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Diversity and correlation analysis of national bell pepper (*Capsicum annuum* L.) accessions in Niger

Abstract. The study on the diversity and correlation analysis of national bell pepper accessions is of paramount importance because it documented and conserved valuable local genetic resources while providing essential information for breeding and varietal improvement. By assessing agromorphological variability and identifying relationships among key traits, the study helped breeders select superior parent lines and guided farmers in choosing well-adapted accessions for different production contexts. This knowledge supports higher productivity, resilience to climate stress, and improves fruit quality, ultimately contributing to food security, income generation, and better management of national germplasm resources. The purpose was to assess the genetic diversity and identify key trait correlations among national bell pepper accessions in Niger to inform effective selection, conservation, and breeding programmes. Hence, national local germplasm was collected and evaluated in an alpha lattice design with three replicates. Data were collected and analysed

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through correlation, diversity, cluster, and principal component (PCA) analyses. The results uncovered substantial genetic diversity among national bell pepper accessions, highlighting the existence of distinct genetic clusters. Significant relationships were revealed between traits, such as a positive correlation between fruit pericarp thickness and corolla length, fruit pericarp thickness and fruit length, plant circumference and fruit pericarp thickness, total flowers and aborted flowers, plant height and the number of aborted flowers, plant height and the total number of flowers, the height of the first bifurcation and plant height, the height of the first bifurcation and total flowers, and the height of the first bifurcation and aborted flowers. The identified genetic diversity and trait correlations offered crucial information for bell pepper conservation and improvement. The results of this study can be used by breeders and farmers for the selection and cultivation of high-yielding and resilient bell pepper varieties

Keywords: variability assessment; germplasm characterisation; genetic diversity; principal component analysis; cluster analysis; agro-morphological traits

INTRODUCTION

Research on the diversity and correlation analysis of national bell pepper (*Capsicum annuum* L.) accessions in Niger is highly relevant because it provides essential information for strengthening the country's agricultural resilience and productivity. By characterising the genetic variability within local accessions, the study helps identify traits linked to yield, adaptability, and resistance to pests or environmental stresses, which are key factors for improving pepper cultivation in the face of climate change and evolving farmer needs. Understanding correlations among agronomic traits also guides breeders and policy-makers in selecting superior varieties and designing efficient breeding programmes. Ultimately, this research supports food security, enhances the value of local genetic resources, and contributes to sustainable agricultural development in Niger.

No known study has been conducted in the country to date. However, some authors, such as Y. Nas & H. İlbi (2022), have investigated genetic diversity in crops. They reported significant variability among genotypes, which is crucial for breeding programmes and conservation efforts. These studies revealed substantial diversity in morpho-agronomic traits and pungency genes across bell pepper varieties. Additionally, M. Silva & R. Silva (2021) demonstrated considerable genetic variation among the bell pepper genotypes analysed. Bell pepper, also referred to as sweet pepper or capsicum (*Capsicum annuum* L. var. *grossum*), is a member of the Solanaceae

family. As a species belonging to *Capsicum annuum*, it is native to Central and South America. Scientists such as L. Muñoz-Ramírez et al. (2020) and O. Agapie et al. (2023) have shown that domestication occurred more than 6,000 years ago and that the genus represents a highly diverse taxonomic group comprising 44 identified species. Among these, five species have been domesticated: *C. annuum* L., *C. frutescens* L., *C. chinense* Jacq., *C. baccatum* L. (var. *pendulum*), and *C. pubescens* Ruiz & Pav (Hernández-Pérez et al., 2020). *Capsicum* species are diploid, and most possess 24 chromosomes ($n = x = 12$); however, several wild species have 26 chromosomes ($n = x = 13$). According to G. Barboza et al. (2020), *Capsicum annuum* has 24 chromosomes and is one of the most globally important vegetable crops because of its widespread consumption and high nutritional value. Bell peppers (*Capsicum annuum* L.) are versatile and nutritious vegetables available in a wide range of colours. They are valued for their high vitamin C content and other bioactive compounds, such as carotenoids, tocopherols, flavonoids, and capsaicinoids, which contribute to their antioxidant, anti-inflammatory, and anticarcinogenic properties, as noted by L. Anaya-Esparza et al. (2021) and A. Onzo et al. (2021). They are also appreciated for their adaptability and diverse culinary applications. They can be consumed fresh, cooked, pickled, or used as ingredients in pasta, spices, or natural food colourants (Gamela et al., 2020). In 2020, the global production of pepper was

approximately 36 million tonnes. Numerous studies on the genetic diversity of bell peppers have revealed significant variability in morpho-agronomic traits. Understanding genetic diversity, trait correlations among bell pepper accessions, and phylogenetic relationships between accessions is essential for effective conservation, the development of breeding strategies, and varietal improvement programmes.

This study aimed to assess the diversity and correlation patterns of national bell pepper (*Capsicum annum*) accessions collected from Niger.

MATERIALS AND METHODS

The study adhered to ethical standards by ensuring that all plant materials were collected, used, and conserved in accordance with national regulations governing genetic resources and biodiversity. Permissions were obtained from relevant agricultural and research authorities before accessing germplasm from farmers' fields or national collections. Farmers and local communities involved in providing plant material or agronomic information were informed of the study's objectives, and their contributions were acknowledged in accordance with the principles of fairness and transparency. The research

complied with guidelines on the responsible use of plant genetic resources, avoiding any form of biopiracy, and ensuring that data were handled with scientific integrity, accuracy, and confidentiality. No human or animal subjects were involved, and all procedures followed institutional and international standards for ethical research in plant sciences. The study was conducted in accordance with the ethical standards of the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1976).

A collection of national bell pepper accessions was used for this study, which was carried out from April to July 2024 and comprised diverse genotypes representing different geographical regions. Germplasm was collected across the Republic of Niger from December 2022 to February 2023. All regions were included in the collection, except Agadez, where there is no known cultivation of traditional bell pepper cultivars. The targeted regions included Diffa, Zinder, Maradi, Tahoua, Dosso, and Tillabéri (Fig. 1). Agroecological zoning was used to identify areas within each region with potential bell pepper diversity. A participatory approach was employed to document and integrate knowledge of local varieties.

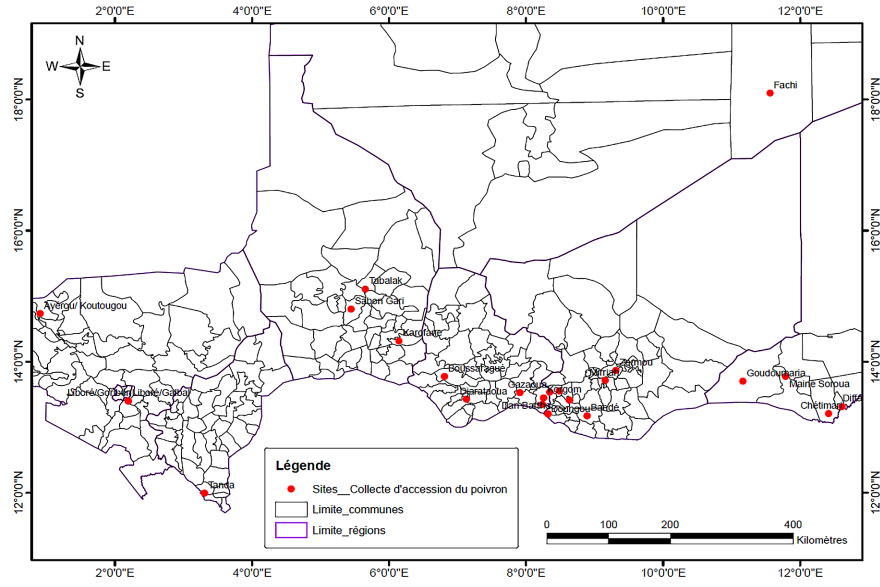


Figure 1. Germplasm collection sites

Source: created by the authors using the geographical coordinates of collection sites recorded during the survey

For the field collection, ethnobotanical surveys were conducted to document traditional knowledge about bell pepper varieties. Details such as local names, uses, and cultivation practices were recorded. Seed samples were collected from multiple sources, including farmers'

fields, home gardens, and local markets. Fifty-six collected cultivars (Table 1) were evaluated at Dogondoutchi (13°64'60" N, 4°05'53" E, altitude 256.3 m). The following table presents the accession numbers, their local names, sites, communes, departments, and regions of collection.

Table 1. Description of the collected cultivars

Accession number	Local name	Site/village	Commune	Department	Region
1	'Kangadi Nglaro'	Gangura	Bosso	Bosso	Diffa
2	'Mangala'	Diffa Market	Diffa	Diffa	Diffa
3	'Bongo'	Diffa Market	Diffa	Diffa	Diffa
4	'Bounami petit'	Diffa Market	Diffa	Diffa	Diffa
5	'Kangadi Nglaro'	Morey	Chétimari	Diffa	Diffa
6	'Mowor'	Chétimari	Chétimari	Diffa	Diffa
7	'Kangadi Nglaro'	Dabagoune	Chétimari	Diffa	Diffa
8	'Kangadi Nglaro'	Walada	Chétimari	Diffa	Diffa
9	'Mangala long'	Toumoure	Bosso	Bosso	Diffa
10	'Mangala petit'	Toumoure	Bosso	Bosso	Diffa
11	'Tattassé koua'	Annassaboul	Goudoumaria	Goudoumaria	Diffa
12	'Kangadi Nglaro'	Annassaboul	Goudoumaria	Goudoumaria	Diffa
13	'Champo'	Annassaboul	Goudoumaria	Goudoumaria	Diffa
14	'Champo'	NGaori	Goudoumaria	Goudoumaria	Diffa
15	'Borkono'	NGaori	Goudoumaria	Goudoumaria	Diffa
16	'Tattassé koura'	NGaori	Goudoumaria	Goudoumaria	Diffa
17	'Tattassé koura'	Kadélaboua	Goudoumaria	Goudoumaria	Diffa
18	'Tattassé'	Falki Babba	Mirriah	Mirriah	Zinder
19	'Koriyaram'	Bosso	Bosso	Bosso	Diffa
20	'Lardou'	Zermou	Mirriah	Mirriah	Zinder
21	'Dan Damso'	Tsamia	Bandé	Bandé	Zinder
22	'Dan Izala'	Tsamia	Bandé	Bandé	Zinder
23	'Maybiro'	Sabon Gari	Karofane	Bouza	Tahoua
24	'Hanchin Sania'	Dan Bartho	Dan Bartho	Kantché	Zinder
25	'Tchilam Glaro'	Diffa	Diffa	Diffa	Diffa
26	'Dan Tcharantchi'	Ichirnaoua	Ichirnaoua	Kantché	Zinder
27	'Dan Damastché'	Ichirnaoua	Ichirnaoua	Kantché	Zinder
28	'Dan Tcharantchi'	Koré Haoussa	Doungou	Kantché	Zinder
29	'Hantchi Sania'	Tassaou	Kantché	Kantché	Zinder
30	'Tattassé'	Djirataoua	Djirataoua	Madarounfa	Maradi
31	'Dourgou'	Kolma	Hawandawaki	Tessaoua	Maradi
32	'Kahon Baréwa'	Kolma	Hawandawaki	Tessaoua	Maradi
33	'Kahon Baréwa'	Romaza	Korgom	Tessaoua	Maradi
34	'Dourgou'	Romaza	Korgom	Tessaoua	Maradi
35	'Hantchi Sa'	Romaza	Korgom	Tessaoua	Maradi
36	'Kahon Baréwa'	Lawni	Gazaoua	Gazaoua	Maradi
37	'Dan Dourgou'	Lawni	Gazaoua	Gazaoua	Maradi
38	'Bakin Iri'	Lawni	Gazaoua	Gazaoua	Maradi
39	'Kahon Baréwa'	Sadjamandja	Gangara	Gazaoua	Maradi
40	'Koriyaram'	Diffa	Diffa	Diffa	Diffa

Table 1, Continued

Accession number	Local name	Site/village	Commune	Department	Region
41	'Bongo/Kouri Moro'	Tam	Mainé Soroua	Maine Soroa	Diffa
42	'Kangadi Nglaro'	Tam	Mainé Soroua	Maine Soroua	Diffa
43	'Bongo/Kouri Moro'	Blakouna	Mainé Soroua	Maine Soroa	Diffa
44	'Kangadi Nglaro'	Blakouna	Mainé Soroua	Maine Soroa	Diffa
45	'Tougandé'	Boussaradjé	Keita	Keita	Tahoua
46	'Tougandé'	Fachi	Tabalak	Abala	Tahoua
47	'Dan Talabé'	Talabé	Tahoua commune2	Tahoua	Tahoua
48	'Maybiro'	Sabon Gari	Karofane	Bouza	Tahoua
49	'Soumba'	Tounfafi	Madaoua	Madaoua	Tahoua
50	'Tattassé'	Soutoura	Doguéraoua	Malbaza	Tahoua
51	'Na Damana'	Konni	Konni	Konni	Tahoua
52	'Tonko Béro'	Tanda	Tanda	Gaya	Dosso
53	'Saye Hillo'	Koutougou	Ayérou	Ayérou	Tillabéri
54	'Simbad'	Gorou Béri	Liboré	Kollo	Tillabéri
55	'Chinoi'	Gorou Béri	Liboré	Kollo	Tillabéri
56	'Simbad'	Galbal	Liboré	Kollo	Tillabéri

Source: created by the authors using germplasm collection data obtained during the survey

The soil had a sandy-clay texture. The trial was conducted in an incomplete block design, specifically an alpha lattice design (9×3) with three replicates. Each replication consisted of three sub-blocks, each containing nine experimental units. Each accession was represented once per replication and transplanted into ten planting hills per elementary plot, with a spacing of 40 cm between plants within rows and 50 cm between rows. Each elementary plot measured 1 m in width and 2 m in length, covering an area of 2 m². The experimental units, or elementary plots, were spaced 0.5 m apart, while sub-blocks were spaced 1 m apart. A distance of 2 m was maintained between replications. The nursery was established in January 2024. Transplanting was carried out 50 days after sowing, when the seedlings had reached the stage of six to nine leaves. This operation was followed by the incorporation of carbofuran for the control of insects and nematodes. Prior to transplanting, the elementary plots were thoroughly tilled, levelled, and watered. Irrigation was carried out at regular intervals, either early in the morning or in the evening, and with different quantities of water depending on the phenological stage. From transplanting to early flowering, 20 L of water was applied per plot. From early flowering to harvest, 30 L per plot was applied. The weeding was carried out as required. Fertilisation

was performed using NPK (15-15-15) fertiliser applied on the 15th, 30th, 50th, and 80th days after transplanting at a rate of 30 g per plot.

Phenotypic data on various morphological and agronomic traits were recorded. Leaf shape, leaf colour, and stem pubescence (presence or absence of small hairs) were recorded at the vegetative stage. Plant height was measured on the central rows (cm) when the first fruits on 50% of the plants had begun to ripen. Canopy width was measured on the central rows (cm) and recorded after the first harvest at the widest point. Stem length (height of the first bifurcation) was measured on the central rows (cm) after the first harvest. Stem diameter was measured on the central row at the middle of the first bifurcation after the first harvest. The duration to 50% flowering, defined as the number of days from sowing to the stage when 50% of the plants in an experimental unit had flowered, was recorded. Corolla spot (presence or absence of a spot on the corolla) and corolla shape were recorded on the outer rows. Corolla length was determined as the mean length of ten petals measured on plants from the outer rows. Anther colour and anther length (the mean length of ten flowers selected from different plants) were recorded at the anthesis stage on the outer rows. Fruiting date, defined as the number of days from sowing to 50%

fruiting within an experimental unit, and fruit colour were recorded at maturity. Fruit shape, fruit length (mean length of ten fruits), fruit width (mean width of ten fruits measured at the widest point), fruit weight (mean weight of ten fruits), pedicel length (mean length of ten pedicels), fruit pericarp thickness (mean thickness of ten ripe fruits), number of locules (mean number determined from fruit cross-sections), and the number of seeds per fruit (mean value based on ten fruits from ten randomly selected plants) were recorded at the second harvest. Number of fruits (total number of fruits), fresh fruit yield (mean yield of plants in the middle row), dry fruit yield (mean yield of plants in the middle row), and seed yield were recorded at each harvest. Statistical analyses, including principal component analysis (PCA) and correlation analysis, were performed using R software to explore the relationships among traits.

To summarise the multidimensional morpho-agronomic traits and to identify the main factors underlying the variability among the

studied pepper accessions, PCA was applied. This method enabled the reduction of data dimensionality and provided a clear assessment of the contribution of individual traits to the genetic and phenotypic diversity of the ecotypes.

RESULTS AND DISCUSSION

The PCA revealed key traits that contribute to the diversity among accessions (Fig. 2). It illustrates the relationships between the principal components (PCs) and the original variables. Hence, the first principal component is essentially orthogonal to plant height, plant width, height of the first bifurcation, and the number of aborted flowers. Likewise, this component is also orthogonal to plant circumference, grain number, and corolla length. The second PC is oriented in the opposite direction to plant height, plant width, height of the first bifurcation, and the number of aborted flowers. Furthermore, the graph indicates that the second component is primarily aligned with grain number, corolla length, pericarp thickness, anther length, and fruit width.

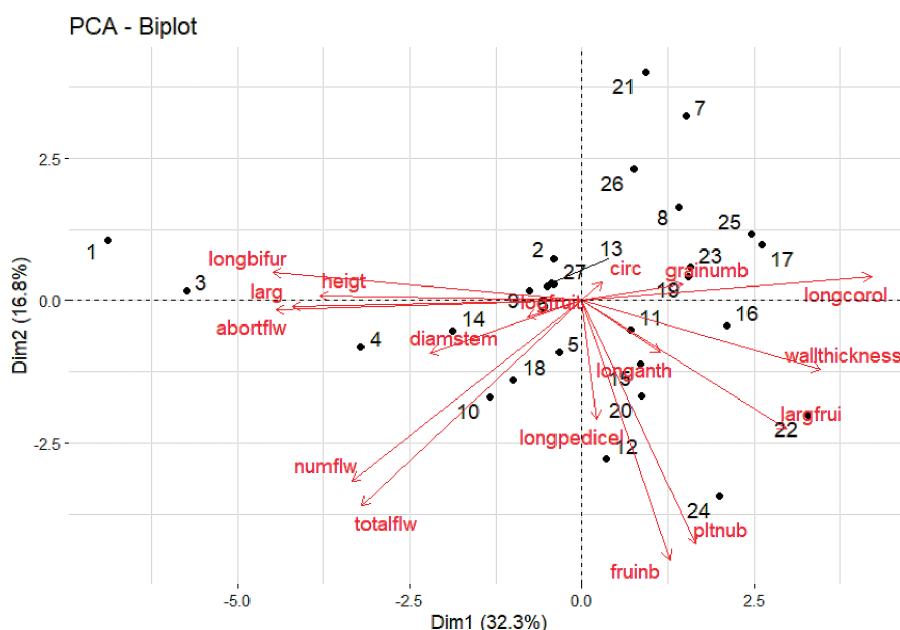


Figure 2. Principal components of pepper ecotypes

Note: V = accession; 1 = V4, 2 = V9, 3 = V10, 4 = V12, 5 = V21, 6 = V22, 7 = V23, 8 = V25, 9 = V29, 10 = V30, 11 = V31, 12 = V32, 13 = V33, 14 = V34, 15 = V35, 16 = V37, 17 = V38, 18 = V39, 19 = V40, 20 = V46, 21 = V49, 22 = V53, 23 = V54, 24 = V56, 25 = V57, 26 = V58, 27 = V59

Source: created by the authors using germplasm evaluation data

The first principal component is negatively correlated with four original variables, including plant height, plant width, height of the first bifurcation, and the number of aborted flowers. Hence, the first component increases as these variables decrease. The first component is positively correlated with corolla length. Thus, this component increases with increasing corolla

length. The second component is strongly and negatively correlated with plant number, fruit number, and flower number. Therefore, the second component decreases as plant number, fruit number, and flower number increase. The third principal component is strongly and negatively correlated with fruit length and anther length (Table 2).

Table 2. Principal components

	PC1	PC2	PC3	PC4	PC5
Pltnub	0.14	-0.50	0.12	0.20	0.16
Fruinb	0.11	-0.52	0.16	0.14	0.13
Heigt	-0.32	0.01	-0.24	-0.07	0.01
Circ	0.02	0.04	0.21	0.05	-0.78
Larg	-0.35	-0.01	0.09	-0.24	0.03
Longbirtur	-0.37	0.06	-0.001	-0.18	0.09
Diamstem	-0.18	-0.11	-0.10	0.56	-0.16
Longcorol	0.35	0.05	-0.16	-0.20	0.09
Longanth	0.09	-0.11	-0.55	0.05	0.04
longpedicel	0.02	-0.24	-0.30	-0.48	0.04
Logfruit	-0.07	-0.03	-0.59	0.24	-0.21
Largfrui	0.25	-0.26	-0.14	-0.16	-0.14
Pericarpthickness	0.29	-0.14	-0.02	-0.27	-0.43
Grainumb	0.12	0.03	0.15	-0.21	-0.03
Totalflw	-0.27	-0.42	0.04	-0.06	-0.091
Numflw	-0.28	-0.32	0.11	-0.12	-0.05
Abortflw	-0.37	-0.02	-0.09	-0.18	-0.20

Note: PC = principal component, Pltnub = plants number, Fruinb = number of fruits, Heigt = plant height, Circ = plant circumference, Larg = plant width, Longbirtur = height of the first bifurcation, Diamstem = stem diameter, Longcorol = corolla length, Longanth = anther length, Longpedicel = pedicel length, Logfruit = fruit length, Largfrui = fruit width, Pericarpthickness = pericarp thickness, Grainumb = mean number of grains per fruit, Totalflw = total number of flowers, Abortflw = number of aborted flower

Source: created by the authors using germplasm evaluation data

Significant diversity was revealed among national bell pepper accessions, as indicated by the presence of distinct genetic clusters.

Hence, at a linkage distance of 8, the hierarchical clustering dendrogram shows four major groups (Fig. 3).

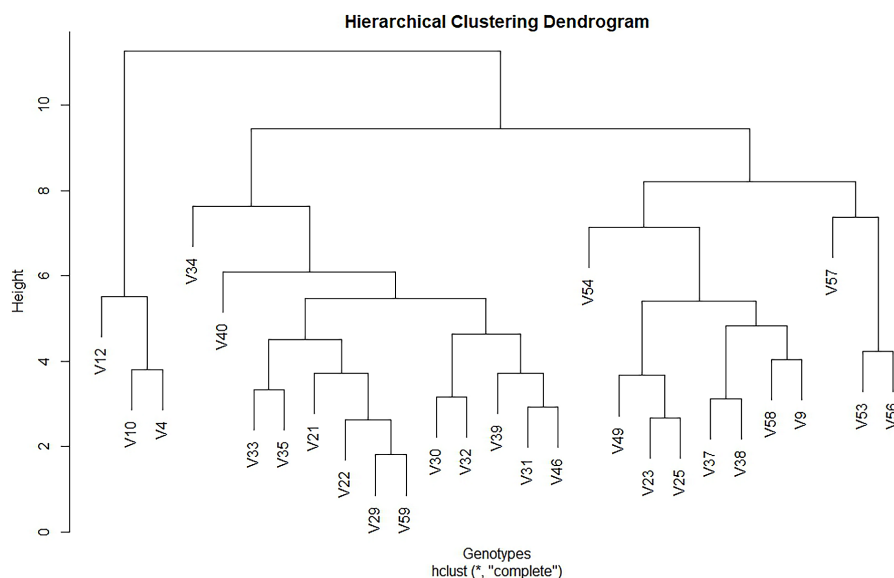


Figure 3. Classification of different ecotypes

Note: V = accession, 1 = V4, 2 = V9, 3 = V10, 4 = V12, 5 = V21, 6 = V22, 7 = V23, 8 = V25, 9 = V29, 10 = V30, 11 = V31, 12 = V32, 13 = V33, 14 = V34, 15 = V35, 16 = V37, 17 = V38, 18 = V39, 19 = V40, 20 = V46, 21 = V49, 22 = V53, 23 = V54, 24 = V56, 25 = V57, 26 = V58, 27 = V59

Source: created by the authors using germplasm evaluation data

The first cluster is composed of V4, V10, and V12. The second cluster, which is the largest, comprises 13 varieties, including V34, V40, V33, V35, V21, V22, V29, V59, V30, V32, V39, V31, and V46. The third cluster is made up of eight ecotypes, namely V54, V49, V23, V25, V37, V38, V58, and V9. The fourth cluster comprises three cultivars: V57, V53, and V56. The first group, including V4, V10, and V12, shows similarities in terms of plant width, plant height, number of aborted flowers, and height of the first bifurcation. This group is markedly dissimilar to the fourth group (V57, V53, and V56). The similarities observed within this cluster are related to fruit number, fruit width, anther length, and pedicel length. At a linkage distance of 4, Group 1 is subdivided into two clusters. On the one hand, V10 and V4 formed one subgroup, while on the other hand, V12 formed a separate subgroup. At this level, Group 2 is divided into six subclusters: subgroup 1 (V46, V31, V39), subgroup 2 (V32, V30), subgroup 3 (V59, V29, V22, V21), subgroup 4 (V33, V35), subgroup 5 (V40), and subgroup 6 (V34). V40 differs from the other accessions in terms of grain number, whereas V34 is distinct

in terms of stem diameter. V33 and V35 are similar in terms of plant height and fruit length. Figure 4 illustrates the correlation matrix among the studied traits, highlighting the strength and direction of significant relationships between morphological and agronomic characteristics of the pepper accessions.

Correlation analysis shows several highly significant ($p < 0.001$) positive associations among traits, including fruit pericarp thickness and corolla length, fruit pericarp thickness and fruit length, plant circumference and fruit pericarp thickness, total number of flowers and number of aborted flowers, plant height and number of aborted flowers, plant height and total number of flowers, height of the first bifurcation and plant height, height of the first bifurcation and total number of flowers, and height of the first bifurcation and number of aborted flowers. Highly significant ($p < 0.01$) positive associations were observed among traits such as fruit length and corolla length, height of the first bifurcation and mean number of fruits, plant height and mean number of fruits, and number of fruits and fruit length. Significant ($p < 0.05$)

positive associations were also detected among traits, corolla length and number of grains (seeds), total fruit number and fruit length, total fruit number and fruit pericarp thickness, and pedicel length and fruit length.

Very highly significant ($p < 0.001$) negative associations were found among traits, including plant canopy width and corolla length, and height of the first bifurcation and corolla length. In addition, highly significant ($p < 0.01$) negative correlations were observed between the number of aborted flowers and corolla length, and between the number of aborted flowers and fruit length. Furthermore, signif-

icant negative correlations ($p < 0.05$) were recorded between the number of flowers and corolla length, plant height and number of grains (seeds), plant height and corolla length, plant height and fruit length, and plant height and fruit pericarp thickness. Qualitative traits, such as leaf shape, leaf colour, and stem pubescence, classified the accessions into five groups. The largest group was composed of accessions with deltoid-shaped leaves, dark green colour, and without stem pubescence. The second group included accessions with deltoid-shaped leaves, dark green colour, and with stem pubescence (Fig. 5).

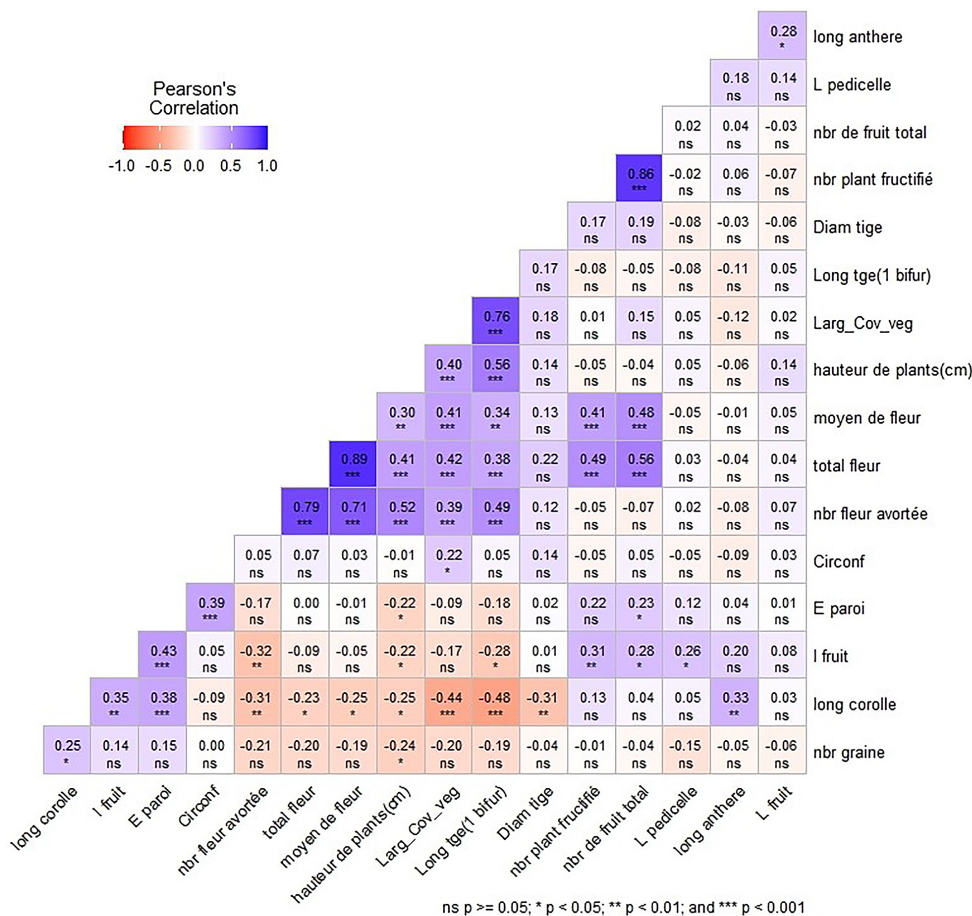


Figure 4. Cluster showing the diversity of pepper accessions

Note: V = accession, 1 = V4, 2 = V9, 3 = V10, 4 = V12, 5 = V21, 6 = V22, 7 = V23, 8 = V25, 9 = V29, 10 = V30, 11 = V31, 12 = V32, 13 = V33, 14 = V34, 15 = V35, 16 = V37, 17 = V38, 18 = V39, 19 = V40, 20 = V46, 21 = V49, 22 = V53, 23 = V54, 24 = V56, 25 = V57, 26 = V58, 27 = V59

Source: created by the authors using germplasm evaluation data



Figure 5. Distribution of accessions according to leaf shape, colour, and stem pubescence

Source: created by the authors using germplasm evaluation data

Additionally, fruit shape and surface texture classified the accessions into eight groups (Fig. 6). The two largest groups consisted of accessions with elongated fruits and smooth texture, on the

one hand, and accessions with elongated fruits and rough (scrubbed) texture, on the other. Furthermore, fruit lobule number and seed colour classified the accessions into nine groups (Fig. 7).

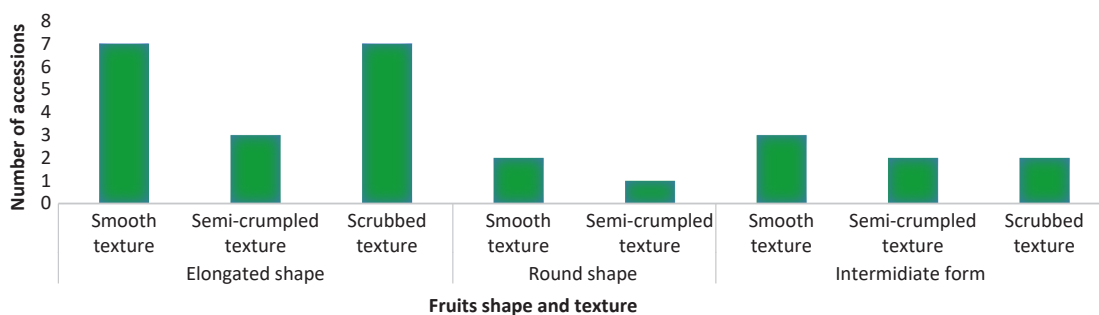


Figure 6. Distribution of accessions according to fruit characteristics

Source: created by the authors using germplasm evaluation data

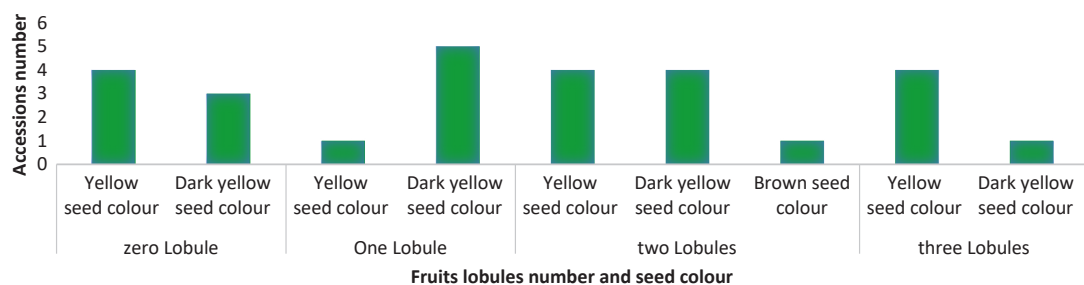


Figure 7. Grouping of accessions according to fruit lobule number and seed colour

Source: created by the authors using germplasm evaluation data

The frequency of yellow seed colour was the highest, followed by dark yellow, whereas brown occurred only once. The figure illustrates the association pattern and correlation between the number of lobules per fruit and seed colour. Hence, fruits with two lobules exhibited three seed colour types: yellow, dark yellow, and brown. In this study, bell pepper accessions from five regions in Niger were evaluated using thirty-eight morphological characters. Results showed substantial genetic diversity among accessions. The qualitative traits effectively discriminated the accessions into several distinct groups. The quantitative traits were also highly discriminative, with the first two principal component axes accounting for most of the observed variation. Cluster analysis further classified the accessions into four major groups, indicating a high level of genetic diversity. According to A. Simonne *et al.* (1997), C. Frank *et al.* (2001), and R. Frankham (2005), genetic diversity plays an important role in the survival and adaptability of a species and is indispensable for its conservation and management. This is because, when genetic diversity is low, a species becomes more susceptible to diseases and natural hazards, and entire crop populations may be severely affected or even lost (Edak *et al.*, 2014). Within a population, variability is essential for maintaining biodiversity, as limited variability reduces the capacity of populations to adapt to environmental change. Consequently, populations with low variability are more prone to decline or extinction (Terfa & Gurmu, 2020; Karim *et al.*, 2022; Menisha *et al.*, 2023). Similar findings have been reported for okra by H. Chheda & C. Christian (1982) and for Bambara groundnut by H. Aktaş *et al.* (2013) and C. Uba *et al.* (2021), emphasising the importance of understanding genetic diversity within landrace collections. Accessions were grouped into eleven clusters based on their morphological similarities. The largest cluster contained six accessions, whereas the smallest contained one. This indicated that individuals within the same cluster are genetically similar, while accessions in different clusters are genetically divergent (Pickersgill, 1991; Tong & Bosland, 2003; Sanwal *et al.*, 2012). These findings provide valuable insights into the genetic diversity of bell pepper

accessions in Niger and can inform future conservation and breeding strategies.

Very highly significant positive associations were observed between height of the first bifurcation and plant height, height of the first bifurcation and total number of flowers, and height of the first bifurcation and number of aborted flowers. This implies that a higher position of the first bifurcation is associated with taller plants and increased numbers of both total and aborted flowers. Hence, the height of the first bifurcation may be used as an indirect selection criterion to improve these traits. In addition, very highly significant positive associations were found between plant circumference and fruit pericarp thickness, and between plant height and number of aborted flowers. This indicates that accessions with larger plant circumference tend to have thicker fruit pericarps, and that taller genotypes are more prone to flower abortion.

The results also showed significant negative correlations between the number of aborted flowers and corolla length, and between the number of aborted flowers and fruit length. This implies that flowers with shorter corollas are less susceptible to abortion than those with longer corollas. This interpretation is further supported by the significant negative correlation between the number of flowers and corolla length, indicating that genotypes with shorter corollas tend to produce more fertile flowers. Hence, considering that the experiment was conducted during the hot season, it can be assumed that accessions with shorter corollas lose fewer flowers under high-temperature conditions. Thus, this trait (short corolla) can be used to indirectly select genotypes with improved heat tolerance. Furthermore, genotypes that lost more flowers also produced shorter fruits. This may be explained by the fact that these accessions are more sensitive to heat stress.

CONCLUSIONS

This research provides a comprehensive assessment of the diversity in Niger's bell pepper germplasm, revealing significant correlations among key agronomic traits. The positive correlations between specific traits point to potential targets for simultaneous improvement through strategic breeding. Understanding the

genetic basis of these trait associations can facilitate the development of superior bell pepper varieties with enhanced agronomic performance. This study offers an in-depth examination of the diversity and correlations among national bell pepper accessions, enriching current knowledge of genetic variability and trait relationships in bell pepper. The findings emphasise the critical role of genetic diversity analysis in crop improvement programmes aimed at increasing productivity and fruit quality. This diversity reflects the processes of adaptation and selection by local farmers and represents a vital buffer against climate change and pest pressure.

Future research should focus on a more detailed exploration of the genetic potential of Niger's national bell pepper collection to enable its more effective use in breeding programmes. First, emphasis should be placed on the genetic analysis of accessions exhibiting rare and unique trait combinations, such as brown seeds with two lobules, in order to identify uncommon alleles that could serve as valuable resources for the development of new varieties. Second, correlated traits should be evaluated for their impact on yield, fruit quality, and nutritional value, thereby allowing the identification of trait complexes suitable for simultaneous improvement through targeted breeding strategies. Third, it is essential to integrate the morphological data obtained with molecular marker analyses,

which would help to establish relationships between phenotypic variability and the genetic structure of the collection. This comprehensive approach will promote the rational utilisation of genetic resources, facilitate the effective selection of promising genotypes, and enhance the productivity and resilience of new varieties, ultimately supporting sustainable agricultural development in Niger.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest associated with this study. The research was conducted independently, without any financial, commercial, or personal relationships that could have influenced the study design, data collection, analysis, or interpretation of the results. All funding sources were transparently acknowledged, and the study reflects independent scientific judgement and a commitment to advancing knowledge of Niger's genetic resources.

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Різноманітність та кореляційний аналіз національних доступів солодкого перцю (*Capsicum annuum* L.) Нігеру

Анотація. Дослідження різноманітності та кореляційного аналізу національних доступів солодкого перцю має велике значення, оскільки воно задокументувало та зберегло цінні місцеві генетичні ресурси, а також надало важливу інформацію для селекції та вдосконалення сортів. Оцінюючи агроморфологічну мінливість та виявляючи взаємозв'язки між ключовими ознаками, дослідження допомогло селекціонерам у виборі кращих батьківських ліній та направило фермерів у виборі добре адаптованих доступів для різних умов вирощування. Це знання сприяє підвищенню продуктивності, стійкості до кліматичного стресу та покращенню якості плодів, що в кінцевому підсумку посприяє продовольчій безпеці, генерації доходів та кращому управлінню національними ресурсами генетичного матеріалу. Метою дослідження було оцінити генетичну різноманітність та визначити ключові кореляції ознак серед національних доступів солодкого перцю в Нігері для ефективного відбору, збереження та програм селекції. Для цього було зібрано національний місцевий генетичний матеріал і оцінено за схемою Альфа-Латіс із 3 повтореннями. Дані були зібрані та проаналізовані за допомогою кореляційного аналізу, оцінки різноманітності, кластерного аналізу та аналізу головних компонент (РСА). Результати виявили значну генетичну різноманітність серед національних доступів солодкого перцю, підкреслюючи існування окремих генетичних кластерів. Було встановлено значущі взаємозв'язки між ознаками, такі як позитивна кореляція між

товщиною перикарпу плода та довжиною віночка, товщиною перикарпу та довжиною плода, обхватом рослини та товщиною перикарпу плода, загальною кількістю квіток та кількістю абортіваних квіток, висотою рослини та кількістю абортіваних квіток, висотою рослини та загальною кількістю квіток, висотою першого відгалуження та висотою рослини, висотою першого відгалуження та загальною кількістю квіток, висотою першого відгалуження та кількістю абортіваних квіток. Виявлена генетична різноманітність та кореляції ознак надали важливу інформацію для збереження та поліпшення сортів солодкого перцю. Результати роботи можуть використовуватися селекціонерами та фермерами для відбору та вирощування високопродуктивних і стійких сортів солодкого перцю

Ключові слова: оцінка мінливості; характеристика генофонду; генетична різноманітність; аналіз головних компонент; кластерний аналіз; агроморфологічні ознаки