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HIGHLIGHTING PHENOTYPIC VARIATION AND UNDERSTANDING CORRELATIONS BETWEEN TRAITS WITHIN BAMBARA GROUNDNUT COLLECTION FROM BURKINA FASO FOR POTENTIAL CANDIDATES IN BREEDING PROGRAM

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ABSTRACT

For Bambara groundnut breeding improvement, this investigation was undertaken to characterize agromorphological variation and trait relationships within a Bambara groundnut collection from Burkina Faso and identify candidate accession for use in breeding. Twenty-four genotypes from the INERA germplasm repository were evaluated at the Tenkodogo University Centre experimental site during the 2023-2024 rainy season in a randomized complete block design. Fifteen groundnut descriptors were scored, trait correlations and differences between genotypes were assessed. For most of the studied characters (13/15) there were large phenotypic differences. This wealth of genetic diversity could be exploited for use in plant breeding. Negative correlations were observed between physiologic and agronomic traits, for example between yield and flowering ($r = -0.61$), and several agronomic traits. Certain genotypes showed distinctive and interesting growth and agronomic characteristics such as high number of leaves (> 60 leaves), early flowering (< 35 days), high number of pods (> 22 pods), 100-seeds weight (> 45 g) and high grain yield (> 1000 kg ha⁻¹). This diversity shows a possibility for selection of promising genotypes from this collection for dual purpose, for food and feed.

Keywords: Bambara groundnut, Burkina Faso, Trait correlations, Germplasm collection

1 INTRODUCTION

Bambara groundnut (*Vigna subterranea* [L.] Verdc.) is an important crop in Sub-saharan Africa [1, 2, 3]. Bambara groundnut plays an important socio-economic role in rural areas of across the continent where it is an important cash crop, especially for women farmers [4, 5, 6]. In addition to this, the crop has great potentiel to help diversify agroecosystem [7]. Bambara groundnut is a very wealthy crop, on average it contains 5.5% fiber, 6.5% fat, 23.6% protein, 64.4% carbohydrate and is rich in minerals [8]. Despite its nutritional, agronomic and socio-economic importance, Bambara groundnut remains under-studied, with poor yields being the largest limiting factor [7]. However, this climate-resilient crop is an ideal candidate crop for diversifying local food and nutrition security [7].

The release of new high-performance varieties with high economic value involves the identification and introgression of interesting traits followed by ensuring the true breeding nature of these traits. Valuation of any species requires keen knowledge of its genetic diversity for effective improvement, as well as safeguarding against genetic erosion [9]. To ensure breeding and conservation outcomes, characterization and evaluation of the genetic diversity existing is essential [10].

Within Burkina Faso, there has been limited work on description of the morphological, physiological and agronomic characterization in Bambara groundnut accessions [11, 12]. Bambara groundnut has been a neglected crop, despite the plants great potential. Bambara groundnut possesses climate smart agronomic features, including its ability for atmospheric nitrogen fixation, up to 100 kg ha⁻¹ [13] and ability to tolerate adverse pedoclimatic conditions such as drought and poor soils [2, 14]. Thus, Burkina Faso is an ideal country for expanded production of Bambara groundnut due to arid farmland being available where the crop thrives [15]. Despite this potential, yields remain very low often less than 500 kg ha⁻¹, although the potential pods yield could reach 3000 kg ha⁻¹ in the large parts of the semi-arid zone in eastern and southern Africa [16, 17]. Average yields range from 350 to 800 kg ha⁻¹ in the regions where the soil is poor and rainfalls low, similar to the potential regions in Burkina Faso [18].

These very low yields in Burkina Faso are due to several factors, however, the lack of improved seeds varieties is of particular concern. Therefore the objectives of this study were to (1) Characterize the collection of Bambara groundnut for intra- and inter-specific morphological diversity and (2) Identify candidate accessions for use in breeding.

2 MATERIAL AND METHODS

2.1 Genetic material and experiment management

Twenty-four Bambara groundnut genotypes were sourced from the National Institute of Environment and Agricultural Research (INERA) genebank especially. The plant material comprised of 11 breeding lines (KVS360, KVS311, KVS9, KVS314, KVS97-2, KVS075-1, KVS235, KVS141-2, KVS109A, KVS8 and KVS143) and 13 local genotypes (Gen_Zab, Acc04, Acc58, Acc34, Acc35, Acc01, Acc04, Acc17, Acc08, Acc28, Acc37, Acc53 and Acc63) collected from producers. The genotypes were grown in randomized complete block design with four replications at the experimental site of Tenkodogo University Centre during the 2023-2024 crop season. The row spacing was 40 cm between plot, and 20 cm between two sowing holes on the plot. Blocks measured 9.20 m long and 4 m large and were distant from 1 m. The total area of the experimental plot was 174.80 m². A total of 21 seeds were sown on each plot at one seed per hole, after flat ploughing using a tractor. Mineral fertilizer, NPK (14-23-14) was applied (75 kg ha⁻¹) at basal. Regular manual weedings were carried out throughout the development of the plants.

2.2 Data collection and analysis

Fifteen (15) characters were phenotyped (Table 1), chosen to align with the standard Bambara groundnut descriptors established by the International Institute of Plant Genetic Resources [19]. Analysis of variance and Pearson correlation between traits were calculated using Genstat 12ed and XLSTAT 2021 4.1 softwares, a significance level of $P = 0.05$ was used to determine genotypic differences.

Table 1: Bambara groundnut characters studied

Period	Variable	Code	Notation
Vegetative	Rate of emerged plants at 21 days after sowing	RES21	%
	Number of days from sowing to first flowering	FFL	Day
	Number of days from sowing to 50% flowering	FLO50	Day
	Plant height	PIH	cm
	Plant Spread	PLS	cm
	Number of leaves per plant	NL/P	Number
	Weight of pod per plant	WP/P	g
	Weight of seeds per plant	WSP	g
	100-seeds weight	W100S	g
	Pod length	PLen	mm
Post-harvest	Pod width	PWid	mm
	Seed length	SLen	mm
	Seed width	SWid	mm
	Number of pods per plant	NP/P	Number
	Yield	YLD	Kg ha ⁻¹

3 RESULTS

3.1 Variation within Bambara groundnut germplasm for studied characters

There was substantial variation in almost all of the traits measured (Table 2). The rate of emergence at 21 days after sowing (RES21), number of days from sowing to 50% flowering (FLO50), number of leaves per plant (NL/P), weight of seed per plant (WS/P), 100-seeds weight (W100S), pod length (PLen) and yield (YLD) showed particularly very high variability (Table 2). Other characteristics showed relatively low variability including the weight of seeds per plant (WS/P), and seed length (SLen) (Table 2). In most cases, genotypic variance was higher ($V_G > V_E$) than environmental variance. In contrast, weight of pods per plant (WP/P), number of pods per plant (NP/P) and seed length (SLen) recorded higher values of environmental variance than genotypic variance ($V_E > V_G$). All characters were differed among genotypes ($P < 0.05$), except for the number of pods (NP/P) and the weight of pods (WP/P) per plant (Table 2).

Table 2: Analysis of variance of 24 Bambara groundnut genotypes

Variable	Min	Max	SD	V _P	V _E	V _G	P-value
RES21 (%)	67.86	98.81	8.42	70.98	11.82	59.16	< 0.001**
FFL (day)	31.00	35.50	1.19	1.43	0.16	1.27	< 0.001**
FLO50 (day)	32.75	37.75	1.34	1.8	0.2	1.6	< 0.001**
PIH (cm)	18.85	25.70	1.75	3.08	1.01	2.07	< 0.001**
PLS (cm)	31.50	42.00	2.77	7.71	2.96	4.75	0.001**
NL/P (#)	35.10	76.95	9.14	83.6	32.55	51.05	0.001**
WP/P (g)	12.01	20.54	2.39	5.72	4.39	1.33	0.199 ns
WS/P (g)	4.55	10.93	1.80	3.24	1.29	1.95	0.002*
W100S (g)	31.75	65.25	8.30	68.93	22.13	46.8	< 0.001**
NP/P (#)	15.81	28.97	3.74	14.01	10.14	3.87	0.153 ns
PLen (mm)	12.42	21.78	2.28	5.21	0.59	4.62	< 0.001**

PWid (mm)	9.22	13.61	1.23	1.52	0.15	1.37	< 0.001**
SLen (mm)	8.29	12.65	0.97	0.94	0.53	0.41	0.034*
SWid (mm)	6.75	9.65	0.67	0.45	0.17	0.28	0.001**
YLD (kg ha ⁻¹)	417.19	1156.30	188.87	35673	11620	24053	< 0.001**

Legend: RES21 : Rate of emerged plants at 21 days after sowing ; FFL : Number of days from sowing to first flowering FLO50 : Number of days from sowing to 50% flowering; PIH : Plant height ; PIS : Plant Spread ; NL/P : Number of leaves per plant ; WP/P : Weight of pod per plant WS/P : Weight of seed per plant ; ; W100S : Weight of 100 seeds ; NP/P : Number of pods per plant ; PLen : Pod Length ; PWid : Pod width ; SLen : Seed Length ; SWid : Seed width ; YLD : Yield ; F : coefficient of Fischer ; Min : Minimum ; Max : Maximum ; SD : Standard deviation ; V_F : phenotypic variance ; V_E : Environmental variance ; V_G : Genotypic variance ; ns : Not significant ; * : Significant difference at 1% ; ** : High significant difference at 1%

3.2 Comparative analysis of genotypes performances

There were large genotypic differences in the Burkina Faso germplasm collection (Table 3). Most of the genotypes showed high rate of emerged plants at 21 days after sowing (> 80% - Table 3), indicating seed was generally of good quality. Genotypes KVS97-2, Acc17, Acc37, KVS143, Acc08, KVS360 and KVS87 were the earliest to flower. The first flowering and 50% flowering appeared at the latest on the 32nd and 33rd days after sowing (DAS) respectively. However, the genotypes Acc01, Acc04, Acc58, KVS314, KVS311, Gen_Zab and KVS109A observed the latest 50% flowering score (≥ 35 days). Flowering is grouped in all the genotypes in the collection with an average of 1.78 days between first and 50% flowering. The average number of leaves was 57.40, with high number (> 60 leaves) recorded for the genotypes Gen_Zab, KVS235, Acc58 and KVS97-2 (65.20) ; Acc04 (65.85), KVS360 (66.40), Acc42 (66.60) and KVS141-2 (76.95). With regard to the plant height and spread, mean values were 23.05 and 38.57 cm respectively. The genotypes Acc34, Acc01 and Acc04 combined plants with large aerial dimensions. The lowest number of pods was registered with Acc01 (15.81). However, KVS235 (28.97), KVS141-2 (27.68), KVS311 KVS143 and KVS075-1 (25.68) yielded abundant number (> 25) of pods per plant. The higher values of 100-seeds weight were obtained with Acc04 (51.25 g), Acc17 (52.25 g), Acc63 (58 g), Acc34 (60.75 g) and Acc01 (65.25). These values revealed that these local cultivars have enormous potential. The genotypes Acc34, Acc01, Acc63, KVS075-1 and KVS143 combined interesting values for yield attributes such as weight of pods per plant, weight of seeds per plant and 100-seeds weight. The highest yields (> 900 kg ha⁻¹) were recorded for Acc42 (904.69 kg ha⁻¹), KVS235 (909.38 kg ha⁻¹), Acc35 (923.44 kg ha⁻¹), Acc58 (973.44 kg ha⁻¹), Acc08 (989.06 kg ha⁻¹), Acc34 (998.44 kg ha⁻¹), KVS9 (1035.94 kg ha⁻¹), KVS87 (1085.94 kg ha⁻¹), Acc17 (1098.44 kg ha⁻¹), Acc01 (1104.69 kg ha⁻¹), Acc63 (1120.31 kg ha⁻¹) and KVS143 (1156.25 kg ha⁻¹).

Table 3: Performances of 24 Bambara groundnut genotypes from Burkina Faso

Genotype	RES21	FFL	FLO50	PIH	PIS	NL/P	WP/P	WS/P	W100S	NP/P	PLen	PWid	SLen	SWid	YLD
Acc35	95.24	32.00	34.50	20.35	34.25	50.35	13.47	8.52	39.00	21.66	15.82	10.46	9.84	8.09	923.44
KVS075-1	82.14	32.00	34.00	18.85	32.60	47.85	18.06	10.67	48.25	25.68	14.13	10.50	10.49	8.56	851.56
KVS109A	89.29	35.50	37.75	21.85	37.50	35.10	13.17	5.16	33.25	21.95	15.36	10.34	9.34	7.30	557.81
KVS141-2	90.48	33.00	34.50	22.95	39.10	76.95	14.44	5.87	31.75	27.68	15.23	11.16	8.29	6.75	668.75
KVS143	96.43	31.50	33.00	21.25	35.15	54.50	17.52	10.10	46.75	22.67	15.19	10.74	10.60	8.43	1156.25
KVS314	76.19	33.75	36.25	23.50	42.00	58.65	13.44	4.55	38.75	18.14	14.95	10.36	11.47	8.55	417.19
KVS360	89.29	31.75	33.25	22.55	37.85	66.40	15.64	8.88	42.25	24.07	15.32	10.62	9.78	7.88	878.13
KVS87	95.24	32.00	33.50	21.25	36.40	56.85	18.49	9.48	40.50	23.32	16.36	10.99	10.87	8.44	1085.94
KVS9	95.24	32.00	33.75	21.75	36.90	56.85	16.59	9.65	42.50	23.68	14.58	10.22	9.91	8.06	1035.94
KVS97-2	76.19	31.00	32.75	20.85	35.20	65.20	15.40	9.64	39.00	24.63	15.80	10.88	10.15	8.14	871.88
Acc01	86.90	33.00	35.00	25.70	40.45	57.40	18.73	10.37	65.25	15.81	21.09	13.54	12.23	9.66	1104.69
Acc08	95.24	31.50	33.00	20.80	33.55	58.60	15.81	8.67	39.25	23.70	12.42	9.22	12.66	9.27	989.06
Acc17	95.24	31.00	32.75	21.70	34.65	56.50	16.83	9.18	52.25	22.43	15.96	11.48	10.67	8.84	1098.44
Acc28	95.24	31.50	34.00	22.10	36.60	54.80	16.08	7.51	48.25	17.70	17.31	12.21	10.44	8.19	853.13
Acc34	79.76	33.00	34.75	25.00	40.00	57.30	20.54	10.93	60.75	15.96	21.78	13.58	12.25	9.63	998.44
Acc53	97.62	32.75	33.75	22.70	38.25	57.95	13.67	6.97	43.50	22.45	15.26	10.23	9.41	7.69	759.38
Acc37	98.81	31.25	32.75	18.95	31.50	48.50	12.82	6.75	46.00	17.16	15.79	11.46	10.28	8.44	807.81
Acc04	77.38	33.25	35.00	24.45	41.00	65.85	18.23	7.76	51.25	15.89	20.13	13.61	11.13	8.81	678.13
Acc42	98.81	32.00	34.00	23.15	37.60	66.60	16.65	8.84	45.50	22.79	16.67	11.44	10.17	8.23	904.69
Acc58	85.71	33.50	35.00	21.75	35.05	64.70	18.39	9.74	48.00	20.56	17.55	12.03	10.33	8.83	973.44
Acc63	89.29	32.75	33.50	24.00	38.55	58.35	19.43	10.04	58.00	22.98	17.77	12.23	10.38	8.24	1120.31
KVS235	67.86	31.75	33.75	19.80	34.05	62.95	16.75	10.75	41.75	28.97	14.35	9.97	11.09	8.82	909.38
KVS311	91.67	35.00	36.25	22.55	39.65	37.40	12.01	6.49	34.25	27.38	13.40	9.44	10.53	7.99	640.63
Gen_Zab	85.71	34.00	36.75	23.45	39.10	61.95	19.68	8.62	41.50	19.42	18.37	12.42	10.94	9.13	842.19
Mean	88.79	32.53	34.31	22.14	36.96	57.40	16.33	8.55	44.90	21.95	16.27	11.21	10.55	8.41	880.27

Legend: RES21 : Rate of emerged plants at 21 days after sowing ; FFL : Number of days from sowing to first flowering FLO50 : Number of days from sowing to 50% flowering; PIH : Plant height ; PIS : Plant Spread ; NL/P : Number of leaves per plant : WP/P : Weight of pod per plant WS/P : Weight of seed per plant ; ; W100S : Weight of 100 seeds ; NP/P : Number of pods per plant ; PLen : Pod Length ; PWid : Pod width ; SLen : Seed Length ; SWid : Seed width ; YLD : Yield.

3.3 Trait Relationships

The traits that define Bambara groundnut show strong relationships with each other (Figure 1). Several relationships stand out, for example flowering and agronomic traits were negatively correlated (Figure 1). Early flowering is negatively associated with yield related traits [e.g. 50% flowering negatively correlated with number of pods per plant ($r = -0.209$), weight of pods per plant ($r = -0.123$), 100-seeds weight ($r = -0.229$) and yield ($r = -0.612$)]. Further, negative relationships were observed between yield and growth traits such as plant height ($r = -0.047$) and plant spread ($r = -0.369$). Here we see that yield and aerial biomass are inversely related (figure 1).

There were significant and very significant positive correlations between yield components (Figure 1). For example, yield and weight of pods per plant ($r = 0.631$, $p = 0.001$), as well, weight of seeds per plant ($r = 0.845$, $p < 0.0001$) and 100-seeds weight ($r = 0.569$, $p = 0.004$). Weight of pods per plant with weight of seeds per plant ($r = 0.758$, $p < 0.0001$), 100-seeds weight ($r = 0.690$, $p = 0.000$), seed length ($r = 0.460$, $p = 0.024$) and seed width (0.628 , $p = 0.001$). There were also strong positive relationships between agronomic characteristics (Figure 1). This gives an indication that productivity could be a direct linear function with carboassimilation due to the photosynthetic activities in the leaves.

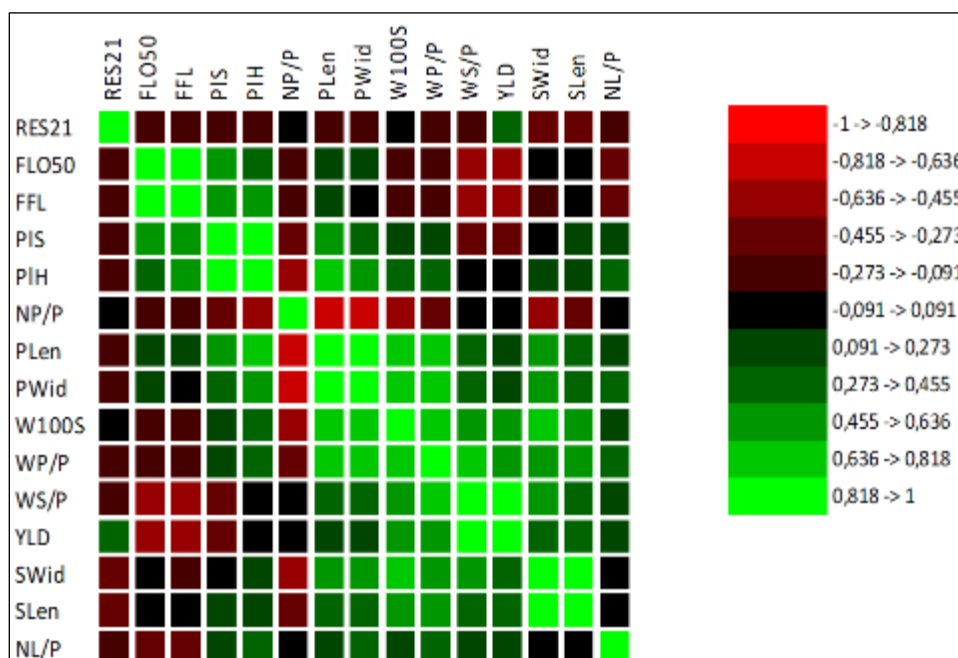


Figure 1: Pictorial representation of the correlation matrix for 15 characters in Bambara groundnut accessions from Burkina Faso

Legend: RES21 : Rate of emerged plants at 21 days after sowing ; FFL : Number of days from sowing to first flowering FLO50 : Number of days from sowing to 50% flowering; PIH : Plant height ; PIS : Plant Spread ; NL/P : Number of leaves per plant ; WP/P : Weight of pod per plant WS/P : Weight of seed per plant ; W100S : Weight of 100 seeds ; NP/P : Number of pods per plant ; PLen : Pod Length ; PWid : Pod width ; SLen : Seed Length ; SWid : Seed width ; YLD : Yield ; $[\pm 0,091 \text{ to } \pm 0,273]$: Non significant correlation ; $[\pm 0,273 \text{ to } \pm 0,636]$: Significant correlation ; $[\pm 0,636 \text{ to } \pm 1]$: High significant correlation

4 DISCUSSION

Bambara groundnut has great potential as a crop in Burkina Faso, however, there is limited understanding of the phenotypic variation in the national germplasm collection. Here, we have undertaken a systematic analysis of agronomic, physiological traits in Burkina Faso germplasm. Having variation in important traits between accessions for flowering and yield attributes is incredibly important for the establishment of breeding programs that have the potential to release improved cultivars for all of the diverse climatic zones in Burkina Faso. The large difference between the traits shows that there is useful phenotypic variation within Bambara groundnut genotypes cultivated in Burkina Faso. This suggests that current genotypes could be selected for different uses. This diversity and the possibility of finding genotypes with interesting traits can be used to help adapt to increasingly unfavorable climatic conditions. Germplasm preservation is crucial to maintain diversity within species, which can be used to breed for variable environmental conditions [20]. Similar to previous diversity analysis conducted on Bambara groundnut collections in different countries, a large amount of phenotypic variation within Bambara groundnut accessions was identified [21, 22, 23, 24]. The limited environmental impact on these traits (high heritability) shows the large potential utility of these accessions for breeding. It is important that traits are mostly genetically controlled, otherwise it will be difficult to make progress breeding, which requires traits of interest to have heritable transmission.

The accessions all had good germination, showing the value of the national certification standard [25]. Bambara groundnut are generally highly susceptible to insect attacks during the storage [26, 27] resulting in a significant drop in germination capacity, it is thus nice to see seed quality regulations having the intended effect. The high number of leaves (> 60) recorded in a subset of genotypes shows variation in photosynthetic activity which gives insight into the migration of the leaves assimilate toward seeds during pods filling [28, 29]. The genotypes explored here showed fewer leaves than previously reported [30, 31]. Genotypes exhibited low values to previous reports in terms of height and spread [20, 31]. Yield component traits were generally higher than previous reports [20]. Additionally, the abundant number of pods (> 25) yielded by KVS235, KVS141-2, KVS311 KVS143 and KVS075-1 and the highest values of 100-seeds weight obtained with Acc04, Acc17, Acc63, Acc34 and Acc01 show that genotypes cultivated in Burkina Faso have good production potential, but this potential is not well exploited.

The high yielding cultivars could easily form the basis for a new breeding program that could be used to develop improved cultivars for Burkina Faso. Over all genotypes, the average yield ($880.27 \text{ kg ha}^{-1}$) obtained with the collection is lower than other collections [31], however, half of the collection had high yields (Acc42, KVS235, Acc35, Acc58, Acc08, Acc34, KVS9, KVS87, Acc17, Acc01, Acc63 and KVS143 – table 3). This subset of the collection shows great potential, it also tends to later flowering. While longer flowering was associated with lower yield in Burkina Faso. [32] reported much longer flowering cycles (41.96 days) lower yields (798.3 kg ha^{-1}) with local Bambara groundnut from Benin. The germplasm evaluated here makes a key selection objective for increasing productivity is to reduce plant size in favor of fruits production. However, there is potential for genotypes with high above-ground biomass and high fruit production could be very interesting for the development of dual-purpose varieties.

Knowledge of the relationships between characters is an important to optimally achieve breeding objectives. The extent and the direction of correlations are crucial for identifying the optimal type of selection, and optimizing the allocation of resources within breeding programs. For Bambara groundnut, the negative correlations between flowering and most of the studied traits indicates that in Burkina Faso improved varieties must reach maturity quickly. This need for early flowering has been previously reported [9, 33]. However, contrary results have been report by [34] with accessions from Ivory Coast, where environment has abundant rainfall. There is a tradeoff between biomass production and seed yield, this indicated that finding genotypes that have an ideotype of short and fast flowering are likely to be the best parents. Further, there is also a desire for fewer larger pods, but fewer pods per plant. The strong positive relationship between yield components and yield, suggests that overall yield may be a better trait for selection. These trends are very interesting in terms of improving productivity as they indicate a very good pod filling rate.

5 CONCLUSION

This study highlighted agromorphological variation and traits relationships within 24 Bambara groundnut sourced from Burkina Faso. We compared the genotypes in terms of productivity and agronomic traits. There was tremendous variation in the genotypes which showed distinctive and interesting physiological and agronomic characteristics. We have identified genotypes from the present collection which so promise for both grain yield and fodder production. Hybridization between individuals with high values for traits of interest could be the basis for new breeding leading to the release of elite varieties. While there is good diversity in the germplasm collection, any new varieties developed should be combined with appropriate cultural options in order to maximize the yield potential of high-yielding cultivars.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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Disclosure of conflict of interest

The authors declare that they have no conflicts of interest.

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