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RESEARCH ARTICLE

Agronomic evaluation and genetic characterization of bell pepper (*Capsicum annuum* L.) accessions from Niger

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Abstract

In Niger, bell pepper is an economically important vegetable crop that contributes to food security and income generation. However, limited information is available on the agronomic performance and genetic variability of local bell pepper accessions. This study aimed to evaluate the agronomic performance and estimate genetic parameters of national bell pepper accessions. A total of 56 accessions were evaluated using an alpha lattice design, and phenotypic data were recorded for important morphological and agronomic traits. Analysis of variance revealed significant differences among accessions for plant height, stem circumference, first bifurcation height, flower corolla length, anther length, pedicel length, fruit width, fruit wall thickness, and number of fruits per plant, indicating substantial genetic variability for these traits. The observed variation was primarily attributed to genetic differences among the evaluated accessions. The intraclass correlation coefficient (ICC) ranged from 54% to 95% across the studied traits, demonstrating moderate to high repeatability and confirming the existence of exploitable genetic variation. These findings indicate that the evaluated bell pepper germplasm possesses considerable breeding potential and can serve as a valuable genetic resource for the selection and development of improved cultivars with enhanced productivity and adaptation to the agroecological conditions of Niger.

Keywords: Niger, genetic, variation, breeding, bell pepper

Introduction

Ranked as the third most important solanaceous vegetable after potato and tomato, pepper (*Capsicum annuum*) is a major vegetable and spice crop (Vijaya *et al.*, 2025). According to Bosland and Votata, 2000, *Capsicum annuum* is the most dominant among the five domesticated Capsicum (*C. annuum*, *C. baccatum*, *C. chinense*, *C. frutescens*, and *C. pubescens*) species cultivated worldwide It is commonly grouped into non-pungent (sweet pepper) and pungent (chilli or hot pepper) varieties according to pungency level (Bosland and Votava, 2000). The crop is widely cultivated for its fruits with high nutritional value, rich antioxidant properties and diverse flavors content (Likeng-Li-Ngue *et al.,* 2025; Saleh *et al.,* 2018). Additionally, according to Garane *et al.*, 2019, pepper generates attractive income opportunities for smallholder farmers, contributing to improve their living standards. It ranks among the most economically significant horticultural crops grown across tropical and subtropical regions, in approximately 126 countries worldwide (Tiamiyu *et al.,* 2023). Based on FAOSTAT data for 2019, the global cultivated area and total production were estimated at nearly 2 million hectares and 38.02 million tones, respectively (FAOSTAT 2019). Similarly, bell pepper is an economically important vegetable crop in Niger. There is yet limited scientific information on agronomic performances and genetic parameters of local accessions the country. Evaluating these accessions agronomically will identify high performing and locally adapted genotypes that can contribute to improved productivity, food security, and income generation for farmers in the region. Additionally, genetic characterization is essential for understanding the extent of variability, and traits heritability within Nigerien germplasm, which is a key resource for future breeding programs aimed at developing cultivars with desirable traits such as higher yield, disease resistance, stress tolerance, and enhanced nutritional quality. Hence, studying Niger's native plant genetics is crucial for developing resilient crops, conserving biodiversity, and guiding agricultural stakeholders, as they face challenges from climate change, pests, and market shifts. Therefore, the objective of this study, was to assess agronomic and genetic performances of national bell pepper accessions

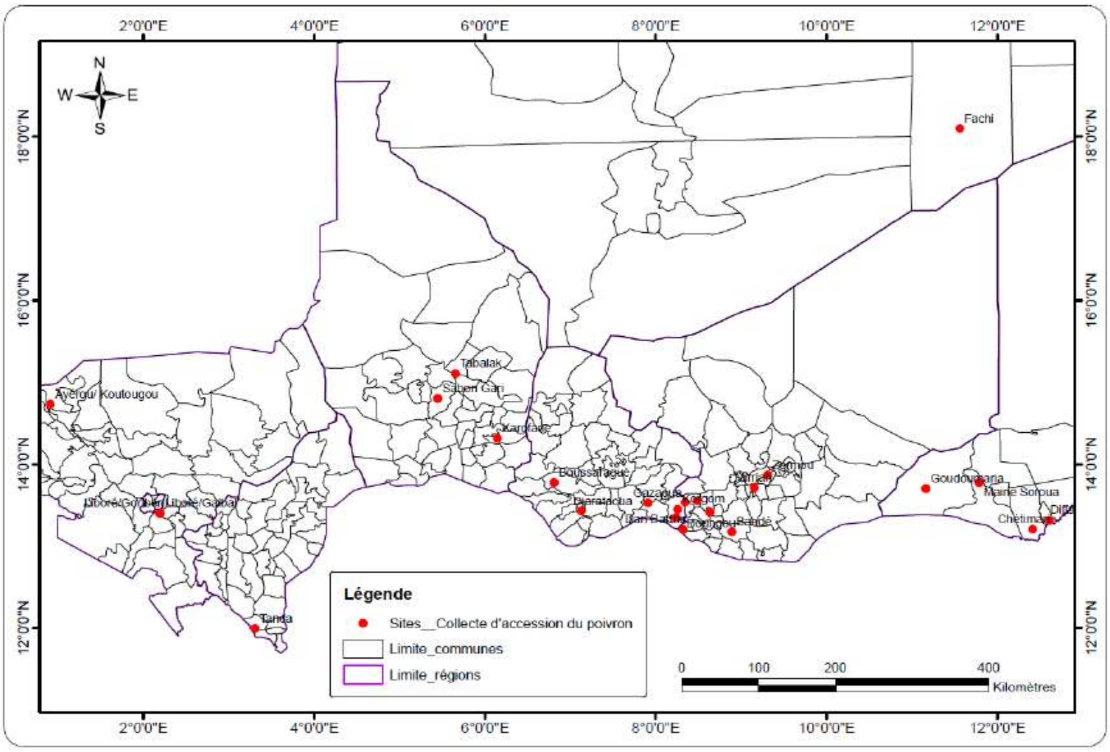
Materials and methods

A collection of national bell pepper accessions was used for this study, comprising diverse genotypes representing different geographical regions. Germplasm was collected throughout Niger Republic country, where all the regions were concerned, except Agadez. The concerned regions included: Diffa, Zinder, Maradi, Tahoua, Dosso, and Tillaberi (Fig. 1). The agroecological zoning was used to identify regions with potential bell pepper diversity: Irrigated farming areas near river valleys along the Komandougu River, traditional home gardens and urban markets. For the field collection, ethnobotanical surveys were conducted to document traditional knowledge about bell pepper varieties. Details like local names, uses, and cultivation practices were recorded. Samples from multiple sources were collected, including: farmer fields, home gardens, local markets.

The research location lies at 13°64’60’’ north latitude, 4°05’53’’ east longitude, and an altitude of 256.30 meters. The soil has a clay-sandy texture. The experimental design was an Alpha Lattice design with 3 replicates. The spacing was 40 cm between plants on the row and 50 cm between rows. Each elementary plot measured 1 m width and 2 m 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 on January 2024. Transplantation was carried out 50 days after sowing, when the plants had reached the stage of 6 to 9 leaves. The operation was followed by the incorporation of carbofuran (to control insects and nematodes). Irrigation was carried out at regular intervals, early in the morning or in the evening, and with different quantities of water. From transplanting to 50% flowering, the amount of water irrigated was 20l per plot was applied. From 50% flowering to harvest, the quantity of water irrigated is 30l per lot was applied. The weeding was done when needed. Fertilization was done using NPK (15-15-15) fertilizer applied on the 15th, 30th, 50th and 80th days after transplanting at a rate of 30g/plot.

Phenotypic data on various morphological and agronomic traits were recorded. Leaf shape, leaf color, stem pubescence (presence or absence of small hairs) were recorded at vegetative stage. Plant height was recorded on central plants, when the 1st fruits on 50% of plants have begun to ripen. Canopy width was measured on center lines (cm) after 1st harvest at widest point. The stem length (height 1st bifurcation) measured on center lines (cm) after 1st harvest. The stem diameter was measured on center line in the middle of the 1st bifurcation after the first harvest. The duration: Date to 50% flowering (number of days from sowing to 50% flowering) was determined when 50% of the plants in the experimental unit have flowered. Corolla spot (presence or absence of spot-on corolla) and corolla shape were recorded on outer lines. The corolla length in cm was determined as the average of 10 petals on external lines. The anther color and anther length (average length of 10 flowers selected from different plants) were recorded during anthesis on outer lines. Fruiting date (number of days from sowing to 50% fruiting 50% in one experimental unit), fruit color data were recorded at maturity. Fruit shape, fruit length (average length of 10 fruits), fruit width (average width of 10 fruits measured at widest point), fruit weight (average weight of 10 fruits), pedicel length (average length of 10 pedicels),

Fig 1: germplasm collection site



fruit wall thickness (average thickness of 10 ripe fruits), number of locules (average number of fruits after pedicel cross-section) and the number of seeds per fruit (Average 10 fruits from 10 random plants) were recorded at the second (2nd) harvest. The number of fruits (total number of fruits), fresh fruit yield (average yield of plants in middle row), dry fruit yield (average yield of plants in middle row) and seed yield were recorded at each harvest. Statistical analyses were performed using R software.

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	Marché/Diffa	Diffa	Diffa	Diffa
3	Bongo	Marché/Diffa	Diffa	Diffa	Diffa
4	Bounami petit	Marché/Diffa	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	Hanchi tsania	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 tsania	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 tsa	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

Accession Number	Local Name	Site/Village	Commune	Department	Region
40	Koriaram	Diffa	Diffa	Diffa	Diffa
41	Bongo/Kouri Moro	Tam	Mainé Soroua	Maine Soroua	Diffa
42	Kangadi Nglaro	Tam	Mainé Soroua	Maine Soroua	Diffa
43	Bongo/Kouri Moro	Blakouna	Mainé Soroua	Maine Soroua	Diffa
44	Kangadi Nglaro	Blakouna	Mainé Soroua	Maine Soroua	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 commune	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

The intra-class correlation (ICC) was calculated as follow: ICC= δ2A/ (δ2A + δ2) (Dowdy *et al.*, 2004). An estimator for broad sense heritability for the family means is:
Where σ2F is the family variance component in the reference population and σ2P is the phenotypic variance of family mean deviation. The heritability was estimated using REML Method. Proc mixed asycov, and proc iml were used. The Rep, block (rep) and entries were considered as random. Mid parent offspring regression was also used for heritability estimation

Results and discussion

Statistically significant differences were found among varieties for plant height ($p = 0.0352$) and circumference ($p = 0.02576$). Furthermore, there was a statistically highly significant difference among the varieties for the height of the first bifurcation among the accessions ($p = 0.00966$). The Intra class correlation coefficient shows that 74% of the variance is due to differences between ecotypes (Table 2). Plant height and plant circumference (plant widths) are essential agronomic traits for pepper. Accessions with narrow circumferences permit the cultivation of more individuals within a unit area. This can boost the efficient use of agricultural area. According to Do Rêgo *et al.*, (2009), the importance of pepper plant circumference is to determine the space between and within rows.

The table 3 presents the analysis of variance for plant canopy width and plant canopy diameter. There is no strong statistical evidence that the studied accessions differ in their canopy width ($p = 0.065761$). There is no statistically significant difference in canopy diameter among the ecotypes.

The table 4 shows the analysis of variance of three floral traits: flower corolla length, anther length and pedicel length. For all three floral traits, there are highly statistically significant differences among accessions. The p-value is infinitesimally small ($p = 3.37E-18$) for corolla length.

The ICC value shows that 95% of the total variation is driven by inherent differences between the varieties. Like corolla length, anther length displayed strong significant difference among varieties (p = 4.69E- 12). The ICC (98%) is even higher than for corolla length. There are also high significant differences among the varieties for pedicel length. The ICC value (58%) shows that more than half of the variation is due to varietal differences. There are highly significant differences among the varieties for fruit width

Table 2: ANOVA for plant height, circumference and height of first bifurcation

Source de of variation	**DF**	**SS**	**MS**	**F $_{Cal}$**	**F $_{table}$**
		Plant height			
Rep	2	39,527	19,7635	1,455032	0,243933
Var	26	398,2272	15,31643	1,127629	0.0352
Block/Rep	6	43,1538	7,192299	0,529513	0,782953
Error	46	624,8116	13,58286		
Intra class correlation		59%			
		P circumference			
Rep	2	37999,86	18999,93	0,93557	0,3997
Var	26	487882,8	18764,72	0,923988	0.02576
Block/Rep	6	99390,09	16565,01	0,815673	0,563387
Error	46	934186,7	20308,41		
Intra class correlation		54%			
		First bifurcation height			
Rep	2	3,671303	1,835652	0,207356	0,813486
Var	26	505,6128	19,44665	2,196698	0,009662*
Block/Rep	6	69,41469	11,56912	1,30685	0,273245
Error	46	407,2229	8,852672		
Intra class correlation		74%			

Table 3: ANOVA for plant canopy traits

Source de of variation	**DF**	**SS**	**MS**	**F $_{Cal}$**	**F $_{table}$**
		Plant canopy width			
Rep	2	22,08725	11,04362	0,844615	0,436278
Var	26	564,074	21,69515	1,659242	0,065761^{NS}
Block/Rep	6	191,5687	31,92812	2,441858	0,039212
Error	46	601,4657	13,07534		
Intra class correlation		6%			
		Plant canopy diameter			
Rep	2	2,790344	1,395172	2,892734	0,065561
Var	26	13,59517	0,522891	1,084157	0,395775NS
Block/Rep	6	1,821074	0,303512	0,629299	0,705965
Error	46	22,1859	0,482302		
Intra class correlation		39%			

(p = 6.19E-06) (Table 5). Moreover, the ICC value indicates that 88% of the variation is due to genetic differences between varieties, making fruit width a highly stable and diagnostic characteristic. There is no statistically significant difference in fruit length among accessions. There are significant differences in the number of fruits produced by the different varieties. The ICC (52%) indicates that about half the variation is genetic, and the other half is due to environmental noise. There are very high significant differences in fruit wall thickness among accessions. The obtained ICC (60%) indicates that the trait is predominantly under genetic control.

There is no significant difference in the total number of flowers produced by the different accessions (Table 6). All varieties have a similar potential for fruit production based on flower count. The significant replication effect means that the overall flower production was significantly different between the main experimental replications, but this affected all varieties equally. The ICC (42%) indicates that the genetic component for this trait is weak, and it is heavily influenced by other factors. There is no significant difference in the rate of flower abortion among the varieties. Hence, the propensity for flowers to fail is not a distinguishing genetic factor in this experiment. The ICC indicates that only 16% of the variation is due to varietal differences. There are highly significant differences in the number of plants that successfully set fruit among the varieties (p = 1.05E-05). The ICC shows that despite environmental influence, the genetic differences between varieties are high and account for 89% of the observed variation. The table 7 shows accession's traits genetic components. The flower corolla length showing high broad sense heritability (H^2 = 93%) is highly controlled by genetics. The anther length is also highly heritable with a value of H^2 equal to 86%. Additionally, the fruit width (H^2 = 71%) shows strong genetic control as well as the number of fruiting plants (H^2 = 70%). The pedicel length and fruit wall thickness have heritability (H^2) equal to 59% and 58% respectively. For the first bifurcation height (H^2 = 55%) and fruits number (H^2 = 55%), more than half of trait potential is heritable. Agronomic evaluation and genetic characterization of bell pepper landraces using an extensive range of descriptors may enable the discovery of distinguishing traits or traits combination among different accessions (Martínez-Ispizua *et al.*, 2022; Sudré *et al.*, 2010; This is a crucial objective that helps to define the plant architecture and life cycle of each cultivar, thereby enhancing the agronomic value of local accessions and supporting breeding strategies (Bianchi et al. 2020). Results showed significant differences among varieties in term of plant height, circumference, first bifurcation height, floral traits (flower corolla length, anther length and pedicel length), fruit width, fruit wall thickness, fruits number. Findings of several studies corroborated the present results this includes: Bantayehu *et al.*, (2024), Shimeles *et al.*,(2016) who reported a wide range of means for fruit number, plant height, yield, number of primary branches, pedicel length. This indicates that the genetic differences between varieties are the primary driver of these traits. This may also imply that the differences between varieties for these traits are stark. Crops improvement effectiveness depends on the amount of variability and genetic divergence present in the genetic material for targeted traits (Fasikaw *et al.*, 2020; Abraham *et al.*, 2017). Hence, selection programs are aided by the availability of genetically diverse germplasm within the gene pool of a crop species (Devaraja *et al.*, 2015; Richard *et al.*, 2016). According to Shimeles (2018), genetic variability in crops is critical for further improvement through providing many options for breeders to develop novel varieties. Belay

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et al., (2019) stated that significant genetic variability among genotypes could traits be due to genetic diversity and may be an opportunity for breeder in the selection of varieties with traits of interest. Significant differences among pepper varieties have been reported by researchers such as Nsabiyera *et al.*, (2013), Birhanu (2017) and Shimeles (2018) Daniel (2023).

The intra class correlation (ICC) varying from 54% to 95% according to the trait, indicated that there was enough variation among tested accession for most of the traits studied and their significant potential for improvement of pepper. This also indicates that the traits are predominantly under genetic control and can be used to distinguish varieties. The environment has small influence on trait with high ICC. Hence, breeder can be extremely confident that selecting best parent for targeted trait. For instance, a breeder wanting wider fruits can make rapid progress by selecting the best varieties, as the trait will be reliably passed on. Results showed higher heritability for traits such as first bifurcation height, flower corolla length, anther length, pedicel length, fruit width, fruits number, fruit wall thickness and fruiting plants. The broad sense heritability ranged from 55% for first bifurcation height to 93% for flower corolla length. According to Janaki *et al.*, (2015) and Johnson *et al.*, (1955), higher heritability means that selection for these traits becomes easier and simultaneous response to selection will be greater. However, for traits with low heritability, selection will be effective, but progress may be slower and more sensitive to testing conditions than for the highly heritable traits.

Table 4: ANOVA for flower traits

Source de of variation	**DF**	**SS**	**MS**	**F $_{Cal}$**	**F $_{table}$**
		Flower corolla length			
Rep	2	0,004498	0,002249	0,795516	0,457459
Var	26	1,627785	0,062607	22,14733	3,37E-18***
Block/Rep	6	0,031393	0,005232	1,85091	0,110039
Error	46	0,130035	0,002827		
Intra class correlation		95%			
		Anther length			
Rep	2	0,000218	0,000109	0,127714	0,880416
Var	26	0,236704	0,009104	10,6786	4,69E-12***
Block/Rep	6	0,001074	0,000179	0,210021	0,971858
Error	46	0,039217	0,000853		
Intra class correlation		98%			
		Pedicel length			
Rep	2	0,256308	0,128154	1,366485	0,265157
Var	26	6,186184	0,23793	2,537013	0,002837**
Block/Rep	6	0,578861	0,096477	1,028718	0,418996
Error	46	4,314044	0,093784		
Intra class correlation		58%			

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Table 5: ANOVA of varieties fruit characteristics

Source de of variation	DF	SS	MS	F $_{Cal}$	F $_{table}$
		Fruit width			
Rep	2	2,479282	1,239641	3,556916	0,036615
Var	26	39,77569	1,529834	4,389572	6,19E-06***
Block/Rep	6	3,183722	0,53062	1,522515	0,192117
Error	46	16,03172	0,348516		
Intra class correlation		88%			
		Fruit length			
Rep	2	1,400807	0,700404	0,177231	0,838156
Var	26	149,9923	5,768935	1,459777	0,129083 NS
Block/Rep	6	8,675017	1,445836	0,365856	0,896771
Error	46	181,7887	3,951928		
Intra class correlation		88%			
		Fruits number			
Rep	2	166,0247	83,01235	0,466261	0,630276
Var	26	9980,988	383,8841	2,156187	0,011185*
Block/Rep	6	2786,21	464,3683	2,608248	0,029268
Error	46	8189,766	178,0384		
Intra class correlation		52%			
		Fruit wall thickness			
Rep	2	0,003832	0,001916	0,370336	0,692542
Var	26	0,333044	0,012809	2,47608	0,003529**
Block/Rep	6	0,023907	0,003985	0,77022	0,597243
Error	46	0,237969	0,005173		
Intra class correlation		60%			

Table 7: Genetic components

Statistic	First bifurcation height	Flower corolla length	Anther length	Pedicel length	Fruit width	Fruits number	fruit wall thickness	fruiting plants
Mean	19,44*	0,06***	0,01***	0,24**	1,53***	383,88**	0,013**	6,30***
GVar	505,61	1,63	0,24	6,19	39,78	9980,99	0,33	163,80
Evar	407,22	0,13	0,04	4,31	16,03	8189,77	0,24	68,76
PVar	912,83	1,76	0,28	10,50	55,81	18170,75	0,57	232,57
H2	55%	93%	86%	59%	71%	55%	58%	70%

Table 6: ANOVA for reproductive traits

Source de of variation	DF	SS	MS	F_{Cal}	F_{table}
		Total flowers number			
Rep	2	5722,889	2861,444	4,360206	0,01845
Var	26	17359,33	667,6667	1,017376	0,467485 ^{NS}
Block/Rep	6	2625,653	437,6089	0,666819	0,676715
Error	46	30188,12	656,2636		
Intra class correlation		42%			
		Aborted flowers number			
Rep	2	3987,728	1993,864	5,033745	0,010546
Var	26	15326,77	589,491	1,488239	0,117514^{NS}
Block/Rep	6	1181,025	196,8375	0,496939	0,807315
Error	46	18220,58	396,0996		
ICC		16%			
		Number of fruiting plants			
Rep	2	12,61728	6,308642	4,220157	0,020761
Var	26	163,8025	6,300095	4,214439	1,05E-05***
Block/Rep	6	37,28475	6,214125	4,15693	0,002033
Error	46	68,76463	1,494883		
Intra class correlation		89%			
		Number of seeds per fruit			
Rep	2	36048,08	18024,04	0,630026	0,537111
Var	26	760079,2	29233,82	1,02186	0,462475
Block/Rep	6	183230,9	30538,48	1,067465	0,395705
Error	46	1315987	28608,42		
Intra class correlation		42%			

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