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Geospatial Mapping of Agro-Morphological and Phenological Traits of Indigenous Sorghum Germplasms in Niger

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Abstract

Sorghum breeding significantly relies on the understanding of genetic diversity dynamics. Despite its importance, research on the geographical distribution of essential agro-morphological and phenological traits for achieving targeted breeding outcomes has been limited. This paper presents an analysis of five key traits—stem flavor, days to 50% maturity, plant height, grain color, and grain size—across 483 germplasm samples from 71 villages in Niger, based on data collected during a 2003 survey. The primary aim is to map the geographical distribution of these traits. The findings, illustrated on a map of Niger, provide insights into the regional distribution of these characteristics, aiding breeders and agronomists in understanding trait combinations for developing new sorghum varieties.

Keywords

Biodiversity, Plant Breeding, Geographical Distribution of Local Varieties

1. Introduction

The rural diet alongside millet. It flourishes predominantly in regions receiving annual rainfall between 450 and 800 mm. Identified as a secondary hub of sorghum diversity, Niger showcases a rich racial diversity, with four out of five recognized sorghum races present [1] [2]. The biodiversity of these cultivated sorghums is evident in their agro-morphological traits and phenotypic variety,

exhibiting differences in plant height, panicle compactness from loose to compact, 1000 grain weights ranging between 14 to 46 grams, and significant grain color and texture variation [2]-[4]. Additionally, the diversity in growth cycles and photoperiod sensitivity allows traditional sorghum varieties to adapt remarkably to Sahelian ecological conditions. The tendency of sorghum to flower rapidly as the rainy season wanes, when daylight shortens, is notable [5]. Early sowing corresponding to the onset of the rainy season and aligning the growth cycle with the rainy period limit bestows ecological robustness: reduced operational costs through weed management, efficient use of organic matter mineralization, rainwater optimization, and soil protection against early-season runoff [6]. The management of varietal diversity by farmers further mitigates risks and addresses various cultivation and usage constraints [7]. The notable genetic diversity of local varieties stems from traditional seed management practices (selection, exchange, variety introduction, seed reproduction methods, etc.) and significant outcrossing rates, ranging from 3 to 31% [8]. Studies by [2] [8] [9] have analyzed the genetic diversity of West African traditional varieties. These locally cultivated varieties are tailored to diverse ecological contexts and production objectives. Over three decades, sorghum production has nearly doubled, primarily driven by expanded cultivation areas [10]. Despite these adaptations and increased output, Niger's sorghum yield remains the lowest in the region, averaging 343 kg/ha [11]. Alarming reductions in sorghum biodiversity have been recorded in specific Nigerien regions, attributed to erratic rainfall patterns, shorter rainy periods, soil degradation, and pest pressures, such as midges and striga [12]. Historically, enhanced cereal production in Niger has been largely due to the extension of cultivation areas. As rural spaces reach saturation, intensifying agricultural practices becomes essential. In this evolving context, millet and sorghum should serve as viable options for intensified cropping systems.

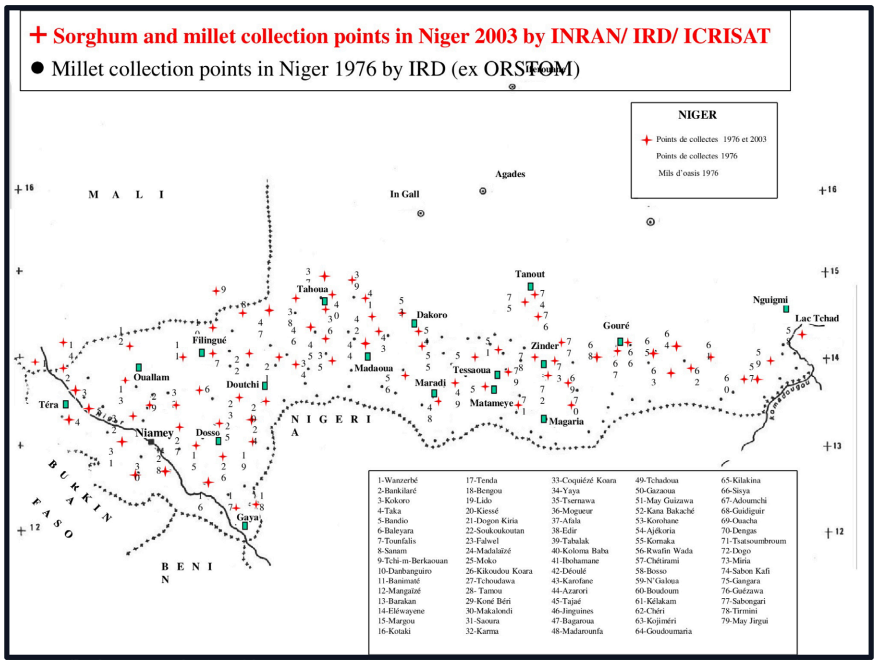
The genetic erosion of sorghum and the pursuit of varietal performance are crucial for both the development of new varieties and the conservation of genetic resources. Sorghum breeders require a foundational database concerning the parentage of sorghum varieties [13]. Understanding the agro-morphological and phenological traits of local germplasms, along with their supplementary data, is critical for selecting parent types for new varieties that are suited to the sociocultural and agroeconomic environments and resilient to climatic challenges [14].

This study primarily aims to balance the preservation of sorghum biodiversity with the enhancement of its productivity across various regions of Niger. It involves mapping 483 local sorghum samples collected during the 2003 survey onto the national map. This effort is intended to assist breeders and agronomists in selecting parent lines based on the studied traits, thereby facilitating effective crossbreeding.

2. Materials and Methods

A total of four hundred eighty-three (483) local sorghum samples were collected during a 2003 prospection and collection mission focused on millet and sorghum

across six (6) out of the eight regions in Niger. Figure 1 shows collection points of sorghum germplasm in 2003 in 71 villages.



(IRD = Research Institute for Development source ex-ORSTOM = Office for Overseas Scientific and Technical Research).

Figure 1. Map of sorghum germplasm collection points in 2003 in 71 villages.

The regions involved in this study were: Dosso (13˚02'46" N, 3˚11'50" E) located in the southwest, Tillaberi (14˚13'00" N, 1˚27'00" E) also in the southwest, Tahoua (13˚53'40" N, 5˚15'52" E) in the northeast, Maradi (13˚30'0" N, 7˚6'6.3" E) in the central south, Zinder (13˚48'25.8" N, 8˚59'17.2" E) in the center-east and Diffa (13˚18'56" N, 12˚36'62" E) in the southeast of Niger.

The samples are distributed as follows according to the different regions (Figure 2).

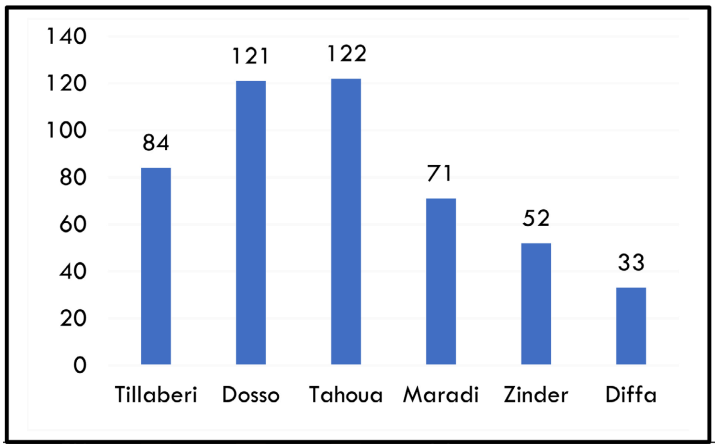


Figure 2. Distribution of number of samples collected according to region.

The germplasms collected from 71 villages in Niger were assessed at the ICRISAT (International Crop Researsh Institut for the Semi Arid Tropics) experimental station in Sadoré. Situated in the southwest of Niger (latitude 13˚14' N, longitude 2˚17' E, and altitude 235 m), this station is in the Sahelian zone along the 550 mm isohyet with an average annual rainfall of 560 mm. It is a collaborative trial conducted in 2004 by the sorghum breeder of INRAN in partnership with the INRAN-IRD-ICRISAT research institutions which took part in the germplasm collection in 2003.

The experimental design was a complete randomized block design (RCBD) with two separate 2 m repetitions. Each variety was sown at a density of 4 seeds per hole along a 10 m line, with a spacing of 0.8 m between holes and between lines in each repetition. Thinning to 2 plants per hole was conducted during weeding to minimize competition among sorghum plants and enhance seedling development. Prior to sowing, the experimental plot received applications of organic manure at 10 t/ha and NPK 15-15-15 mineral fertilizer at 150 kg/ha. A subsequent application at the seedling-elongation stage included 100 kg/ha of Calcium Ammonium Nitrate (CAN), 100 kg/ha of gypsum, and additional NPK. This combination of fertilizers was intended to supply the essential nutrients for the optimal growth and development of the morphological and phenological traits of the various cultivars. Irrigation was provided as necessary during periods of drought. The study, as outlined by [15] investigated five agro-morphological traits.

1) Stem flavor, assessed as either sweet or bland
2) Plant height, measured as the height of the main stem at 50% flowering
3) Duration in days from the beginning to 50% maturity
4) Pigmentation of anthers (glumes)
5) Seed size, determined by the weight of grains at 12% moisture content

It is crucial to highlight that observations for each characteristic were conducted on an average of ten (10) plants. Excel software facilitated the analysis of the results, while ARC-view software was employed to generate the maps.

3. Results

The outcomes are presented on a map of Niger to provide a clearer perspective on the geographical distribution of these traits. The agroecological zones or isohyets are shown for reference purposes only, as climate changes are highly variable and thus unreliable for definitive conclusions. It is important to note that each point represents a village where collections were made and the numbers on the map denote the number of varieties collected in each village. Due to the scale of the map, two adjacent villages may be represented as a single point.

3.1. The Flavor of the Stem

As reported by [15], the stem flavor was assessed on two levels: Bland and Sweet. **Figure 3** illustrates the distribution of various samples across regions based on stem flavor. Although different flavor types are present in all regions, their pro-

portions vary. Specifically, bland or non-sweet varieties account for 63% of the 483 samples collected, equating to 304 samples. Notably, a significant proportion of these non-sweet varieties is found in the regions of Dosso, Tahoua, and Maradi. Additionally, the regions of Tillabéri and Zinder generally exhibit moderate sorghum cultivation, with even less in the Diffa region. Sweet varieties, on the other hand, constitute 37% of the total samples collected, amounting to 179 samples. These sweet varieties are more prevalent in the regions of Tahoua, Tillabéri and Dosso, while they are less common in Maradi, Diffa, and Zinder (Figure 3).

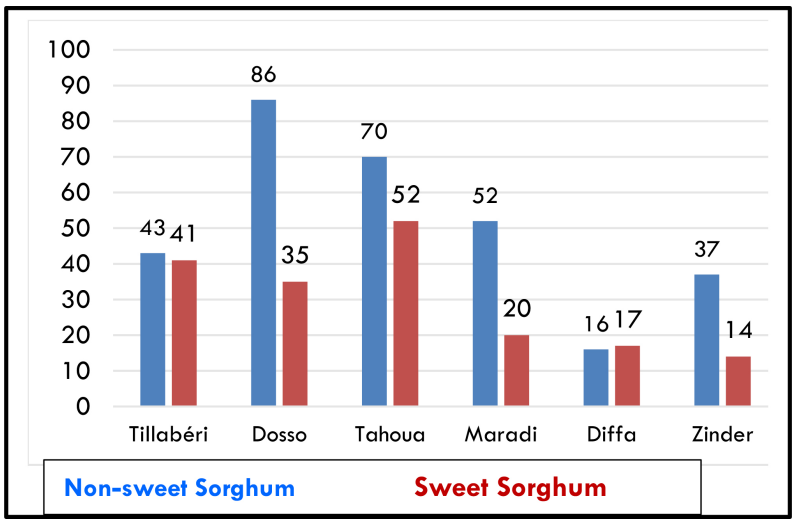
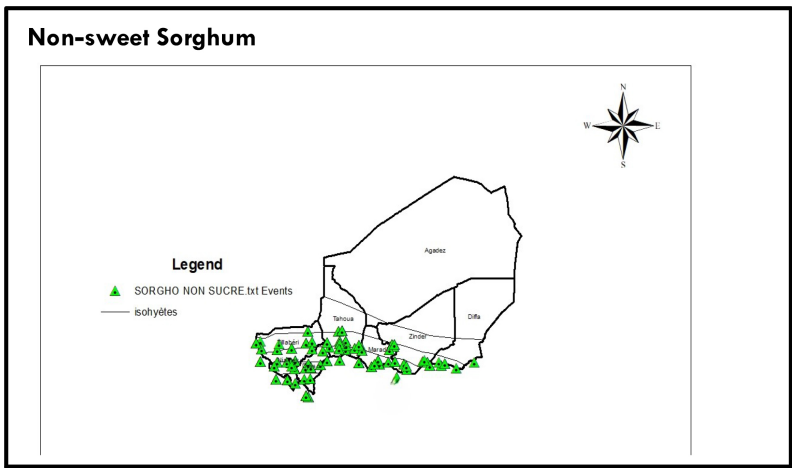


Figure 3. Distribution of various samples by flavor across different regions.

Figure 4 illustrates the depiction of the stem flavor profiles of various samples across regions based on stem flavor.

Within the 300 to 500 mm isohyet range, there is a notable presence of non-sweet varieties, especially in the Maradi region and to a lesser extent in the Northwest of the Zinder region. Additionally, the Tahoua region exhibits a higher prevalence of both non-sweet and sweet varieties, predominantly concentrated in the Maradi and Zinder regions.



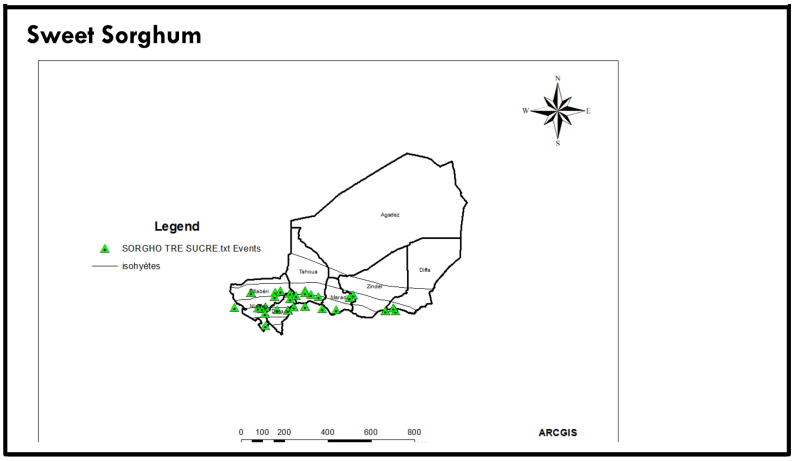


Figure 4. Depiction of the stem flavor profiles of various varieties across regions.

3.2. Plant Height

The plant height across various regions was assessed in accordance with the guidelines from [15]. The measurements are classified into three categories: short (≤180 cm), medium (180 to 200 cm), and tall (>200 cm). Predominantly, tall varieties (180 to 200 cm) are found across all regions, followed by medium-sized varieties, and finally, short varieties (≤180 cm). Notably, the Dosso region hosts a substantial number of tall varieties, succeeded by Maradi and Tillabéri, with Zinder and Tahoua having moderate occurrences. In the regions of Diffa and Zinder, only tall varieties are cultivated. Conversely, medium-sized varieties are more frequently grown in Tillabéri, Dosso and Tahoua. Short varieties are primarily cultivated in Tahoua, are less prevalent in Dosso and Maradi, and are nearly absent in Tillabéri, Diffa, and Zinder (**Figure 5**, **Figure 6**).

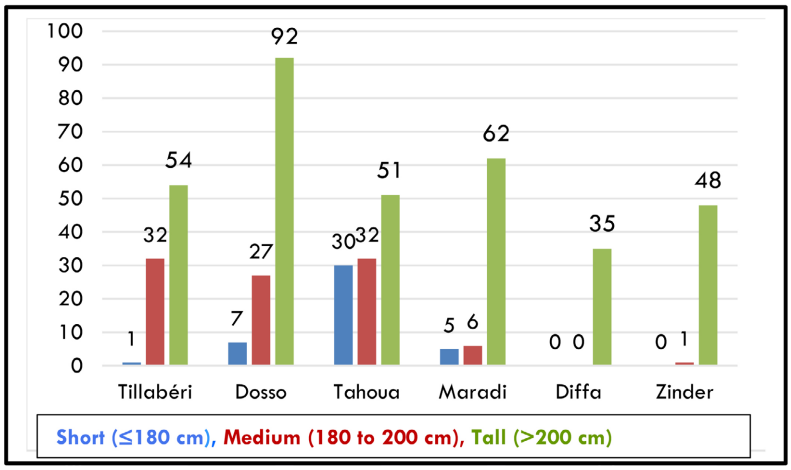


Figure 5. Distribution of various samples categorized by plant height across different regions.

The distribution of various samples categorized by plant height across different regions is shown in **Figure 6**.

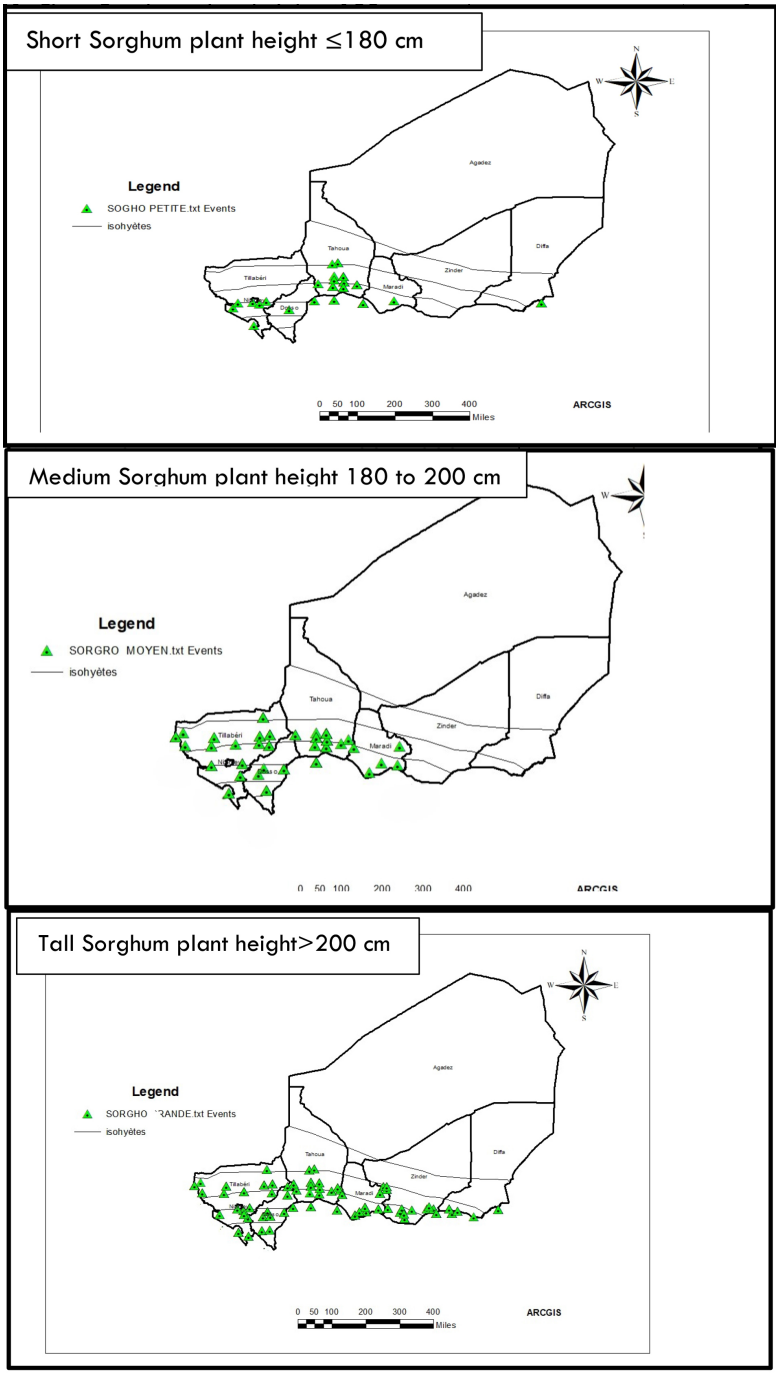


Figure 6. Distribution maps of various samples categorized by plant height across different regions.

3.3. Maturity

Sorghum maturity is categorized into three primary groups: early varieties, which mature up to 85 days; medium-late varieties, maturing in 86 to 100 days and late varieties, more than 100 days for maturation. As illustrated in **Figure 7**, early varieties are not cultivated in the Zinder and Diffa regions, where only medium-late and late varieties are grown. In Diffa, these two categories are cultivated in nearly

equal proportions, whereas in Zinder, late varieties slightly outnumber medium-late ones. Early varieties, where present, are cultivated on a limited scale in regions such as Tillabéri, Dosso, Tahoua, and to a lesser extent, Maradi. Overall, medium-maturity varieties are more widely cultivated across all regions. Specifically, the regions of Tahoua, Tillaberi, Dosso, and Maradi exhibit the highest cultivation rates for medium-maturity varieties, with 28%, 23%, 18%, and 16%, respectively. Late-maturity varieties are predominantly grown in Dosso (32%), followed by Tahoua (18%), Zinder (16%), and to a lesser extent in Maradi and Tillaberi, at 15% and 10%, respectively.

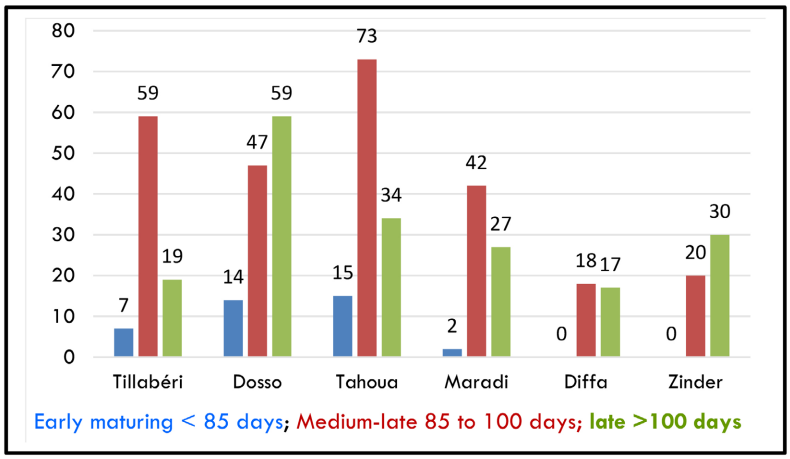
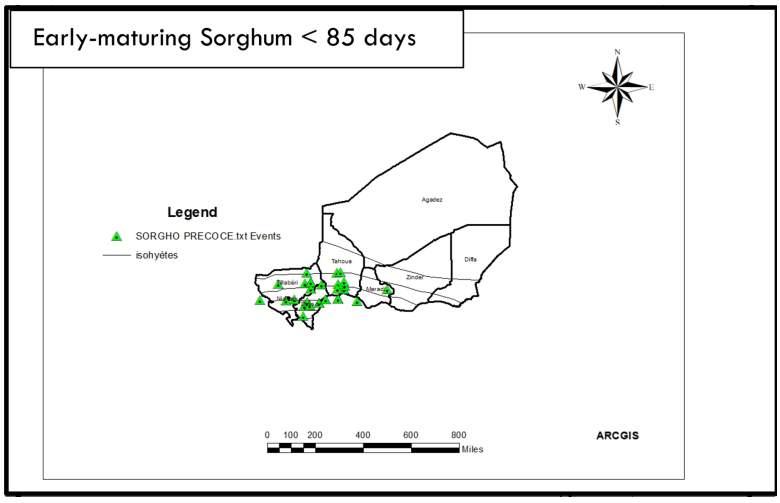


Figure 7. Regional distribution of various plant maturity cycles across different regions.

Accordingly, **Figure 8** shows the distribution of various maturity cycles across different regions.

3.4. Seed Color

The seed color is assessed at maturity on 10 ears collected from the same variety, following a customized color chart which includes white, black, red, brown, or purple. As indicated in **Figure 9**, white-seeded varieties constitute nearly 58% of



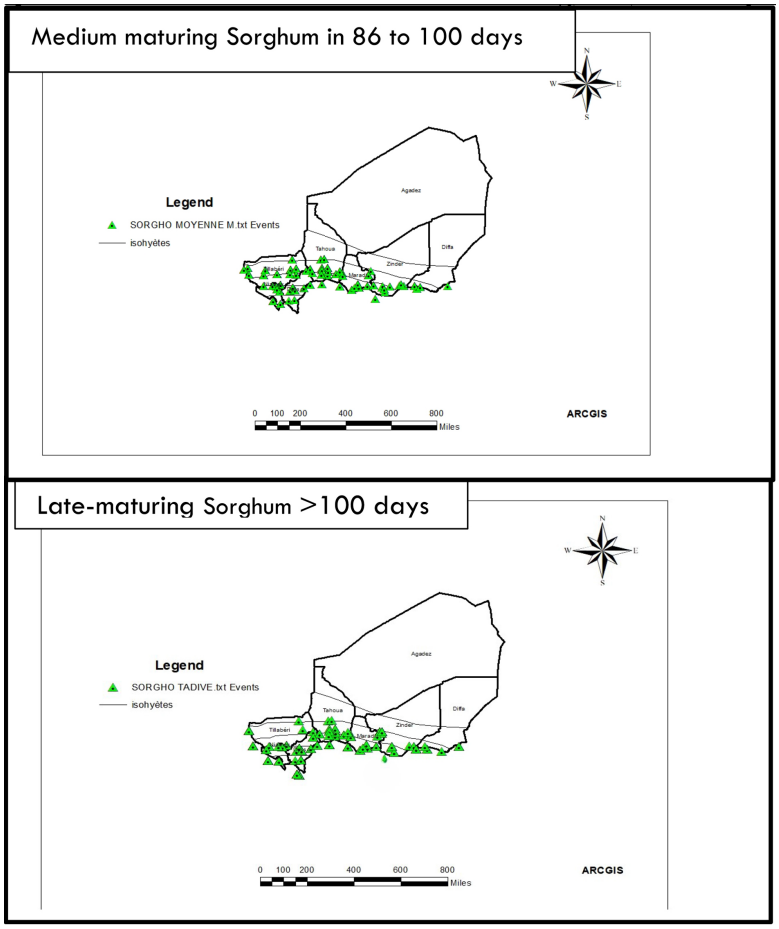


Figure 8. Distribution map of various maturity cycles across different regions.

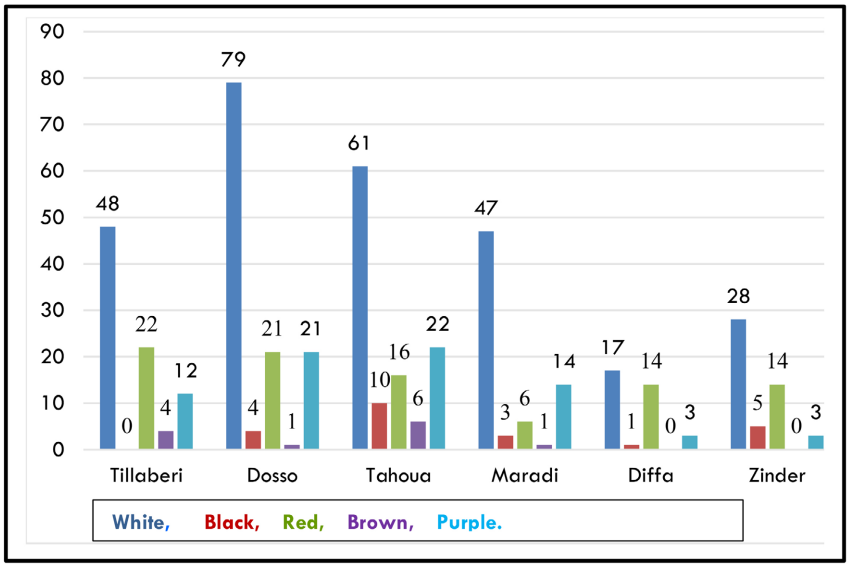
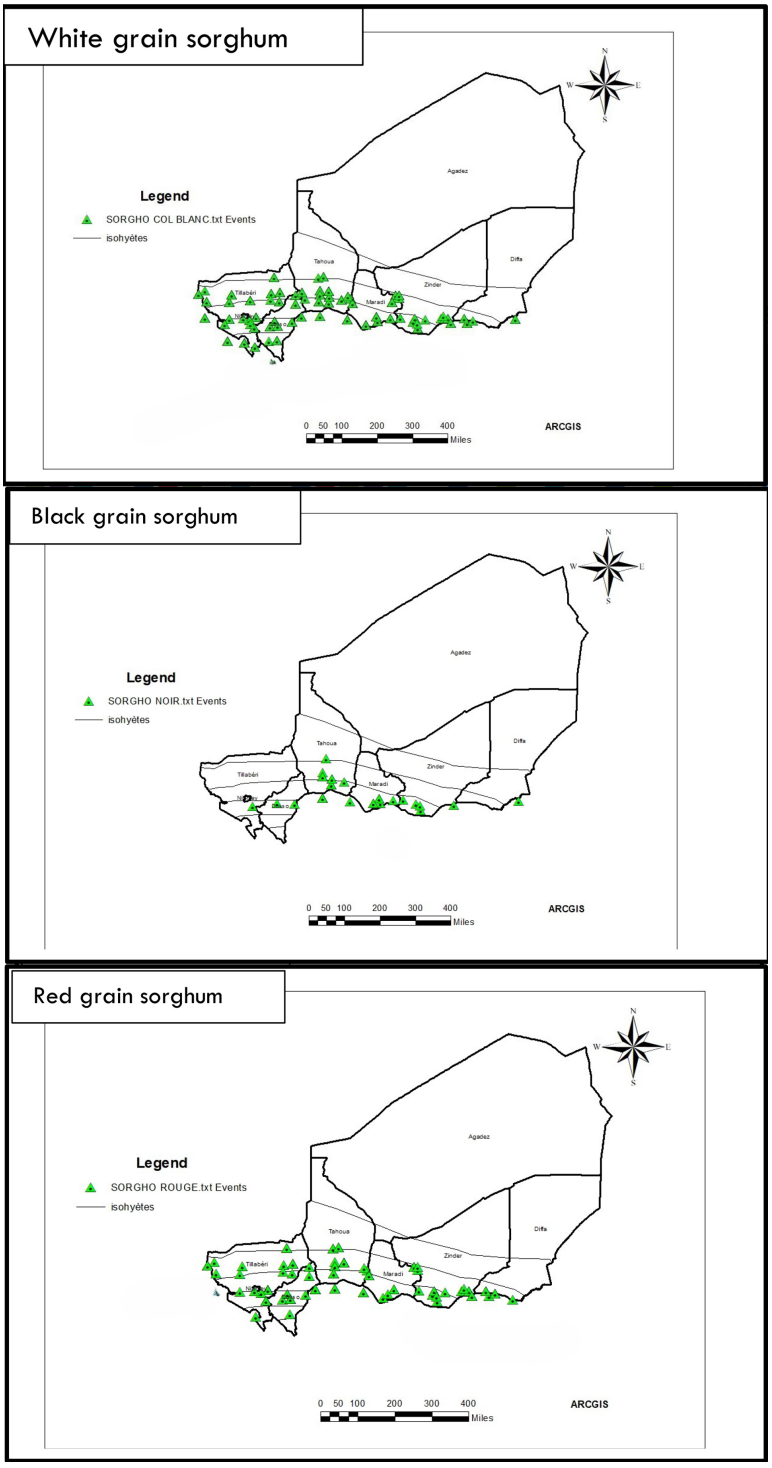


Figure 9. Distribution of seed color variations across regions.

all seed colors across all regions. They are particularly prevalent in the regions of Dosso, Tahoua, Tillabéri, and Maradi. The red seed color is also notable across all

regions, ranking second to white but in significantly smaller quantities. Black-seeded varieties are predominantly found in the regions of Tahoua, Diffa, and Dosso, yet they are nearly absent in the regions of Tillabéri and Diffa. It is noteworthy that brown-seeded varieties are also not present in Zinder and Diffa.

The repartition of various maturity cycles of different sorghum germplasm collected across the different regions is shown in **Figure 10**.



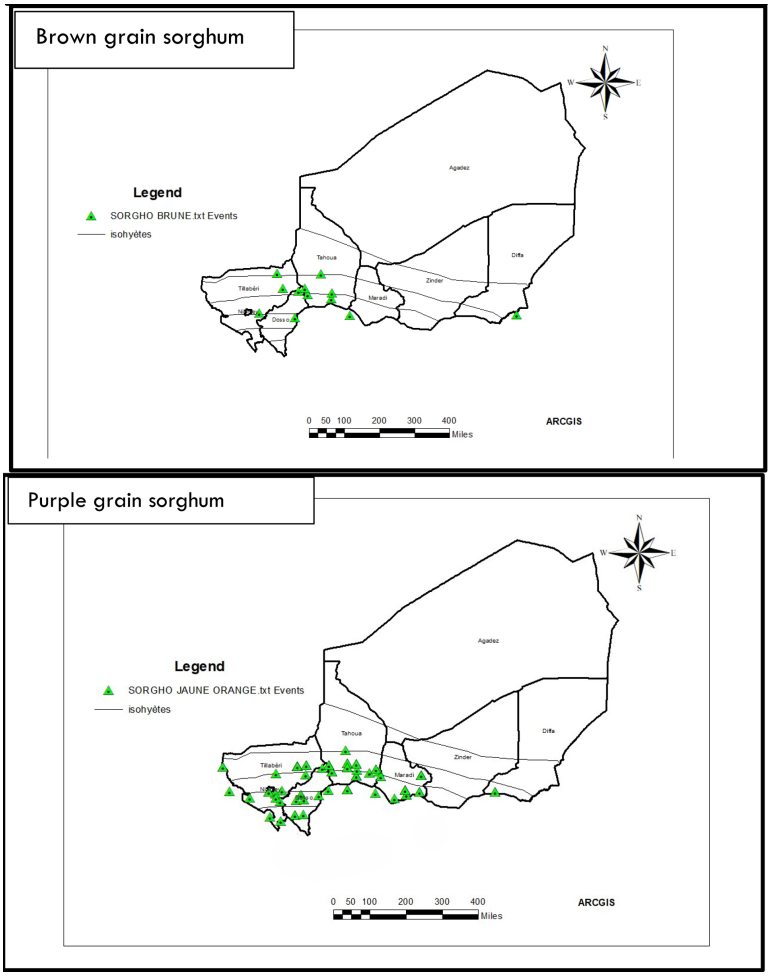


Figure 10. Distribution map of seed colors across regions.

3.5. Seed Grain Weights

The grain weight is assessed with a standard moisture content of 12% [15]. In this study, the weight of 1000 grains were measured based on their classification into small (<20 g), medium (20 to 35 g) or large (>35 g) categories. As illustrated in **Figure 11**, all regions exhibit a range of grain sizes (small, medium, and large), although the proportions vary. Notably, medium-sized grain varieties dominate cultivation across alregions, accounting for 59.21%, followed by small grain varieties at 21.3%, and large grain varieties at 20.28%, which are predominantly cultivated in the Zinder region. Medium-sized grain varieties are predominantly grown in Dosso, Tahoua, Tillaberi, and Maradi. In contrast, small grain varieties are most commonly cultivated in Tahoua, Dosso, Tillaberi and Maradi, respectively, and are scarcely grown in the Diffa and Zinder regions (**Figure 11**).

The distribution of grain weights of different sorghum accessions collected based on size across regions is shown in **Figure 12**.

4. Discussion

In plant breeding programs, understanding the genetic structure of local crop

varieties, which farmers often favor for their adaptability, flavor, or post-harvest processing qualities, is crucial for selecting optimal entries and defining target zones

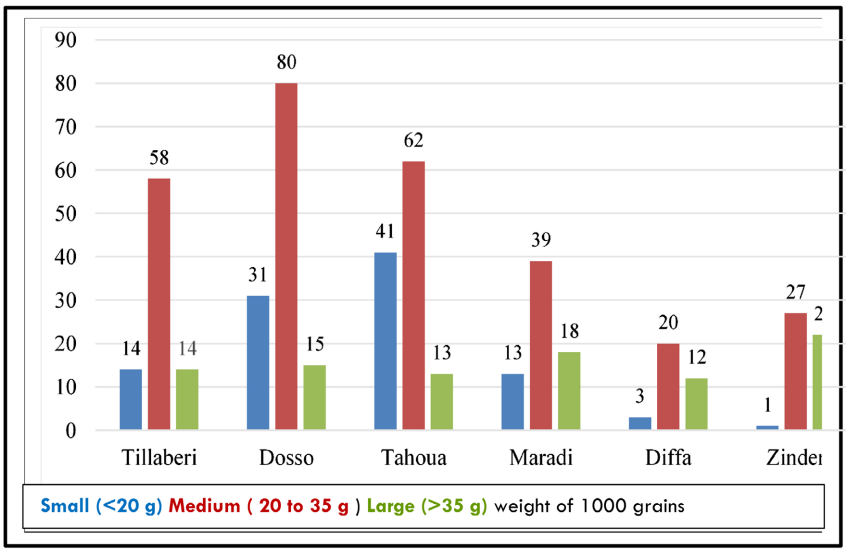
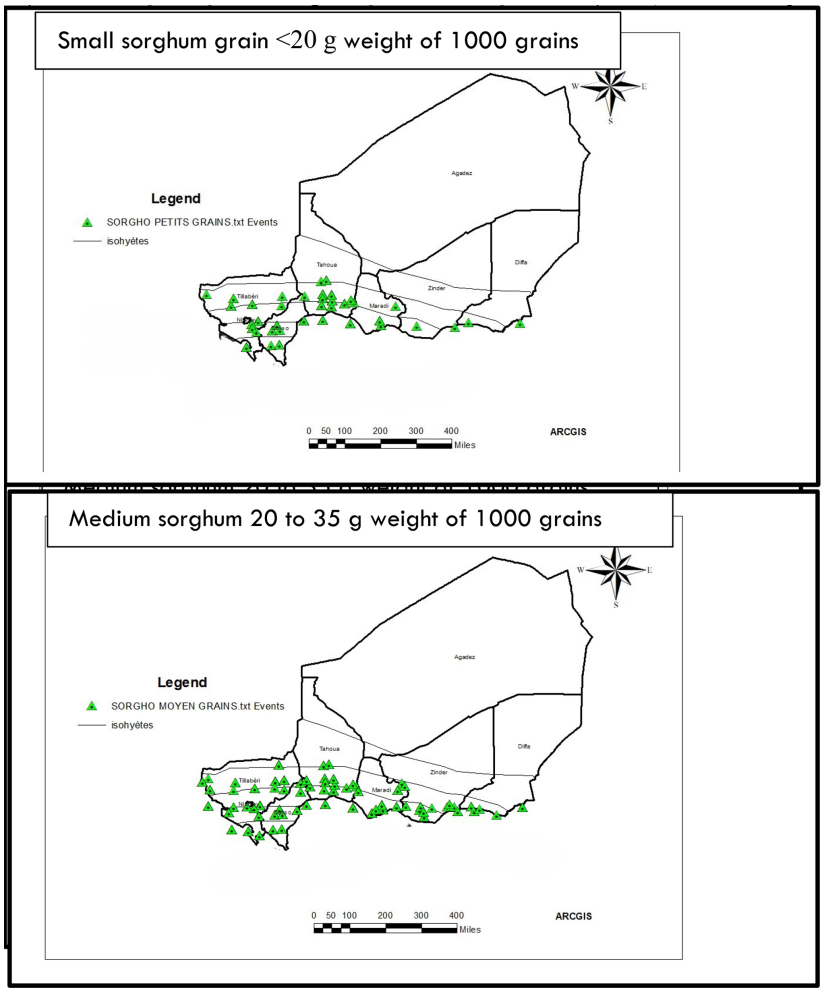


Figure 11. Distribution of grain weights based on size across regions.



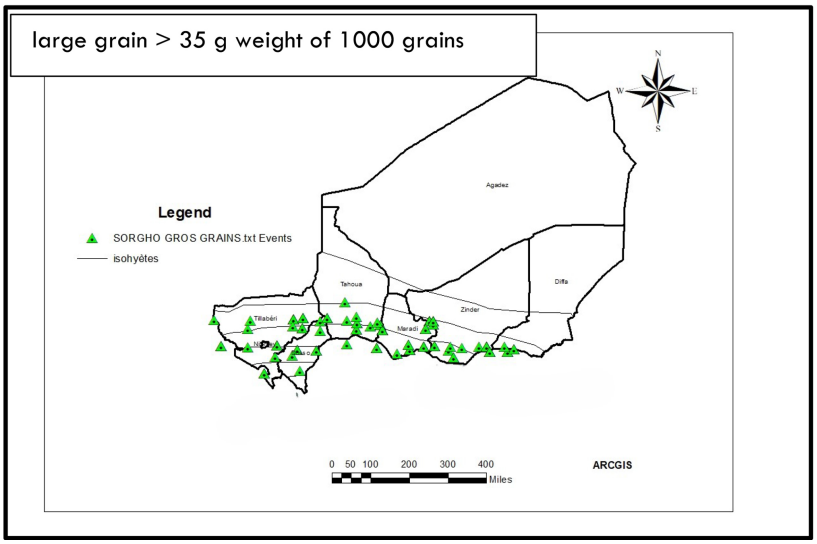


Figure 12. Distribution map of grain size across regions.

for improved varieties. Our research indicates that the regions of Dosso, Tahoua, and Maradi have the highest number of collected local varieties, whereas Zinder and Diffa have fewer, with Tillabéri falling in between. This finding aligns with [16]'s study on Niger sorghums, which suggests that the Central region, being the most densely populated, has the greatest variety per village, while the Eastern region, being the least populated, has the fewest, and the Western region holds an intermediate position [12]. Niger is characterized by significant phenotypic and genetic diversity in sorghums, serving as a convergence zone for four of the five primary sorghum races (Guinea, Bicolor, Caudatum, Durra) [12]. These botanical races are often linked to specific culinary properties or uses, such as sweet sorghums whose stalks are harvested pre-maturity and consumed by chewing [14]. In Niger, sweet sorghum stalks are marketed as an early alternative to sugarcane [16]. Our study finds that sweet varieties are particularly prevalent in Maradi and Zinder, corroborating [14] who notes that there are geographical and ethnic distribution patterns of sorghum races in Niger, exemplified by the "Takanda" group, a set of botanical races with specific uses of sweet sorghums belonging to the bicolor race.

Our study reveals extensive phenotypic diversity among sorghum varieties in Niger, characterized by a wide range of plant heights, seed colors, and the weight of 1000 grains. Previous research has similarly documented significant phenotypic variation among local sorghum genotypes, particularly with respect to plant height, panicle compactness, and both the color and vitreousness of grains [2]-[4]. Our findings indicate that shorter sorghum varieties are predominantly located between the 300 and 500 mm isohyets, especially in the drier regions of Tahoua, northern and far-western Tillabéri, as compared to the country's agricultural belt which primarily consists of medium-height varieties found in southern Tahoua, Maradi, and Zinder, and to a lesser extent in Dosso within the same isohyet range. In contrast, taller varieties are concentrated between the 400 and 600 mm isohyets in southern Maradi, Dosso, and Tahoua. Regarding seed color, white-

seeded varieties account for nearly 58% of the total across all regions, being particularly prevalent in Dosso, Tahoua, Tillabéri, and Maradi. Red grain varieties are also prominent throughout, whereas black grain varieties are notably more prevalent in Tahoua, Diffa, and Dosso, and nearly absent in Tillabéri and Diffa. Medium-grain varieties dominate cultivation across all regions (59.21%), followed by small-grain varieties (21.3%) and large-grain varieties (20.28%), with the latter being more extensively cultivated in the Zinder region.

The range of cycle durations and photoperiod sensitivity imparts traditional sorghum varieties with exceptional adaptability to the Sahelian environment and climate. Our research indicates a widespread presence of early-maturing varieties across the agricultural belt of Niger, predominantly in the regions of Tillabéri, Dosso, Tahoua, and Maradi (isohyets between 300 and 500 mm). Furthermore, medium-maturing varieties are more prevalent between isohyets 300 and 600 mm in the regions of Tillabéri, Dosso, and Maradi. Late-maturing varieties are located in the regions of Dosso, southern Tahoua, and Maradi, specifically between isohyets 400 and 700 mm. The adaptation of the plant's growth cycle to the expected duration of the rainy season via photoperiodism is the primary focus of selection, as it significantly influences grain yield and quality.

In Niger, the adoption of improved sorghum varieties is limited, with most production relying on local varieties selected by farmers. These local varieties are specifically adapted to their challenging, heterogeneous, and unpredictable environments. Additionally, ethnic traditions, social structures, and dietary preferences likely play roles in shaping the diversity and organization of crops [7].

5. Conclusion

In the context of increasing saturation of rural areas and significant demographic growth, enhancing sorghum productivity has become essential to meet the escalating food demands of the population. The initial phase in developing sorghum populations involves gaining a comprehensive understanding and characterization of the diversity of local sorghum varieties. These varieties may originate from ex situ collections (comprising varieties gathered in the 1970s and 1980s) or from new explorations conducted during the participatory diagnostic phase. Concurrently, it is crucial to define the production constraints and objectives for sorghum, as well as farmers' preferences. This dual approach of diversity characterization and diagnostic analysis will enable the identification of traditional varieties in each region that possess traits aligning with environmental constraints and farmers' expectations. The current study has revealed the extensive diversity of sorghum genetic resources in Niger. The traits examined have provided deeper insights into the morphology of local sorghum varieties in Niger. Mapping the agronomic traits studied will undoubtedly aid users of sorghum-derived products and serve as a foundational resource for researchers. This study will facilitate a precise understanding of the interactions between sorghum varietal traits and their geographical distribution, thereby aiding in the targeted search and collection

of desired germplasms.

Acknowledgments

We are grateful to the farmers from Niger who contributed to this study by providing seed samples and information on their varieties. We also thank the different people who participated in the 2003 collection.

Conflicts of Interest

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

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