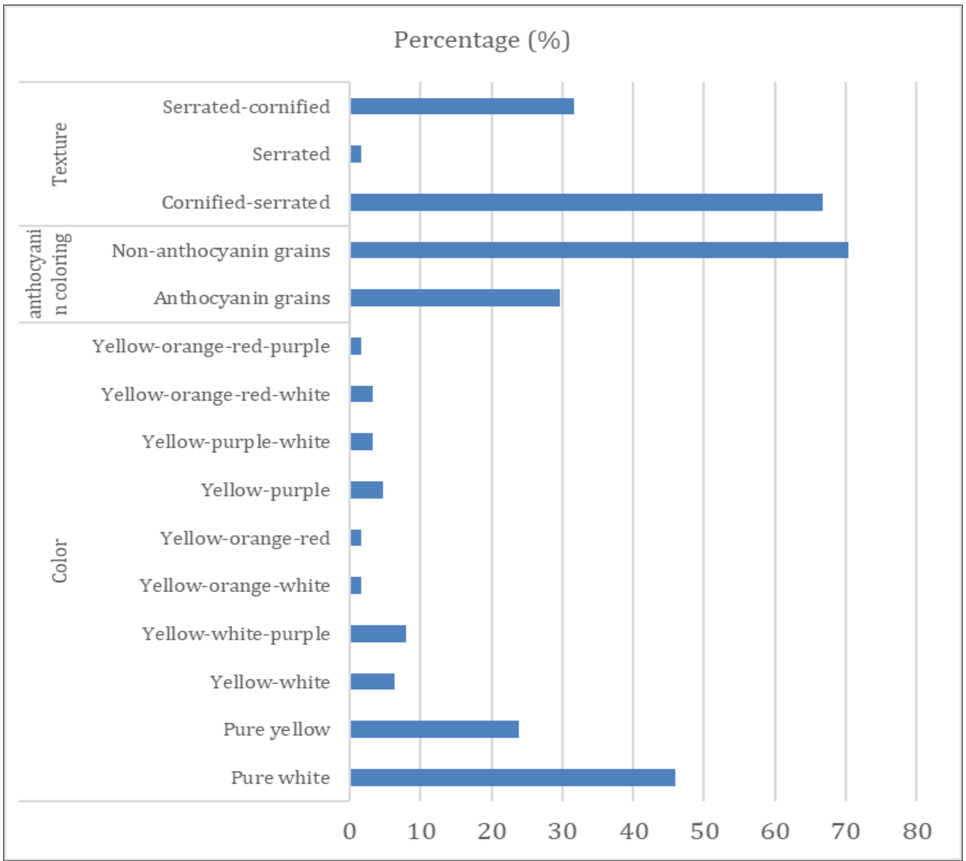

Figure 3 Different colors of the grains in the collected samples

The samples collected exhibited a variety of grain pigmentation and texture types. The color of the grains varied greatly, with pure white and yellow pigmentation dominating, accounting for 46.03% and 23.8% respectively. The rest of the samples had grains of different colors, ranging from a mixture of yellow-white-purple (7.9%), yellow-white (6.3%), yellow-purple (4.77%), and yellow-orange-red-white (3.2%). Most of the samples collected had grains that did not contain anthocyanin (70.32%). In terms of grain texture, 66.7% of the samples were horned-dented, 31.7% were dented-horned, and only 1.6% were dented.

3.2. Description of the characteristics of the samples collected

3.2.1. Types of samples collected

Figure 4 illustrates the types of the samples collected in each village. It reveals that the maize samples collected were stored either as kernels or cobs by the producers. The samples consisted of grains of different colors. Some samples were monochromatic (yellow or white), others were bicolored (yellow-white or yellow-purple), and some were even tricolored (yellow-red-purple).

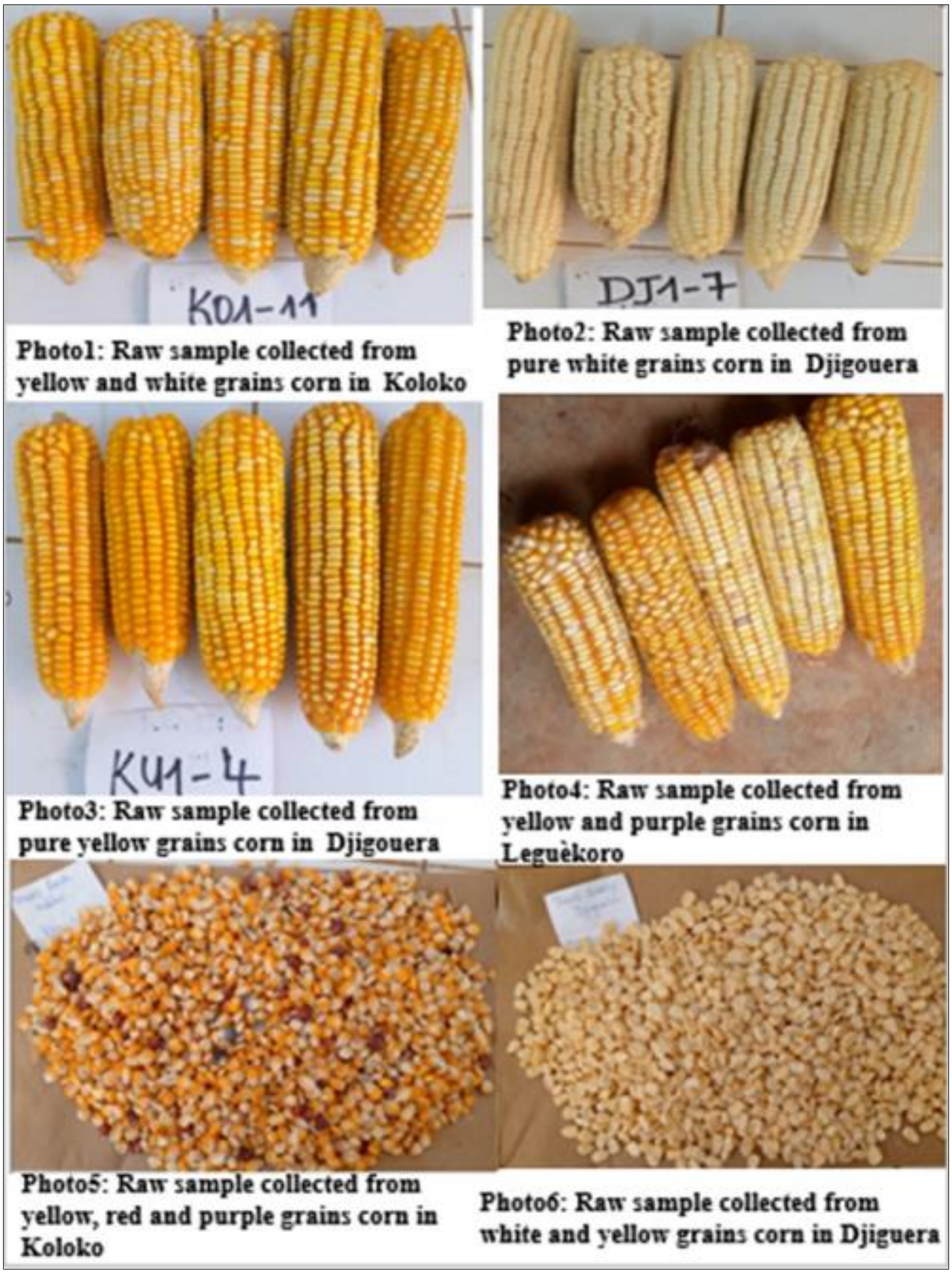

Photo1: Raw sample collected from yellow and white grains corn in Koloko

Photo2: Raw sample collected from pure white grains corn in Djigouera

Photo3: Raw sample collected from pure yellow grains corn in Djigouera

Photo4: Raw sample collected from yellow and purple grains corn in Leguèkoro

Photo5: Raw sample collected from yellow, red and purple grains corn in Koloko

Photo6: Raw sample collected from white and yellow grains corn in Djiguera

Figure 4 Sample cobs and grains, showing types and colors collected

3.2.2. Characterization of the grains in the samples collected

Analysis of variance of the grains in the collected samples showed considerable variability for the quantitative characteristics taken into account in the analysis. Variance coefficients greater than 15% were observed for all variables studied, indicating the existence of variability in the material. Highly significant differences were observed for all selected characteristics.

Table 3 Results of the variance analysis of grains

Statistics	GL	GW	PMG
Minimum	0.100	0.300	200.000
Maximum	12.200	1.900	450.000
Average	0.926	0.792	301.930
Coefficient of variability (%)	67.4	18.4	18.0
Standard deviation	0.022	0.005	1.942
F	2.822	9.231	6819.271
Pr > F	< 0.0001	< 0.0001	< 0.0001

3.2.3. Characterization of the cobs from the samples collected

The results of the analysis of variance (Table 4) showed significant differences for the characteristics cob length (LE) and number of kernels per row (NGR). A highly significant difference was observed for the thousand-grain weight (PMG) trait. However, no significant differences were observed for the average cob diameter (SME) and number of rows per cob (NR) traits.

Table 4 Results of the analysis of variance of the cobs collected

Statistics	SME	LE	NR	NGR	PMG
DJ1-1	4.675 a	16.350 ab	14.500 a	41.000 a	292.500 e
K01-11	4.633 a	18.333 a	14.000 a	37.667 a	368.000 a
KU1-4	4.533 a	16.500 ab	15.333 a	38.667 a	305.333 d
DJ1-7	4,667 a	14.267 ab	15.333 a	40.667 a	261.333 g
DJ1-2	4.600 a	15.975 ab	13.500 a	37.250 a	308.750 d
OR4-1	4,575 a	15.150 ab	13.500 a	38.000 a	318.750 c
SA3-1	4.680 a	12.200 b	12.000 a	32.200 a	331.000 b
SA1-1	4.220 a	14.780 ab	12.400 a	40.400 a	272.600 f
Minimum	4.000	8.800	10.000	28.000	255.000
Maximum	5.300	19.500	18.000	45.000	374.000
Average	4.561	15.229	13.613	38.032	306.516
Coefficient of variability (%)	6.9	15.8	13.2	11.5	9.8
Standard deviation	0.057	0.440	0.327	0.797	5.496
F	1.103	3.331	2.388	2.550	193.505
Pr > F	0.394	0.013	0.054	0.042	< 0.0001

3.2.4. Cob-based sample structuring

The two PCA axes together account for 76.37% of the total variability. Axis 2 contributed 33.31% of the total variability, while axis 1 contributed 43.06%. The variables number of grains per row (NGR) and the number of rows per cob (NR) were arranged on axis 1. Samples DJ1-1, KU1-4, and DJ1-7 were correlated with this axis, meaning that they had a high number of grains per row and number of rows per cob. The variables thousand-grain weight (PMG), average cob cross-section (SME), and cob length (LE) were arranged on axis 2. Sample KO1-11 was correlated with this axis, meaning that it had the highest thousand-grain weight and the largest average cob cross-section.

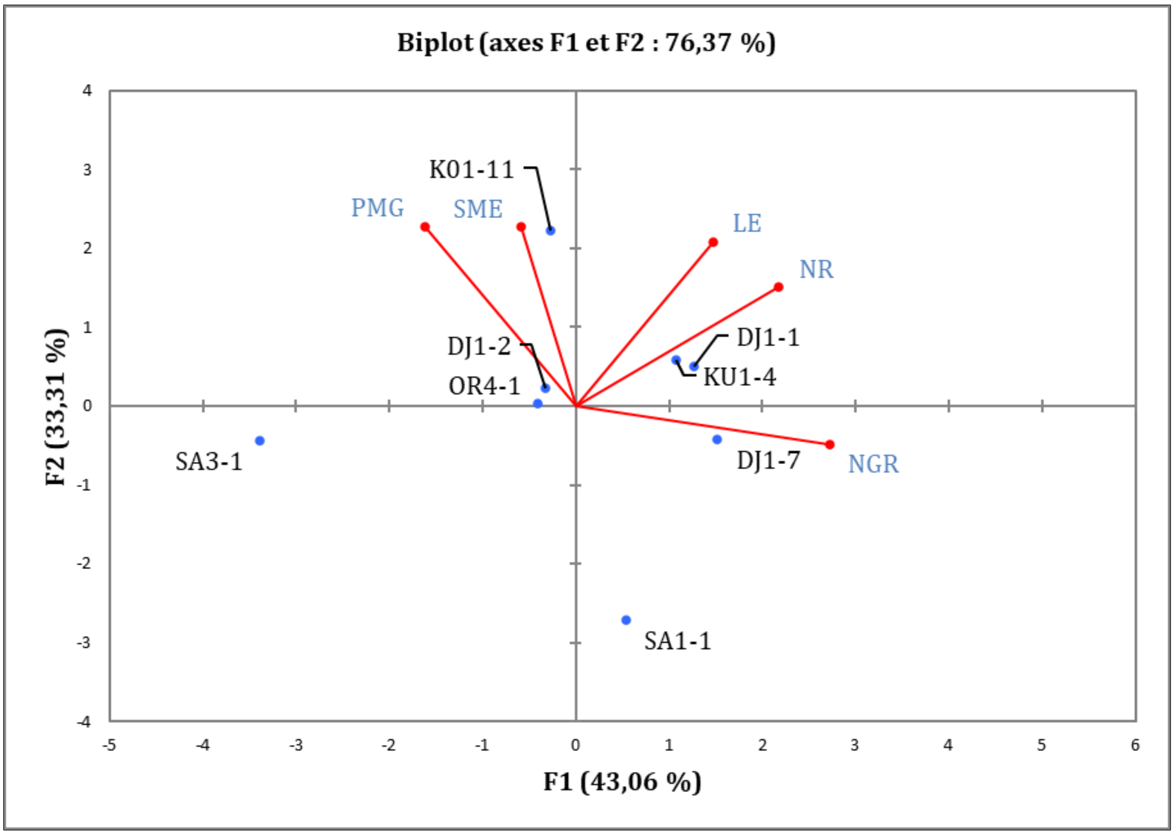

Figure 5 Representation of samples along the F1 and F2 axes of PCA

4. Discussion

4.1. Varietal diversity of maize cultivated in the province of Kenedougou

A significant variety of maize was cultivated in the Kenedougou province. In fact, eight (08) different improved varieties out of approximately fourteen (14) were commercialized by seed producers. This diversity could be explained, on the one hand, by the widespread promotion of improved maize varieties through various channels, such as agricultural productivity projects and programs carried out in the province. On the other hand, it could be explained by the strong involvement of the central government through the Ministry of Agriculture, which significantly increased subsidies for improved varieties for the benefit of producers. Despite this multitude of varieties available to them at subsidized prices, producers continued to produce local varieties. These so-called local varieties could be local or degenerated or recycled varieties that have been around for so long that producers do not know their names. These results corroborate those of [6], who found that 63% of producers were cultivating local or recycled varieties of improved maize in the main agroecological zones for maize; in contrast to [20], who found an adoption and exposure rate of 62% for improved varieties in the Boucle du Mouhoun region. This stubbornness in producing local or recycled varieties could be explained by the fact that farmers did not have access to subsidized improved varieties, because local varieties provide certain economic, socio-cultural, agronomic, or nutritional value. According to [15], farmers produce local varieties for cultural and nutritional reasons.

Early-maturing varieties were the most widely used by producers. This could be explained by the fact that they were the most readily available, i.e., they were offered as part of a government subsidy scheme, but it could also be a choice made by certain producers in view of the uncertain seasonal climatic. Furthermore, it could be linked to varietal search programs geared toward the development of early cycle varieties to adapt to new climates. These results are similar to those of [6], who found that early-maturing varieties were the most widely used by producers in all agroecological zones.

Additionally, research has developed varieties according to agroecological zones, with late-maturing varieties being developed for the sub-Saharan zone. This parameter was not always been taken into account in the distribution of improved varieties subsidized by the state, which were also the most widely produced by smallholders in the province. Taking this parameter into account would improve agricultural yields, particularly in areas with sometimes very high rainfall, since late-maturing varieties are more productive than early-maturing ones.

The varieties grown differ according to their genetic nature. In fact, composite varieties were the most widely grown by producers. This could be explained by the fact that breeding programs initially developed and popularized several composite varieties, which are now the best known to producers. They are also undemanding, easy to multiply by seed producers and, for the most part, early maturing. In addition, from an economic standpoint, they are less expensive and require fewer inputs, and many of them are resistant to biotic and abiotic stress, even if their yields are average. Research should reorient its breeding program to develop and disseminate several high-yielding, early-maturing hybrid varieties for the benefit of producers.

Producers explored a variety of sources of supply, with the largest supply coming from government-subsidized seeds and traditional local seeds (inherited), to the detriment of seeds sold by seed companies. This diversity of supply sources can be justified by ease of access or by the modest means available to producers when the need arises. It should be added that producers do not prepare their campaigns in advance; most wait until sowing time to decide what to sow for the season. In addition, over the last two years, with the advent of the agricultural offensive, the government has subsidized several thousand kilograms of improved seed varieties and fertilizers for producers, which has made it easier for small farmers to acquire and access these varieties. Nevertheless, producers' choices and preferences for varieties may not be taken into account, which could justify the production of other varieties such as local varieties. Efforts should therefore be made to take producers' preferences into account.

Several generations of seeds of different varieties were grown by producers, with a predominance of first-generation seeds. However, third-, fourth-, and fifth-generation seeds were also produced by producers, albeit at low rates. The predominance of first-generation seeds among producers could be due to their accessibility thanks to subsidies from the government and its technical partners. In principle, improved seeds should be renewed each year in the case of maize, as recycling them leads to a decline in their genetic potential.

Unfortunately, most producers, due to a lack of information or knowledge or a lack of resources, recycle these varieties for several years, with the result that yields fall year after year. Extension services need to be strengthened and producers need to be made aware of the genetic nature of improved varieties.

A characterization variable such as grain color has been a criterion for producers' choice, and the grains in the samples collected were mostly white. This could be explained by the seed that was available to them, i.e., the subsidized varieties offered to them by the government. In fact, in the study area, it should be noted that white-grain varieties were the most widely distributed and in the greatest quantities during the two years of the study. This could also be due to producer preference. This was observed by [6], who found that producers prefer white maize for economic reasons but also for its high yield.

Some of the samples collected had multicolored grains with anthocyanin pigmentation. The presence of these types of grains could justify the genetic nature of the sample in terms of its genetic purity. The anthocyanin pigmentation of the grains in a sample indicates the state of genetic degeneration of this material in a farming environment. It could be a criterion for recognizing degenerated improved varieties and impure improved varieties on the one hand, and local varieties on the other.

From the above, it appears that most farmers did not make good choices in terms of the varieties to produce. This poor choice could be explained by the genetic nature of the varieties grown, most of which were local varieties or degenerate varieties. According to [15], local varieties are hardy but their yields are low. Furthermore, improved varieties that are recycled over several years gradually lose certain important features, such as yield potential, due to genetic drift or pollution from interaction with other nearby varieties.

This loss of yield potential is greater in hybrid varieties than in composite varieties. According to [9], grain yields are 30-40% for hybrid varieties and 14-25% for composite varieties compared to local varieties. Research should include participatory selection into breeding programs and provide producers with training sessions tailored to their needs, so they can understand the consequences of recycling improved varieties and using local varieties on agricultural yield.

4.2. Characterization of maize samples collected

A highly significant difference was observed in the grains for all selected traits. This indicates the existence of significant variability in the grains. This variability can be attributed to the diverse sources and genetic backgrounds of the samples. This also suggests that grain size and thousand-grain weight were not used as selection criteria for the varieties. According to [21], grain data are criteria that can be used to identify varieties. Furthermore, these different grain sizes and thousand-grain weights could be used and incorporated into breeding programs. At the cob level, a significant difference was observed in the material evaluated for cob length (LE) and number of kernels per row (NGR). This would mean that there is variability between the cobs of the samples collected. This could confirm previous studies that found that cobs can be used to characterize the samples collected [16,15,17]. However, no significant differences were observed for the mean cob cross-section (SME) and number of rows per cob (NR) traits. This indicates low variability for these traits. These results corroborate those of [17], who found no significant differences in the average section and number of rows per cob in their collected samples. This suggests that these characterizations are of agronomic interest to farmers. The PCA divided the material into two groups characterized by the number of grains per row, the number of rows, the average cob section, and the thousand-grain weight. These variables were decisive in expressing the diversity of the material. This would give maize farmers the opportunity to select long-cob variety parents in order to obtain new hybrid varieties with high yield potential that better meet the needs of both local and industrial populations.

5. Conclusion

Few studies have been conducted on the typology of cultivated varieties. This study identified eight (08) different improved varieties cultivated, with early-maturing varieties being the most widely used by producers. Cultivated varieties differ according to their genetic makeup, and producers explored a variety of supply sources, with the largest supply coming from state-subsidized seeds. Several generations of seed varieties were cultivated by producers, with a predominance of first-generation seeds, but also third-, fourth-, and fifth-generation seeds. Characteristic variables such as pure grain color, multicolored grains, and anthocyanin coloring were observed. Significant variability was observed in cobs and grains. Given the types of varieties adopted by producers, future research should focus on developing white-grain hybrid varieties with early maturity and high yields.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The authors declare that they have no conflicts of interest.

Authors Contributions

- MO: field survey, data measurement and collection, data analysis, and manuscript writing.
- AD: designed and supervised the work, supervised data analysis and manuscript revision.
- ST: supervised data analysis and revised the manuscript.
- AT: revised the manuscript. DN: contributed to the measurement and collection of data.

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