Special Supplement: Pulses

Agronomic performance and seed quality of heirloom fava bean landraces[1]

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ABSTRACT

Obtaining high-quality heirloom fava bean (*Phaseolus lunatus* L.) seeds is crucial to crop success, as it directly influences the initial plant development and final yield, in addition to being essential for the species conservation. This study aimed to evaluate the seed physiological quality, morphological characterization, agronomic performance and correlations among variables of fifteen heirloom fava bean varieties. The experiment was conducted in two stages: in the laboratory, where germination, moisture content and weight tests were performed on one hundred seeds; and in the field, where variables such as emergence speed index, final emergence, hypocotyl height and diameter, leaf dimensions, onset of flowering and fruiting, pod morphometry, number of seeds per pod, yield per plot and growth habit were evaluated. A wide variability was observed in the physical and physiological quality of the seeds among the analyzed varieties. Varietal discrimination was influenced by hypocotyl diameter and leaf dimensions. The leaflet width correlated positively with grain yield, whereas no significant correlation was observed between yield and seed quality.

KEYWORDS: *Phaseolus lunatus* L., morphoagronomic descriptors, seed physiological potential.

RESUMO

Desempenho agronômico e qualidade de sementes de variedades crioulas de feijão-fava

A obtenção de sementes crioulas de feijão-fava (*Phaseolus lunatus* L.) de alta qualidade é crucial para o sucesso da lavoura, pois influencia diretamente no desenvolvimento inicial das plantas e na produtividade final, além de ser fundamental para a conservação da espécie. Objetivou-se avaliar a qualidade fisiológica de sementes, caracterização morfológica, desempenho agronômico e as correlações entre variáveis de quinze variedades crioulas de feijão-fava. O experimento foi conduzido em duas etapas: em laboratório (realizaram-se testes de germinação, teor de água e peso de cem sementes) e em campo (avaliaram-se variáveis como índice de velocidade de emergência, emergência final, altura e diâmetro do hipocótilo, dimensões foliares, início da floração e frutificação, morfometria da vagem, número de sementes por vagem, produção por parcela e hábito de crescimento). Observou-se ampla variabilidade na qualidade física e fisiológica das sementes entre as variedades analisadas. A discriminação varietal foi influenciada pelo diâmetro do hipocótilo e pelas dimensões foliares. A largura do folíolo apresentou correlação positiva com a produtividade de grãos, enquanto não se observou correlação significativa entre produtividade e qualidade de sementes.

PALAVRAS-CHAVE: *Phaseolus lunatus* L., descritores morfoagronômicos, potencial fisiológico de sementes.

INTRODUCTION

Fava bean (*Phaseolus lunatus* L.) is a legume of great importance in human and animal nutrition, standing out as a source of vegetable protein (Adebo 2023). In addition to its use as food, it is applied as green manure, contributing to biological nitrogen fixation and improving soil fertility (Adebo 2023, Peixoto & Berti 2023).

Despite these agronomic and nutritional attributes, its cultivation remains limited in Brazil, partly due to the preference for other more widespread pulses, such as common bean (*Phaseolus vulgaris* L.) and cowpea (*Vigna unguiculata* L.). Thus, considering the current challenges to food security, exploring the cultivation, domestication and use of an underexplored legume, such as fava bean, can help to mitigate the current over-reliance on other

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legumes, since species restriction may have negative agronomic, ecological, nutritional and economic impacts (Adebo 2023).

Although considered underutilized, *P. lunatus* is recognized as the second most important species of the *Phaseolus* genus, standing out for its remarkable characteristics, such as the profitability of grain production for human consumption, its ability to adapt to water scarcity, high temperatures and low-fertility soils (Noh et al. 2015, Soares et al. 2022). It is mostly cultivated by family farmers, using heirloom seeds, usually in intercropping with other crops, forming traditional systems that promote the conservation of the species' genetic diversity (Dantas et al. 2023).

In northern Minas Gerais, a region renowned for fava bean production, a broad phenotypic diversity is observed among local varieties, with seeds of varying sizes, shapes and colors (Souza et al. 2019). In this context, characterizing these varieties is essential to identify the most productive and adapted genotypes. This approach can support genetic conservation strategies, guide improved farm management and provide insights for future genetic and participatory breeding programs. Therefore, this study aimed to evaluate the seed quality, morphological characterization, agronomic performance and the correlation among variables in fifteen fava bean heirloom varieties.

MATERIAL AND METHODS

The experiments were conducted at the Universidade Federal de Minas Gerais, in Montes Claros, Minas Gerais state, Brazil (16º51'38"S, 44º55'00"W and altitude of 678 m), between 2017 and 2018. The area has an Aw climate, considered tropical Savanna, with dry winter and rainy summer, according to the Köppen & Geiger classification.

Threatments consisted of fifteen heirloom fava bean varieties obtained from seed banks and seed houses in municipalities located in the northern Minas Gerais state (Table 1), from the 2017 harvest.

In the laboratory, the seeds were previously tested, excluding those that were malformed or showed signs of pest attack. The experimental design was completely randomized, with four replicates per treatment, represented by the fifteen varieties.

The seed moisture content was determined according to Brasil (2009), using the oven method at 105 ± 3 ºC, for 24 hours, with four replicates of 10 seeds per variety, with the results expressed as percentage of moisture content (w.b.). The seed dry matter weight was determined in parallel with the moisture content, using three samples of 100 seeds.

The weight of 100 seeds was obtained with four replicates of 25 seeds, totaling 100 seeds per treatment, which were weighed on an analytical scale with precision of 0.0001 g (Brasil 2009), with results expressed in grams. The sizes were also calculated and classified as small (smaller than 30 g), medium (30-40 g), normal (40-60 g) and large (larger than 60 g) (Vilhordo et al. 1996).

The physiological potential was determined through germination and seedling dry matter tests in the laboratory, and the emergence speed index and final seedling emergence were evaluated in the field.

Table 1. Identification of seeds of heirloom fava bean varieties obtained from seed banks in municipalities located in the north of the Minas Gerais state, Brazil.

Varieties	Popular name	Community and municipality	Geographic coordinates
1	Três meses	Assentamento Americana, Grão Mogol	16º22'55.5"S; 43º00'39"W
2	No denomination	Pau d'Óleo, Montes Claros	16º26'50.79"S; 44º0'14.38"W
3	Fava rajada	Assentamento Americana, Grão Mogol	16º22'55.5"S; 43º00'39"W
4	Olho de lambu	Touro, Serranópolis de Minas	15º53'31.70"S; 42º59'10.32"W
5	Fava baetona	Assentamento Americana, Grão Mogol	16º22'55.5"S; 43º00'39"W
6	Fava carioca	Assentamento Americana, Grão Mogol	16º22'55.5"S; 43º00'39"W
7	Anduzinha	João Congo, Varzelândia	15º38'9.66"S; 44º2'27.96"W
8	Fava leite	Touro, Serranópolis de Minas	15º53'31.70"S; 42º59'10.32W
9	Três meses rajada	Touro, Serranópolis de Minas	15º53'31.70"S; 42º59'10.32"W
10	Mulatinha	Touro, Serranópolis de Minas	15º53'31.70"S; 42º59'10.32"W
11	Mulatinha branca	Touro, Serranópolis de Minas	15º53'31.70"S; 42º59'10.32"W
12	Mulatinha parda	Touro, Serranópolis de Minas	15º53'31.70"S; 42º59'10.32"W
13	Olho de pombo	Touro, Serranópolis de Minas	15º53'31.70"S; 42º59'10.32"W
14	Amarelinha	Touro, Serranópolis de Minas	15º53'31.70"S; 42º59'10.32"W
15	No denomination	Touro, Serranópolis de Minas	15º53'31.70"S; 42º59'10.32"W

For the germination test, four replicates of 25 seeds per treatment were used. These seeds were distributed on a Germitest paper substrate, previously moistened with distilled water in a quantity equivalent to 2.5 times the weight of the paper, in a roller system. These seeds were then placed in transparent plastic bags, sealed and transferred to a BOD chamber, maintained at 25 ºC and a 12-h photoperiod. Evaluations were performed on the fifth and ninth days after the test assembly, and the results were expressed as percentage of normal and abnormal germinated seeds, dead and hard seeds (Brasil 2009).

The seedling dry matter was obtained at the end of the germination test, in which the cotyledons of normal seedlings were sectioned and the seedlings placed in crucibles and stored in a drying oven at 65 ºC, for 72 hours. After this period, the samples were weighed on an analytical scale with precision of 0.001 g and the results expressed as g seedling^{-1}.

In the field, the experiment was conducted in a randomized complete block design, consisting of three blocks with the fifteen landraces of fava bean. Each plot consisted of two rows containing three plants each, equidistant 1.20 m, totaling six plants per replicate. Planting took place in May 2018. Three fava bean seeds were sown per hole, intercropped with three corn seeds. The seedlings were thinned after one month of emergence, leaving only one plant per hole. The cultivation area has a history of organic vegetable production. Through physical-chemical analysis (Table 2), the soil was classified as having a medium texture and a pH of 7.7.

Soil fertility was maintained, as required by the corn/fava bean intercropping, by adding 500 g of cured cow manure per hole. Sowing took place in May 2018, with three seeds per hole intercropped with three corn seeds. The fava bean seedlings were thinned at one month after emergence, leaving only one per hole. Two applications of neem extract (*Azadirachta indica*) were made to control *Diabrotica speciosa*, one application on the eleventh day after planting and another on the thirteenth day, and two manual weedings were carried out at the beginning of the crop cycle.

An irrigation system was installed in the experimental area with 0.79-mm-diameter micro-sprinklers and a flow rate of 30 L h^{-1}, covering a wetted radius diameter of 5.5 m, under a working pressure of 1.5 kgf cm^{-2}. During periods of water shortage in the field, irrigation was carried out until the week before the first harvest.

The emergence speed index was determined by counting the number of seedlings that emerged in the field daily until the value remained constant. Seedlings with cotyledons above the ground level were considered emerged, and the emergence speed index was calculated according to Maguire (1962).

The final seedling emergence was determined with a single count, at 12 days after sowing, considering as emerged the seedlings that had cotyledons above the ground. The result was expressed as percentage.

The morphoagronomic characterization of three fava bean plants was carried out individually in the plot until November 2018, using the descriptors recommended for *Phaseolus lunatus* L. (IPGRI 2001), which measured the hypocotyl diameter, length (measurement taken on the terminal leaflet of the third trifoliate leaf, from the base of the blade to its tip) and width of the primary leaflet, number of days to flowering (number of days from the emergence to the stage at which 50 % of the plants were flowering), onset of fruiting (number of days from the emergence until 50 % of the plants had mature pods), pod length and width (20 pods randomly evaluated), number of seeds per pod (20 pods randomly evaluated), seed production per plot and growth habit.

During the experiment, the highest recorded average monthly temperature was 25.5 ºC, in

Table 2. Soil analysis for chemical, physical characterization and textural classification of the experimental area.

pH	P-rem	P-M	K	Ca^{2+}	Mg^{2+}	Al^{3+}	H + Al	SB	t	T	V	OM	OC
H_2O	mg L^{-1}	mg dm^{-3}					$cmol_c$ dm^{-3}				%	dag kg^{-1}	
7.700	33.830	95.000	228	7.360	2.780	0.00	0.820	10.720	10.720	11.540	93	3.080	1.780

Thick sand	Fine sand	Silt	Clay	Textural class
dag kg^{-1}				
12.600	19.400	50.000	18.000	Average

P-rem: remaining phosphorus; P-M: available phosphorus (extracted by the Mehlich method); SB: sum of exchangeable bases = Ca^{2+} + Mg^{2+} + K^{+} + Na^{+}; t: effective cation exchange capacity (CEC) at current pH; T: CEC at pH 7.0 (maximum cation exchange capacity); V: base saturation = (SB/T) × 100; OM: soil organic matter; OC: organic carbon.

November; the highest average humidity was 66.5 % in November; and the average rainfall was 40 mm in October (Figure 1).

Statistical analyses were performed using the R software. After verifying the Anova assumptions and identifying significance using the F test ($p \leq 0.05$), the means were grouped with the Scott-Knott test ($p \leq 0.05$), using the "ExpDes.pt" package. The Pearson's estimated correlation was performed among the studied variables using the "cor" function, and its graphical representation was done using the "ggraph" package.

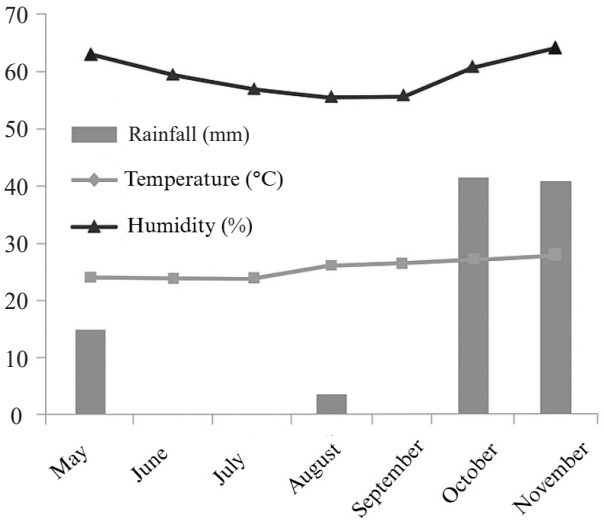

Figure 1. Meteorological data of average values for temperature, humidity and rainfal in Montes Claros (Minas Gerais state, Brazil), in 2018.

RESULTS AND DISCUSSION

As observed in the average results (Table 3), it was possible to group the fava bean varieties in all evaluated variables ($p \leq 0.05$), according to the Scott-Knott test. The germination test showed a variation of 39-92 % among all fifteen treatments. The varieties Três meses, Fava rajada, Olho de lambu, Fava baetona, Três meses rajada, Olho de pombo, Amarelinha and 15 (no denomination) presented the highest averages for normal seedlings, forming the group with averages above 76 % (Table 3), differing from the other varieties, which showed germination percentages below 73 %. Although there is currently no standardization of marketing standards for fava bean seeds, when compared to the minimum germination percentage for *Phaseolus vulgaris* L. (Brasil 2013), most genotypes would meet the minimum standard required for basic seeds of 70 %.

In the first germination count test, the treatments Fava baetona and Olho de pombo had the highest averages, whereas the Fava rajada and Fava carioca did not show normal seedling formation. However, it is important to note that, although the Fava rajada

Table 3. Average values for germination (G), first germination count (FC), water content (WC), weight of 100 seeds (WS), seed dry matter (SDM), seedling dry matter (SM), emergence speed index (ESI) and final emergence (FE) of fifteen landrace varieties of fava bean from seed houses in the north of the Minas Gerais state, Brazil.

Treatment	G (%)	FC (%)	WC (%)	WS (g)	SDM (g)	SM (g)	ESI	FE (%)
1	84 a*	73 b	10.310 c	34.410 c	32.540 b	0.480 b	10.980 a	98.000 a
2	42 b	19 d	9.150 d	31.140 c	31.640 b	0.200 d	11.140 a	96.000 a
3	81 a	0 e	10.680 c	91.410 a	37.260 a	0.900 a	9.700 a	94.000 a
4	79 a	70 b	8.990 d	34.150 c	33.260 b	0.450 b	8.580 b	81.330 a
5	92 a	82 a	8.670 d	31.480 c	32.360 b	0.580 b	10.030 a	88.660 a
6	39 b	0 e	12.090 a	75.220 b	36.060 a	0.190 d	8.890 b	79.660 b
7	54 b	29 d	9.280 d	36.390 c	34.790 a	0.310 c	10.280 a	92.330 a
8	61 b	57 c	10.400 c	27.930 c	32.340 b	0.370 c	8.260 b	79.660 b
9	78 a	57 c	10.130 c	30.030 c	32.190 b	0.360 c	11.390 a	100.00 a
10	47 b	41 c	9.560 d	35.010 c	35.630 a	0.220 d	5.790 c	66.660 b
11	64 b	35 c	11.220 b	32.200 c	32.790 b	0.360 c	10.770 a	94.000 a
12	58 b	47 c	9.230 d	35.000 c	32.510 b	0.300 c	10.400 a	94.330 a
13	91 a	90 a	10.750 c	32.380 c	32.720 b	0.510 b	9.630 a	87.000 a
14	78 a	69 b	9.250 d	32.260 c	32.420 b	0.470 b	10.700 a	96.330 a
15	76 a	71 b	10.410 c	30.150 c	31.800 b	0.370 c	10.240 a	66.660 b
CV (%)	17.140	20.180	3.500	9.950	4.730	25.410	9.160	9.490

* Means followed by the same letter, in the column, can be grouped together by the Scott-Knott test at 5 % of significance; CV: residual coefficient of variation.

had a result zero in the first count, it demonstrated a high vigor in the other analyses.

The moisture content varied between 8.7 and 12.1 %, with the highest percentage obtained for Fava carioca, differentiating it from the other groups (Table 3). All values obtained for moisture content were below the seed deterioration limit, demonstrating that the seed house environment is suitable for seed storage and conservation. According to Carvalho & Nakagawa (2012), storing seeds with moisture content between 12 and 14 % favors increased seed respiration, resulting in vigor loss and low germination, in addition to favoring the proliferation of pests and microorganisms that can compromise seed quality.

The weight of 100 seeds varied from 30.02 to 91.41 g, with the treatment Fava rajada showing the highest weight (91.41 g), differing statistically from the other groups. The weight of 100 seeds is an important measurement variable for broad bean cultivation, as it is associated with seed size and consumer preferences for its grains, which, depending on the region, have a specific size and seed coat color.

The result of the 100-seed weight allowed the seeds of Fava rajada and Fava carioca to be classified as large size, whereas the Fava leite variety was classified as small and the others as normal-sized seeds (Vilhordo et al. 1996). This characteristic highlights the diversity of seed size among the tested fava bean landraces. Advíncula et al. (2015) found the highest 100-seed weight for the Orelha de Vó landrace, at 69.13 g; and Nobre et al. (2012) observed values ranging from 31.7 to 93.2 g. Both studies evaluated fava bean landraces from the northern Minas Gerais state. Barreiro Neto et al. (2015), studying 10 fava bean accessions, found average 100-seed weights ranging from 40 to 89 g.

For the seed dry matter test, the treatments Fava rajada, Fava carioca and Anduzinha mulatinha presented the highest averages, not differing from each other and differing from the other groups (Table 3). The seedling dry matter weight of the Fava rajada variety obtained the highest average, differentiating it from the others. Dry mass is an efficient parameter to evaluate vigor, because the greater the dry matter accumulation, the more vigorous the seedling (Amaro et al. 2015, Bisognin et al. 2016); thus, Fava rajada presented the greatest vigor. Furthermore, it was observed that the greatest dry matter accumulation of the cited varieties coincided with the greatest 100-seed weight. This evidence was also confirmed by Perin et al. (2002) in common bean cultivars, who observed that larger seeds of the same cultivar positively influence the accumulation of biomass in shoots and roots.

Regarding the emergence speed index, 73.3 % of the varieties had averages between 9.63 and 11.39, indicating a greater vigor in these treatments and, consequently, greater uniformity and emergence speed in the field. Seed physiological quality is one of the main quality attributes, represented primarily by vigor (Marcos-Filho 2015a). In this regard, it is important to highlight that it constitutes an important parameter for initial seedling establishment, as it determines the speed and uniformity of germination, as well as the emergence capacity under unfavorable environmental conditions (Marcos-Filho 2015b). Thus, seeds with high vigor germinate more quickly, emerge uniformly and produce more robust seedlings, what contributes to a greater stand density, reduced weed competition and increased yield (Minuzzi et al. 2010, Reed et al. 2022.)

It was observed that the field emergence rate was higher than in the germination test. This may be a factor favored by the broad genetic base of the landraces and their adaptation to the environment. According to Melo et al. (2016), seeds with better physiological quality are less sensitive to field conditions, such as water stress after sowing, and less susceptible to pest attacks early in their development. They also provide uniformity and rapid stand development, hindering the emergence of invasive plants. Furthermore, it is important to mention that the landraces have a high local adaptability and, thus, can find environmental conditions in the field that are closer to their physiological requirements than those reproduced in the laboratory germination test. Therefore, it is clear that studies need to be continuously conducted to better define the ideal conditions for these varieties, since, due to the broad genetic base aforementioned, the conditions considered ideal for each material can vary significantly.

In this study, it was noticed that the treatments Fava rajada and Fava carioca had their results compromised in the first germination count test and in the germination test. It was observed that these varieties, in the first germination count test, still did not have a root system or shoot, showing slower development, when compared to the others.

Figure 2 shows the results of the tests evaluated by correlation estimates for the fifteen heirloom fava bean varieties using the Pearson's correlation. It was observed that the moisture content had no linear correlation with any of the analyzed variables, and possibly seed moisture, in all treatments, did not interfere with seed quality.

The weight of one hundred seeds showed a strong positive linear correlation with seed dry matter, meaning that, as seed weight or seed size increased, seed dry matter also increased. These physical parameters of seed quality for the fifteen fava bean varieties showed a negative correlation with both the germination test and the vigor test.

The germination test was positively associated with the seedling dry matter and first germination count tests. The first germination count test was negatively correlated with both the seed dry matter and 100-seed weight. Therefore, the smaller the seed size, the greater the germination speed and seedling development. Köpper et al. (2010) found that smaller *Cariniana estrellensis* seeds have a higher surface-to-volume ratio than larger seeds, what may facilitate the water acquisition for the initiation of the germination process, but they have smaller reserves. Pardo et al. (2015) noticed that smaller *Glycine max* seeds have higher germination speed and emergence, but Nunes et al. (2015) reported that smaller cotton seeds have lower physiological quality.

Contrasting results are reported for *Phaseolus lunatus*, regarding the relationship between seed size and physiological quality. Batista et al. (2024) found that seed viability and vigor from the Agreste mesoregion of the Paraíba state are independent of seed size. Méx-Alvares et al. (2021) argue that, in tropical bean varieties, smaller seeds emerge with greater vigor, if compared to medium or large-sized seeds. Working with two distinct groups of fava beans, Esquivel-Martinez et al. (2023) suggested the superiority of the Papa group, known for having larger seeds. The authors found that this group produced seeds with the best physiological quality, reflected in the higher germination and seedling emergence percentages.

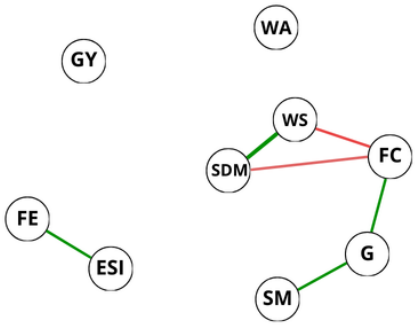

Figure 2. Significant Pearson's correlation for seed quality by the t-test ($p \leq 0.05$) of fifteen heirloom fava bean varieties from seed houses in northern Minas Gerais state, Brazil. WS: 100-seed weight (g); WC: water content (%); G: germination (%); FC: first germination count (%); ESI: emergence speed index; FE: final emergence (%); SDM: seed dry matter (g); SM: seedling dry matter (g); GY: grain yield (kg ha^{-1}).

In addition to the broad genetic base already reported, local adaptation to soil, climate and management conditions directly impacts seed physiological performance (Marcos-Filho 2015a). Thus, the effect of seed size, as shown in the studies, is quite heterogeneous and may vary depending on the origin and growing environment. In this context, it is noteworthy that these factors are already addressed at the national level. Brazilian seed and seedling legislation (Law nº 10.711; Brasil 2003) stipulates that heirloom seeds are not subjected to the same registration, certification, minimum germination and vigor standards required for commercial cultivars, precisely because of the existing diversity. It is difficult to define stable and universal germination and vigor standards, since each batch or variety may respond differently to storage, planting and management conditions. Thus, Brazilian standards recognize that defining a homogeneous and uniform criteria for fava bean is complex and may significantly affect the conservation of these varieties, whose importance is directly linked to their genetic resilience and sociocultural relevance for family farming (Brasil 2003, Brasil 2013).

According to Marcos-Filho (2015a), smaller seeds have a higher surface-to-volume ratio than larger seeds. This means that the imbibition of smaller seeds is generally faster, resulting in advantages, in terms of plant establishment in the field.

The emergence speed index and final emergence are strongly correlated (Figure 2). However, there was no correlation between these variables analyzed in the field and the laboratory tests, what may be related to the environmental conditions of each methodology and the genetic heterogeneity present among varieties. Landraces have the ability to increase the diversity of responses under adverse conditions, reducing the predictability

of tests conducted in a controlled environment (Acosta-Quesada et al. 2022). Similar results were found for *Phaseolus vulgaris*, in which not all laboratory vigor tests correlated with field emergence (Miguel & Cicero 1999).

Grain yield, however, showed no linear correlation with any of the tests that evaluated fava bean seed quality. This demonstrates that relatively small fava bean seed varieties do not necessarily have superior physiological potential to larger seeds. Although seeds with higher physiological quality offer advantages in initial establishment, it must be considered that other factors interact more directly with final grain production, such as the genotype × environment interaction, which is widely recognized for greatly impacting crop yield (Marcos-Filho 2015).

The variables tested in the field showed that there was no statistical difference only in the average hypocotyl height (Table 4). Regarding the hypocotyl diameter, two groups were formed, where 46.6 % of the varieties presented the largest diameters and 53.3 % the smallest diameters. For leaflet length and width, the varieties Fava rajada and Fava carioca presented the highest averages.

When evaluating the seedling traits of fava bean landraces, there was no statistical difference for hypocotyl height, meaning that this variable was not effective in stratifying the fava bean landraces. Therefore, it can be concluded that this morphological descriptor has low discriminatory power and is not recommended for the selection and differentiation of genotypes during the early stages of cultivation. Statistical differences were observed for the other traits, with the landraces Fava rajada and Fava carioca presenting the highest values for hypocotyl diameter and primary leaflet length and width.

Table 4. Averages for the variables hypocotyl height (HH) and diameter (HD), leaflet length (LL) and width (LW) of fifteen landrace varieties of fava bean from seed houses in northern Minas Gerais state, Brazil.

Treatment	HH (cm)	HD (mm)	LL (cm)	LW (cm)
1	4.440 a*	3.630 a	6.480 b	6.330 b
2	4.040 a	3.300 b	5.890 c	5.690 c
3	5.320 a	3.690 a	8.990 a	8.060 a
4	4.620 a	3.440 a	5.910 c	6.000 b
5	4.610 a	3.030 b	6.190 b	5.780 c
6	3.910 a	3.660 a	8.530 a	7.970 a
7	4.720 a	3.250 b	5.840 c	6.280 b
8	4.410 a	3.260 b	5.010 c	4.980 c
9	4.510 a	3.510 a	5.660 c	5.600 c
10	4.240 a	3.160 b	5.010 c	5.170 c
11	4.430 a	2.940 b	6.380 b	6.330 b
12	5.220 a	3.810 a	5.970 c	6.640 b
13	4.810 a	3.390 b	6.720 b	6.270 b
14	4.640 a	3.820 a	6.920 b	6.740 b
15	4.760 a	3.220 b	5.260 c	5.360 c
CV (%)	23.910	14.450	17.410	14.990

CV: residual coefficient of variation.

There was a significant effect among the fava bean landraces, except for the variable flowering onset (Table 5), which occurred between 38 and 42 days, inferring that all fava bean landraces in this study were sensitive to photoperiod, as they are grown in the fall-winter period, providing positive flowering responses in short days. Earliness is an important characteristic of fava bean cultivation, as it allows for its cultivation more than once a year, favoring the production of other crops, as in the case of corn planted in intercropping (Pierre et al. 2022).

Fruiting began between 57 and 59 days after sowing, with the earliest being the varieties 2 (no denomination), Fava rajada, Olho de lambu and Fava carioca (Table 5).

The highest average pod length was presented by the variety Fava rajada (8.75 cm), and the lowest average by the landrace variety 2 (no denomination; 4.59 cm). Regarding pod width, the highest averages were obtained for the varieties Fava rajada and Fava carioca, with no differences between them and with differences from the others. The number of seeds per pod ranged from 2.18 to 2.93, with the varieties Três meses, Anduzinha, Três meses rajada, Mulatinha branca, Amarelinha and 15 (no denomination) having the highest number of seeds per pod, with no differences among them and with differences from the other groups.

All landraces exhibited an indeterminate growth habit, with terminal bud development on a guide. Therefore, landraces planted intercropped with fava bean, in addition to the benefits of intercropping, can also be used as a tutor. Cultivars with indeterminate growth habits have a higher yield than those with determinate growth habits, because vegetative development continues with the emission of new nodes, from which new flowers are produced, providing a greater yield potential (Oliveira et al. 2011).

The most productive fava bean varieties were Três meses, Fava carioca, Anduzinha, Mulatinha branca and Amarelinha, with no differences among themselves and differing from the other groups. The

Table 5. Averages for the variables beginning of flowering (BFL), beginning of fruiting (BFR), pod length (PL), pod width (PW), number of seeds per pod (NSPP) and grain yield (GY) of fifteen landrace varieties of fava bean from seed houses in northern Minas Gerais state, Brazil.

Treatment	BFL (days)	BFR (days)	PL (cm)	PW (cm)	NSPP	GY (kg ha^{-1})
1	39 a*	58 a	5.580 c	1.430 b	2.910 a	788.750 a
2	39 a	57 b	4.590 e	1.420 b	2.400 b	97.930 b
3	38 a	57 b	8.750 a	1.690 a	2.320 b	447.150 b
4	40 a	58 b	5.150 d	1.380 b	2.460 b	477.820 b
5	40 a	58 a	4.770 e	1.350 b	2.450 b	353.000 b
6	39 a	57 b	8.030 b	1.680 a	2.180 b	969.630 a
7	42 a	58 a	4.830 e	1.400 b	2.930 a	623.430 a
8	42 a	59 a	5.360 c	1.460 b	2.520 b	346.470 b
9	41 a	59 a	5.130 d	1.480 b	2.710 a	293.830 b
10	42 a	59 a	5.570 c	1.390 b	2.470 b	254.050 b
11	39 a	59 a	5.950 c	1.450 b	2.640 a	758.450 a
12	40 a	58 a	5.560 c	1.410 b	2.480 b	488.890 b
13	38 a	59 a	4.960 d	1.470 b	2.360 b	174.800 b
14	39 a	59 a	5.670 c	1.390 b	2.910 a	999.390 a
15	40 a	59 a	5.240 d	1.410 b	2.790 a	388.610 b
CV (%)	4.450	1.730	3.790	3.500	5.580	53.760

* Means followed by the same letter, in the column, do not differ from each other, according to the Scott-Knott test at 5 % of significance; CV: residual coefficient of variation.

yield variations observed in this study (623.43 to 999.39 kg ha^{-1}) are higher than the averages found in the northern Minas Gerais state. The most productive varieties also presented higher emergence speed index, final emergence and number of seeds per pod, except for the Fava carioca variety. Based on these results, it can be inferred that seeds with higher emergence speed index and final emergence can produce more vigorous seedlings, what is essential for increasing the success rate in the reproductive phase. Thus, the initial vigor of a seed lot is crucial for expressing the maximum productive potential of a given genotype, in agreement with previous studies stating that high-quality seeds significantly influence the agronomic performance of plants in the field (Struker et al. 2019, Basu & Groot 2023).

Silva et al. (2015), studying 24 accessions, found higher averages than in the present study, in relation to the traits pod length and width (4.94-9.85 cm), flowering onset (89.7 days) and fruit maturation (130.87 days). Close results were found only regarding number of seeds per pod (2.17-2.95 seeds).

Oliveira et al. (2011), studying eight accessions of fava bean, found average pod lengths of 5-5.95 cm, pod width of 1.17-1.77 cm and average flowering time of 55-107 days, with the 55-day accession BSF12, with determinate growth habit, being the most productive one (920.16 kg ha^{-1}).

By estimating the Pearson's correlation (Figure 3), it was found that the variables leaflet length, leaflet width, pod length and pod width showed a strong positive linear correlation with each other.

The onset of flowering and of fruiting showed a negative linear correlation with leaflet length and width, which may have been strongly influenced by environmental conditions. Vegetative traits can reflect photosynthetic activity and dry matter accumulation in plants, and these factors can be directly regulated by environmental conditions (Taiz & Zeiger 2017).

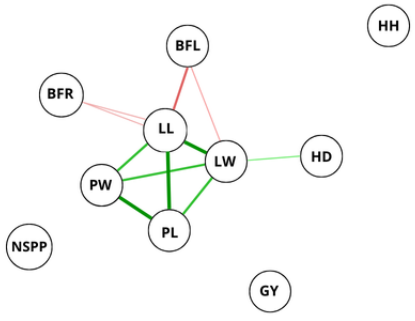

Figure 3. Significant Pearson's correlation estimated by the t-test ($p \leq 0.05$) of fifteen landrace varieties of fava bean from seed houses in northern Minas Gerais state, Brazil. HH: hypocotyl height; HD: hypocotyl diameter; LL: leaflet length; LW: leaflet width; PL: pod length; PW: pod width; SPP: number of seeds per pod; BFL: beginning of flowering; BFR: beginning of fruiting; GY: grain yield.

Thus, under optimal and favorable conditions of water, light and nutrients, vegetative growth is enhanced, while stressful conditions can impact leaf development and promote the anticipation of the reproductive cycle as an adaptive strategy of the plant, increasing the chances of leaving descendants (Chen et al. 2023). The hypocotyl diameter had a positive but weak correlation with leaflet width. The variables hypocotyl height and number of seeds per pod showed no linear correlation with any of the analyzed variables. Grain yield, however, showed a positive but weak linear correlation with leaflet width.

Obtaining variables correlated with grain yield is of great importance in breeding programs; however, correlation allows the breeder to identify the changes that occur in a trait as a result of the selection of another trait correlated with it (Ramalho et al. 1993).

Studies conducted by Silva et al. (2019) with heirloom fava bean varieties showed that yield presented a positive linear correlation with the variables 100-seed weight and number of seeds per pod. The variables pod length and width also correlated positively, whereas 100-seed weight correlated negatively with the variables number of seeds per pod and pods per plant.

The presented results allow to infer that, for fava bean, numerous characteristics must be considered to evaluate agronomic performance and seed quality, enabling the selection of more efficient and promising varieties for farmers and breeding programs (Câmara et al. 2023). Thus, it becomes clear that aspects related to seed quality and the use of morphoagronomic descriptors represent important sources for identifying variability, potentially providing relevant contributions to strategies for conservation, management and selection of genotypes of interest.

CONCLUSIONS

1. The landraces varieties of fava bean (*Phaseolus lunatus* L.) evaluated in the present study showed a wide variability in the seed physical and physiological quality, evidencing a significant genetic diversity in the semiarid region of northern Minas Gerais state, Brazil;
2. Amarelinha, Fava Carioca, Três meses, Mulatinha branca and Anduzinha are promising varieties for breeding programs;
3. No significant linear correlation was identified between the yield and seed physiological quality tests, indicating that these parameters should be analyzed in a complementary manner;
4. Leaflet width showed a positive correlation with grain yield, suggesting its use as a possible auxiliary trait in the selection of more productive genotypes.

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