Pak. J. Bot., 57(5): DOI: http://dx.doi.org/10.30848/PJB2025-5(29)

ANALYSIS OF BEHAVIOUR AND BIOMETRY WITHIN SEVERAL LOCAL POPULATIONS OF PEA (*PISUM SATIVUM* L.) IN A HYPER-ARID REGION OF SOUTH-WESTERN ALGERIA

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Abstract

As part of the evaluation, preservation and development of plant genetic resources of food and fodder interest in Algeria, eight (08) local populations of the species *Pisum sativum* L. (*Fabaceae*) were collected from farmers, in an area of South-Western Algeria, mainly in Adrar. This part of the country is considered to be one of the hottest regions in the world (hyper-arid Saharan zone). Following this survey, a complete randomised block trial, with three (03) replications, was set up at the experimental station (INRAA / Adrar), for two consecutive agricultural campaigns (2018/2019; 2019/2020). Twenty-two (22) morphological, phenological and biometrical characteristics, relating to vegetative development, flowering, pods and seeds, were considered. Ecological factors (rainfall, temperature, altitude), characterizing the origin environments of populations were also taken into account. Analysis of variance revealed significant differences for most of the characteristics. Significant variation was recorded for phenological stages linked to vegetative development, flowering and pod formation, as well as for biometrical characteristics relating to production. Interaction analysis indicates a strong influence of the environment (Year) on most of the morpho-phenological traits of populations, whereas this influence would be lesser on biometrical characteristics. The correlation matrix revealed several significant links. In addition, the results indicated the existence of significant relationships between some phenological characteristics (emergence date and flowering duration) and a single ecological factor (altitude), characterizing the origin environment of the populations. Principal component analysis (PCA) permitted to constitute different groups of populations with similar characteristics. The evaluation of *Pisum sativum* populations can contribute to the diversification and development of legumes for human and animal consumption. This will enable the development of livestock farming and its products and consequently will improve the living standard of local populations in this desert region of the country.

Key words: Behaviour; Fodder; Hyper-arid; Legume; *Pisum sativum*.

Introduction

Peas and other legumes are desirable in crop rotations because they break up disease and pest cycles, provide nitrogen, improve soil microbe diversity and activity, improve soil aggregation, conserve soil water, and provide economic diversity (Pavek, 2012). Three species of peas (*Fabaceae*) are known today: *Pisum sativum* L., *P. fulvum* and *P. abyssinicum* (Hirst, 2015). The pea (*Pisum sativum* L.) is an important grain legume crop plant that has gained worldwide economic importance as a source of protein for animal and human nutrition (Schroeder, 1993); moreover, it has essential amino acids (23 to 25%) that have high nutritional values for resource poor households (Khan *et al*., 2017a). The centers of origin of *Pisum sativum* are Ethiopia, the Mediterranean, and central Asia, with a secondary center of diversity in the Near East (Vavilov, 1949 *In* Pavek, 2012). In Algeria (Mediterranean and North African country), the genus *Pisum* L. is represented by only one species (P*isum sativum* L.), comprising three subspecies (ssp. elatius (Stev.) P. Four.; ssp. arvense (L.) P. Four.; ssp. hortense Neïlr.) (Quezel et Santa, 1962). This work turns on eight local populations of *Pisum sativum* L. and follows the previous studies conducted on fodder legumes in Algeria (Issolah & Abdelguerfi, 1999; Issolah *et al*., 2012; Issolah *et al*., 2015; Chabouni *et al*., 2019; Bouziane *et al*., 2019; Issolah *et al*., 2022; Bouziane *et al*., 2023; Sebkhi *et al*., 2023; Chabouni *et al*., 2024). The aim of this investigation is to analyse the morphology, the behaviour and the real potential of the different local populations of this legume (*Pisum sativum* L.), in order to valorize them, particularly in an hyper-arid zone (Adrar) of the country, where the ecological and living conditions are very hard for people and animals.

Material and Methods

Following a survey carried out in South-Western Algeria (Adrar region / hyper-arid bioclimatic stage), eight (08) local populations of pea (*Pisum sativum* L.) were collected, from farmers, in 2016 (Table 1). Following this stage, a trial was conducted over two successive agricultural campaigns (2018/2019; 2019/2020). Sowing was carried out, respectively, on 21st November 2018 and 13th November 2019, at the INRAA (National Institute of Agricultural Research) station in Adrar, located in an hyper-arid bioclimatic zone. Each local population is represented by thirty (30) individuals. The experimental protocol was based on a randomised complete block design, with three replications. Irrigation (drip system) was provided uniformly throughout the plot.

The soil has a coarse sandy-loam texture; the pH is between 7 and 8.5; the electrical conductivity is fairly high (Laaboudi, 2002). The region has a Saharan climate (less than 100 mm/year) (Anon., 1998).

Table 1. Some ecological characteristics of the origin environments of eight local pea populations in the South-Western Algeria (*Pisum sativum* L.).

Population name	Origin	Climate	Altitude (m)	Rainfall (mm/year)	T (°C)	T max (°C)	T min (°C)
Tinerkouk	South-Western of Sahara (Gourara/ Timimoun)	Hyper-arid	366	21	24	32	16
Aougrout	South-Western of Sahara (Gourara /Timimoun)	Hyper-arid	306	16	25	33	17
Aoulef	South-Western of Sahara (Tidikelt / Adrar)	Hyper-arid	277	9	27	34	19
Tamentit	South-Western of Sahara (Touat / Adrar)	Hyper-arid	240	12	26.5	33	17
Talmine	South-Western of Sahara (Gourara / Timimoun)	Hyper-arid	354	16.42	25	32.38	17
Inzghmir 1	South-Western of Sahara (Touat / Adrar)	Hyper-arid	213	10	27	34	19
Inzghmir 2	South-Western of Sahara (Touat / Adrar)	Hyper-arid	213	10	27	34	19
Ouaina	South-Western of Sahara (Touat / Adrar)	Hyper-arid	264	13	26	34	18

Source: https://fr.tutiempo.net/climat/algerie.html (temperature. rainfall).

***T**: Mean monthly temperature ; **Tmax / Tmin**: Average monthly maximum / minimum temperatures;

Rainfall: Average annual precipitation (mm). Data (temperature, rainfall) determined over a 10-year period (2012-2021)

Twenty-two (22) morphological, phenological and biometrical variables were taken into consideration. Following the morpho-phenological study (Field), a biometrical work (laboratory) has been carried out. Thirty (30) plants were randomly selected for each population. The phenological characteristics were expressed in number of days after emergence:

Date of emergence (DE); Autumn plant height (APH); Autumn plant width (APW) (21 December 2018; 21 December 2019); Winter plant height (WPH); Winter plant width (WPW) (21 March 2019; 21 March 2020); Autumn growth speed in height (AGS); Winter growth speed in height (WGS); Number of branches (NB); Date of first flowers of plant (1F); Date end of flowering (EF); Duration of flowering (DF); Date of appearance of the first pod (P1); Date of full pod formation (FP); Date of total drying of plant (TD); Number of seeds per pod (NSP); Length of pods (LP); Width of pods (WP); Length of seeds (LS); Width of seeds (WS); Number of pods per plant (NPP); Number of seeds per plant (NSPl); Thousand-seed weight (TSW).

The obtained data were subjected to various statistical treatments (variance analysis, correlation matrix, Principal Component Analysis). The ecological factors (altitude, rainfall, temperature) of the origin environments of the different populations, were treated as additional variables. Statistical processing was carried out using MINITAB (2016) and R (2023) softwares.

Results and Discussion

The analysis of variance, based on two factors (populations, years), showed significant variation between the pea populations (*Pisum sativum* L.). Indeed, the results revealed very highly significant differences for most of the morpho-phenological and biometrical characteristics taken into account, over the two agricultural years (2018/2019 and 2019/2020) (Tables 2 and 3).

However, some characteristics proved insignificant probability concerning the effect of populations: Winter plant width (WPH), flowering duration (DF), number of pods per plant (NPP), number of seeds per plant (NSPl).

Previous studies have reported genetic diversity within and between genotypes in *Pisum sativum* L. (Gatti *et al*., 2011; Khan *et al*., 2013; Wani *et al*., 2013; Kumar *et al*., 2015; Ouafi *et al*., 2016; Mohamed *et al*., 2019; Aman *et al*., 2021; Jandoubi *et al*., 2021; Kumari *et al*., 2023; Panwar *et al*., 2023; Shrestha *et al*., 2023).

Furthermore, the analysis of variance revealed a significant effect of the year on the variation of most morpho-phenological and biometrical characteristics, with the exception of the characteristics: winter plant height (WPH), end of flowering (EF) and seed length (LS) (Table 2). Thus, environmental fluctuations had globally a significant impact on the performance of the eight pea populations over the two agricultural campaigns. This confirms the findings of some authors within the same species (*Pisum sativum*) in Algeria (sub-humid region) (Ouafi *et al*., 2016), Tunisia (Mohamed *et al*., 2019) and Ethiopia (Habtamu & Million, 2013).

Within the same family (*Fabaceae*), similar results were reported by Mebarkia *et al*., (2020) for ten varieties of *Vicia* genus, and Mahmah *et al*., (2023) for ecotypes of *Vicia narbonensis* L. and *Vicia sativa* L., evaluated in a semi-arid region of North-Eastern Algeria.

In addition, interaction analysis, between pea populations and years, revealed significant differences for most characteristics, particularly the morpho-phenological ones. However, no significant differences were observed for four (04) biometrical characteristics linked to production (number of seeds per pod (NSP), length and width of pod (LP, WP) and width of seeds (WS)).This finding showed that, the populations of pea are relatively stable for these biometrical characteristics (NSP, LP, WP, WS), unlike all the morpho-phenological characteristics (DE, APH, APW, WPH, WPW, AGS, WGS, NB, 1F, EF, FP, TD, DF, P1), and some biometrical ones (LS, NPP, NSPl), which vary significantly during the two seasons. This result indicates a strong influence of the environment (Year), particularly on the morpho-phenological behaviour of the local pea populations, whereas this influence would be lesser from the biometrical point of view.

A previous study conducted on Algerian genotypes of *Pisum sativum*, settled in a sub-humid region, indicated a significant effect of the interaction between genotype and year on flowering and certain morphological characteristics such as plant length (Ouafi *et al*., 2016), which is consistent with the results of the present study. The same authors reported also a non-significant influence of this interaction on pod size (length and width) (Ouafi *et al*., 2016), which confirm also our results.

In Southern Tunisia, Mohamed *et al*., (2019) highlighted the effect of the interaction between accessions and years on all phenological and production characteristics in local accessions of the species *Pisum sativum*.

Table 2. Results of variance analysis of morpho-phenological and biometrical traits within eight local pea populations in the South-Western Algeria (Adrar) over two agricultural years (2018/2019 and 2019/2020).

Characteristics	Min	Max	Mean	S.D	Probability (p)		
					Pop	Y	Pop x Y
DE (days)	10.25	13.75	12.81	1.10	0.000^{***}	0.000^{***}	0.000^{***}
APH (cm)	9.03	10.84	9.91	0.67	0.000^{***}	0.000^{***}	0.000^{***}
APW (cm)	5.45	8.41	6.60	0.90	0.000^{***}	0.000^{***}	0.000^{***}
WPH (cm)	66.70	70.40	68.95	1.35	0.104^{NS}	0.501^{NS}	0.000^{***}
WPW (cm)	40.23	46.04	43.40	1.93	0.000^{***}	0.000^{***}	0.000^{***}
AGS (cm/day)	0.39	0.51	0.44	0.04	0.000^{***}	0.000^{***}	0.000^{***}
WGS (cm/day)	0.56	0.66	0.63	0.03	0.000^{***}	0.000^{***}	0.000^{***}
NB	3.50	4.03	3.71	0.18	0.000^{***}	0.000^{***}	0.000^{***}
1F (days)	81.82	85.82	82.97	1.47	0.000^{***}	0.000^{***}	0.000^{***}
EF (days)	110.62	112.84	112.28	1.15	0.000^{***}	0.341^{NS}	0.000^{***}
DF (days)	29.95	31.46	30.45	0.64	0.193^{NS}	0.000^{***}	0.023^{*}
P1 (days)	88.83	96.26	91.34	2.32	0.000^{***}	0.000^{***}	0.000^{***}
FP (days)	104.59	111.41	107.62	2.42	0.000^{***}	0.000^{***}	0.000^{***}
TD (days)	123.72	128.34	125.79	1.34	0.000^{***}	0.000^{***}	0.000^{***}
NSP	3.41	3.92	3.74	0.17	0.000^{***}	0.000^{***}	0.495^{NS}
LP (mm)	43.91	47.75	46.33	1.12	0.000^{***}	0.000^{***}	0.072^{NS}
WP (mm)	10.69	11.30	11.08	0.18	0.000^{***}	0.000^{***}	0.088^{NS}
LS (mm)	5.05	5.36	5.23	0.10	0.000^{***}	0.475^{NS}	0.003^{**}
WS (mm)	4.70	4.92	4.80	0.08	0.000^{***}	0.000^{***}	0.071^{NS}
NPP	54.98	65.00	59.69	3.13	0.557^{NS}	0.000^{***}	0.004^{**}
NSPl	170.88	208.25	188.31	10.59	0.453^{NS}	0.002^{**}	0.001^{***}
TSW (g)	75.10	98.80	91.67	8.29	-	-	-

Min. Max: minimum and maximum mean for a population. Mean: value of the species. S. D. standard deviation. Pop x Y: population x year interaction. Date of emergence (DE); Autumn height (APH); Autumn width (APW); Winter height (WPH); Winter width (WPW); Autumn growth speed in height (AGS); Winter growth speed in height (WGS); Number of branches (NB); Date of appearance of first inflorescence (1F); Date end of flowering (EF); Flowering duration (DF); Date appearance of first pod (P1); Date of full pod formation (FP); Date of total drying (TD); Number of seeds per pod (NSP); Pod length (LP); Pod width (WP); Seed length (LS); Seed width (WS); Number of pods per plant (NPP); Number of seeds per plant (NSPl); Thousand-seed weight (TSW). Significance: $p^{*}\leq 0.05$; $p^{**}\leq 0.01$; $p^{***}\leq 0.001$; NS: not significant

Table 3. Homogeneous groups based on means of morpho-phenological and biometrical traits within eight local populations of *Pisum sativum* L. in the South-Western Algeria (Adrar) during two agricultural campaigns.

Populations names	Tinerkouk	Aougrout	Aoulef	Tamentit	Talmine	Inzghmir 1	Inzghmir 2	Ouaina
	Morpho-phenological and biometrical characteristics							
DE (days)	13.63^{a}	12.70^{a}	12.96^{a}	12.89^{a}	10.25^{b}	13.75^{a}	13.40^{a}	12.88^{a}
APH (cm)	10.63^{ab}	9.79^{bcd}	9.12^{d}	9.50^{cd}	10.84^{a}	10.26^{abc}	10.13^{abc}	9.03^{d}
APW (cm)	6.25^{bc}	6.72^{b}	5.81^{c}	6.87^{b}	8.41^{a}	6.95^{b}	6.35^{bc}	5.46^{c}
WPH (cm)	68.83^{NS}	70.45^{NS}	68.31^{NS}	69.05^{NS}	70.40^{NS}	67.71^{NS}	70.13^{NS}	66.70^{NS}
WPW (cm)	43.01^{abc}	43.40^{abc}	40.23^{c}	45.73^{a}	44.29^{ab}	42.32^{bc}	42.21^{bc}	46.04^{a}
AGS (cm/day)	0.50^{a}	0.43^{bc}	0.43^{bc}	0.42^{c}	0.39^{c}	0.47^{ab}	0.47^{ab}	0.41^{c}
WGS(cm/day)	0.63^{a}	0.66^{a}	0.64^{a}	0.63^{a}	0.56^{b}	0.63^{a}	0.66^{a}	0.63^{a}
NB	3.56^{bc}	3.71^{abc}	3.50^{c}	4.03^{a}	3.90^{ab}	3.70^{abc}	3.70^{abc}	3.60^{bc}
1F (days)	81.82^{c}	82.16^{c}	84.64^{ab}	82.49^{bc}	85.82^{a}	82.41^{bc}	82.73^{bc}	81.67^{c}
EF (days)	110.62^{b}	111.56^{b}	112.71^{ab}	112.47^{ab}	114.29^{a}	111.16^{b}	112.63^{ab}	112.84^{ab}
DF (days)	30.05^{NS}	30.55^{NS}	29.57^{NS}	30.97^{NS}	29.95^{NS}	30.08^{NS}	30.94^{NS}	31.46^{NS}
P1 (days)	90.71^{bcd}	92.40^{b}	91.54^{bc}	88.83^{d}	96.26^{a}	91.33^{bcd}	90.54^{bcd}	89.14^{cd}
FP (days)	106.45^{bc}	110.03^{a}	109.63^{a}	107.03^{b}	111.41^{a}	104.59^{c}	106.10^{bc}	105.70^{bc}
TD (days)	125.49^{bc}	125.08^{bc}	126.71^{ab}	125.96^{bc}	128.34^{a}	123.72^{c}	125.78^{bc}	125.21^{bc}
NSP	3.73^{ab}	3.60^{ab}	3.87^{a}	3.41^{b}	3.77^{ab}	3.85^{a}	3.92^{a}	3.77^{a}
LP (mm)	46.59^{ab}	45.79^{b}	46.89^{ab}	43.91^{c}	46.55^{ab}	46.81^{ab}	47.75^{a}	46.37^{ab}
WP (mm)	11.30^{a}	11.18^{a}	11.11^{ab}	10.97^{ab}	11.08^{ab}	11.08^{ab}	11.19^{a}	10.69^{b}
LS (mm)	5.30^{ab}	5.24^{ab}	5.36^{a}	5.05^{c}	5.15^{bc}	5.27^{ab}	5.27^{ab}	5.20^{bc}
WS (mm)	4.75^{b}	4.77^{ab}	4.86^{ab}	4.73^{ab}	4.92^{a}	4.73^{b}	4.74^{b}	4.70^{b}
NPP	59.93^{NS}	61.12^{NS}	54.98^{NS}	59.55^{NS}	60.05^{NS}	55.89^{NS}	65.00^{NS}	61.01^{NS}
NSPl	189.47^{NS}	186.61^{NS}	170.88^{NS}	180.95^{NS}	190.17^{NS}	187.21^{NS}	208.25^{NS}	192.93^{NS}
TSW (g)	98.80	87.58	86.07	97.40	75.10	97.45	93.52	96.40

Date of emergence (DE); Autumn height (APH); Autumn width (APW); Winter height (WPH); Winter width (WPW); Autumn growth speed in height (AGS); Winter growth speed in height (WGS); Number of branches (NB); Date of first inflorescence (1F); Date end of flowering (EF); Duration of flowering (DF); Date of appearance of the first pod (P1); Date of full pod formation (FP); Date of total drying (TD); Number of seeds per pod (NSP); Pod length (LP); Pod width (WP); Seed length (LS); Seed width (WS); Number of pods per plant (NPP); Number of seeds per plant (NSPl); Thousand-seed weight (TSW). Letters (a; b; c; d; e; f): homogeneous groups formed according to Tukey's post-hoc test. NS: not significant

Within the same family (*Fabaceae*), similar findings have been reported for varieties and ecotypes of *Vicia* genus in a semi-arid region in North-Eastern Algeria (Mebarkia *et al*., 2020; Mahmah *et al*., 2023). In a hyper-arid zone of Algeria, the local populations of *Medicago sativa* seem to have a similar and stable behaviour, from one year to another, despite the existence of an important morphological diversity (very significant variation), within and between the populations, during the same year (Chabouni *et al*., 2024).

Concerning the establishment on soil (DE), the general mean of the species was 12.81 days. The populations Talmine (10.25 days) was the fastest to emerge, while the populations Inzghmir 1 (13.75 days), Tinerkouk (13.63 days), Inzghmir 2 (13.40 days), Aoulef (12.96 days), Tamentit (12.89 days), Ouaina (12.88 days), Aougrout (12.70 days), were respectively, the slowest ones (Table 3).

Jandoubi *et al*., (2021) reported an average emergence of 13 days in several *Pisum sativum* accessions of Mediterranean origin, while Aman *et al*., (2021) recorded averages ranging from 9.33 to 16.67 days for Pakistani genotypes.

The results relating to vegetative development indicated that all the studied populations showed a more marked growth in winter than in autumn (Table 3).

The autumn development in height (APH) varies from 9.03 cm (Ouaina) to 10.84 cm (Talmine) while the autumn width (APW) varies from 5.46 (Ouaina) to 8.41 cm (Talmine).

Concerning the winter height, the best value was noted in Aougrout population (70.45 cm) and the weakest one was observed in Ouaina population (66.70 cm).

For the winter width, the most developed populations were, respectively, Ouaina (46.04 cm) and Tamentit (45.73 cm) while the weakest one was Aoulef (40.23 cm) (Table 3).

For the winter growth speed in height, the populations Aougrout and Inzghmir 2 were the best with a value of 0.66 cm / day while the weakest value was noted in Talmine population with 0.56cm / day (Table 3).

Plant height is one of the most important characteristics that determine the yield of a given crop (Aman *et al*., 2021). Difference in plant height might be due to genetic characteristic of genotypes and adaptability to a particular environment (Khan *et al*., 2013, 2017 b). On the other hand, some authors report that plant height is affected by the environment (Ceyhan *et al*., 2012; Solberg *et al*., 2015; Mohamed *et al*., 2019).

An experiment carried out in a sub-humid area of Algeria showed that the height of pea genotypes varied from 63.66 cm to 111.33 cm (Ouafi *et al*., 2016). The last values are higher compared to those recorded through the present study, where the populations grown in an hyper-arid region of Algeria.

Within the same species (*Pisum sativum*), different researchers obtained lengths varying respectively, between 65.67 and 126 cm in Southwest Pakistan (semi-arid region) (Khan *et al*., 2013), 65.67 and 132 cm in Turkey (semi-arid region) (Ceyhan & Avci, 2015), 51.20 and 111.30 cm in Bulgaria (humid region) (Georgieva *et al*., 2016), 65 and 111 cm in Southern Tunisia (arid region) (Mohamed *et al*., 2019), 47.67 and 182.3 cm in Northern Pakistan (humid region) (Aman *et al*., 2021), 48.01 and 83.61cm in Southwest Pakistan (semi-arid region) (Jilani *et al*., 2022) and 90.08 and 223 cm in India (humid region) (Kumari *et al*., 2023).

Furthermore. the present study indicated significant variation ($p \leq 0.001$) within populations (*Pisum sativum)* for traits related to flowering (1F; EF) and pod formation (P1) (Table 2).

Ouaina (81.67 days), Tinerkouk (81.82 days) and Aougrout (82.16 days) populations, were respectively the earliest to produce the first flowers (1F) (Table 3) while the populations Talmine (85.82 days) and Aoulef (84.64 days) were the latest ones. Concerning the end of flowering (EF), the populations Talmine was the latest (114.29 days) while the population Tinerkouk (110.62 days), Inzghmir 1 (111.16 days) and Aougrout (111.56 days) were, respectively, the earliest ones.

The flowering variation, observed among the different local populations of pea, will permit to extend the calendar of use of this plant. The variation recorded will thus help the farmers to ensure the availability of peas over a longer period.

Several studies have shown a wide diversity of flowering within genotypes and varieties of the species *Pisum sativum*: Gatti *et al*., 2011 (Argentina, humid region); Ouafi *et al*., 2016 (northern Algeria, sub-humid region); Chisti *et al*., 2018 (Pakistan, humid region) Mohamed *et al*., 2019; Jandoubi *et al*., 2021 (southern and northern Tunisia, respectively); Aman *et al*., 2021 (Pakistan, humid region) and Shrestha *et al*., 2023 (Nepal, humid region).

According to Wallace *et al*., (1993), flowering time is commonly considered to be the main trait influencing the adaptation of genotypes and populations within some species of *Fabaceae* family. In *Pisum sativum,* this trait is linked to the environment (Ouafi *et al*., 2016; Mohamed *et al*., 2019). Concerning the average number linked to the appearance of the first flowers, the result (82.97 days after emergence) seems to be lower than the average (109.25 days since sowing) reported by Ouafi *et al*., (2016) for *Pisum sativum* genotypes, established in a sub-humid region in Algiers (Algeria). However, it is higher than that reported by Mohamed *et al*., (2019) for local pea accessions (70.7 days since sowing) grown in an arid region (southern Tunisia). On the other hand, Jandoubi *et al*., (2021) reported an average of 94.72 days from emergence for *Pisum sativum* accessions originating from the Mediterranean basin. Shrestha *et al*., (2023) reported an average of 94.85 days in a germplasm of 122 pea accessions in Nepal.

Moreover, most of the characteristics relating to pods and seeds varied significantly within populations of the species *Pisum sativum* (Table 2).

The examination of these characteristics showed that the population Inzghmir 2 had the highest numbers of pods (NPP / 65) and seeds (NSPl / 208.25) per plant (Table 3).

The populations Tinerkouk (98.80 g), Inzghmir 1 (97.45 g), Tamentit (97.40 g) and Ouaina (96.40 g) stood out with the highest thousand-seed weight (TSW) values, respectively (Table 3).

The results of this study revealed that pea (*Pisum sativum*) populations coming from southern Algeria produced relatively long pods. The average pod lengths varied between 43.91 mm and 47.75 mm with a mean of 46.33 mm (Table 2). These values are close to the average length (50.8 mm) observed in pea genotypes from northern Algeria (Ouafi *et al*., 2016), as well as that recorded in Mediterranean genotypes (46.5 mm) (Jandoubi *et al*., 2021). However, the values remain slightly lower than those reported within Southern Tunisian genotypes (58.60 mm) (Mohamed *et al*., 2019), Pakistani genotypes (54.71 mm) (Aman *et al*., 2021) and a Nepalese germplasm (53.4 mm) (Shrestha *et al*., 2023).

On the other hand, the present work indicated that the populations are characterized by relatively wide pods (10.69 - 11.30 mm), with a mean pod width of 11.08 mm (Table 2), compared with genotypes from northern Algeria (7.8 mm) (Ouafi *et al*., 2016). The results of the present study showed that the populations are also relatively close to pods of Mediterranean genotypes (11.2 mm) (Jandoubi *et al*., 2021) and those from southern Tunisia (13.61 mm) (Mohamed *et al*., 2019). However, population widths are significantly lower than those observed by Shrestha *et al*., (2023) on Nepalese germplasm, where the average pod width reached 57.4 mm.

For the number of seeds per pod (NSP), the results indicated a relatively low average number (3.74), compared to the general mean (6.91) observed by Ouafi *et al*., (2016) on pea genotypes in northern Algeria. In Tunisia, Mohamed *et al*., (2019) and Jandoubi *et al*., (2021) observed 5.05 and 4.09, respectively, for the numbers of seeds per pod. In Turkey (Ceylan & Avci, 2015), Pakistan (Aman *et al*., 2021), and India (Lal *et al*., 2018; Kumari *et al*., 2023), different studies reported averages of 4; 4.26; 5.98 and 6.49, respectively.

Moreover, the thousand-seed weight (TSW) results (Table 2) are relatively close (75.10 g - 98.80 g) to the TSW (81.85 g) observed by Mohamed *et al*., (2019) in genotypes from southern Tunisia. Nevertheless, they are relatively lower than the TSW (123 g) reported by Benbrahim & Gaboun (2008), in seven *Pisum sativum* genotypes, of Moroccan and Ethiopian origin, evaluated in a semi-arid region of Morocco, as well as that (TSW) of genotypes from Bulgaria (198.63 g) (Georgieva *et al*., 2016).

Previous work, conducted in a sub-humid region of northern Algeria, reported 100-seed weights ranging from 8.04-18.64 g in pea genotypes (Ouafi *et al*., 2016). Shrestha *et al*., (2023) reported a 100-seed weight of 10.79 g in a Nepalese germplasm.

The weight of a thousand seeds gives an idea of the real size of the seeds (Lesins & Lesins, 1979).

The variation in thousand seed weight seems to depend on origin region of the pea genotypes.

Concerning the number of pods per plant (NPP), the results obtained through our present study appear to be lower (59.69) than those obtained from Tunisian local pea over three consecutive years, with respective averages of 130.58 ; 105.93; 64.94 and an overall average of 100.38 pods per plant (Mohamed *et al*., 2019). However, the results of the present work are higher than the numbers (15 to 37.67 pods per plant) reported by Aman *et al*., (2021) within *Pisum sativum* genotypes in Northern Pakistan (humid region) and those ranging from 15.01 to 18.64 and 13.39 to 19.34 pods per plant over two years of study in Southwest Pakistan (semi-arid region) (Jilani *et al*., 2022). In India, Lal *et al*., (2018) and Kumari *et al*., (2023) reported, respectively, 10.89 to 26.06 and 25.50 to 45.80 pods per plant.

Khan *et al*., (2013) and Singh *et al*., (2017) consider the number of pods per plant as a very useful yield component. The presence of significant genetic variation in pod formation within *Pisum sativum* has been reported by several authors (Ashraf *et al*., 2011; Kosev *et al*., 2013; Kumar *et al*., 2016; Dar *et al*., 2017; Khan *et al*., 2017b; Mohamed *et al*., 2019; Rahman *et al*., 2019 and Jilani *et al*., 2022).

For the number of seeds per plant (NGPl), the results, obtained in the eight populations of *Pisum sativum* vary from 170.88 to 208.25 with a mean of 188.31. Ceyhan & Avci (2015) reported a number varying between 72.50 and 187.50 in Turkey and Khan *et al*., (2017b) indicated 78.33 to 291.00 in Bangladesh. According to Avci & Ceyhan (2013), an increase in the number of grains per unit area is associated with an increase in yield per hectare.

The results observed in different areas indicate that the environment would have an influence on the development of local populations.

Matrix of correlations: Several significant correlations were noted between the morpho-phenological and biometrical traits (Table 4).

The populations characterized by an early emergence (DE), present an important autum width (APW), a weak autumn growth speed in height (AGS), a weak winter growth speed in height (WGS), a late end of flowering (EF), a late appearance of the first pod (P1), a late total drying (TD), a weak number of seeds per pod (NSP), a relatively high seed width (WS) and a weak thousand-seed weight (TSW).

The populations characterized by an early appearance of the first flowers (1F), presented a late date of emergence (DE), an early end of flowering (EF), an early appearance of the first pod (P1), a weak seed width (WS) and a high thousand-seed weight (TSW).

Populations with an early flowering (1F; EF), reached maturity early (P1; TD). A similar finding has been made by several authors (Chaudhary and Sharma, 2003; Espósito *et al*., 2009; Ghobary, 2010; Gatti *et al*., 2011 and Shrestha *et al*., 2023) in the same species (*Pisum sativum*).

However, within the same family (*Fabaceae*), the study carried out by Chabouni *et al*., (2024) on various populations of perennial alfalfa (*Medicago sativa* L.), from southern Algeria, reveals that precocity is an adaptive advantage for these populations, in overcoming the severe environmental constraints, specific to this region.

Smitchger & Weeden (2018) and Aman *et al*., (2021) reported that increasing pod length in *Pisum sativum* species leads to an increase in the number of seeds per pod, which is in fact an important yield determining trait.

Similar studies have been reported by several authors in *Pisum sativum* (Gatti *et al*., 2011; Ramzan *et al*., 2014; Ouafi *et al*., 2016; Bhuvaneswari *et al*., 2016; Rahman *et al*., 2019 and Aman *et al*., 2021).

Moreover, the results of correlation matrix showed some relations between the morpho-phenological characteristics and an ecological factor (altitude), characterizing the origin environment of the local populations (*Pisum sativum*) (Table 5). The rainfall and temperature don't seem to intervene on the behaviour of the local populations. Thus, the results of correlations, considered separately (for each year), indicated that the Algerian populations of pea, coming from high altitude areas, showed respectively, an early date of emergence (DE) (2018/2019) and a short duration of flowering (DF) (2019/2020).

Previous studies pointed of the influence of at least one ecological factor of the origin environment (altitude, rainfall, temperature) on the characteristics linked to the behaviour, phenology and biometry of Algerian populations belonging to the *Fabaceae* family, more particularly the genera *Medicago*, *Hedysarum* and *Trifolium* (Si & Abdelguerfi, 1995; Chebouti & Abdelguerfi, 1999; Issolah & Abdelguerfi, 2003; Issolah & Khalfallah, 2007; Issolah, 2018; Abdi *et al*., 2020; Enkhbat *et al*., 2021; Bouziane *et al*., 2023; Chabouni *et al*., 2024).

In the case of *Medicago sativa* (*Fabaceae*), a trial conducted over two consecutive years, under the same climatic conditions (hyper-arid region), showed that the rainfall and the temperature (provenance environmental factors) acted on almost the totality of the studied characteristics, whereas the effect of the altitude seems to be of less importance (Chabouni *et al*., 2024).

Table 4. Relationships between the morpho-phenological and biometrical characteristics within eight local populations of *Pisum sativum* in the South-Western Algeria during two years (2018/2019 and 2019/2020).

Characteristics	DE	APW	WPW	1F	FP	LS	WS	NPP
DE	-	-0.713	-0.299	-0.765	-0.788	0.495	-0.839	-0.081
	-	**0.047***	0.472	**0.027***	**0.023***	0.212	**0.009****	0.848
AHP	-0.296	0.717	-0.094	0.244	0.118	-0.018	-0.136	0.194
	0.476	**0.045***	0.824	0.561	0.781	0.967	0.749	0.646
APW	-0.713	-	0.148	0.580	0.482	-0.459	0.349	0.014
	0.047*	-	0.727	0.131	0.226	0.252	0.397	0.975
AGS	0.772	-0.334	-0.455	0.527	-0.577	0.596	-0.835	0.035
	0.025*	0.419	0.257	0.180	0.134	0.119	**0.010****	0.934
WGS	0.825	-0.691	-0.298	-0.690	-0.410	0.411	-0.733	0.140-
	0.012*	0.058	0.473	-0.058	0.313	0.312	**0.038***	0.740
NB	-0.467	0.710	0.572	0.201	0.178	-0.659	-0.008	0.211
	0.244	0.053	0.138	0.633	0.673	**0.004****	0.494	0.616
EF	-0.809	0.379	0.246	0.733	0.533	-0.459	-0.839	0.162
	0.015*	0.354	0.557	0.039*	0.174	0.252	**0.009****	0.702
DF	0.173	-0.333	0.717	-0.604	-0.444	-0.543	-0.186	0.663
	0.682	0.421	**0.045***	0.112	0.271	0.164	0.660	0.073
P1	-0.784	0.769	-0.214	0.773	0.746	0.116	0.481	-0.090
	0.021*	**0.026**	0.611	**0.024***	**0.034***	0.971	0.227	0.833
DT	-0.825	0.463	0.033	0.837	0.767	-0.287	0.843	0.086
	0.012*	0.248	0.939	0.010	**0.026***	0.491	**0.008****	0.840
NSP	0.832	0.014	0.380	-0.280	0.682	0.630	-0.595	-0.098
	0.010**	**0.037***	0.195	0.317	0.062	0.094	0.120	0.817
LP	0.105	-0.154	-0.623	0.184	-0.096	0.721	-0.225	0.120
	0.804	0.716	0.099	0.663	0.821	**0.043***	0.593	0.778
LS	0.495	-0.459	-0.873	-0.027	-0.117	-	-0.399	0.344
	0.212	0.252	**0.005****	0.950	0.782	-	0.327	0.405
WS	-0.839	0.349	0.245	0.764	0.698	-0.399	-	-0.211
	0.009**	0.397	0.559	**0.027***	0.054	0.327	-	0.616
NSPl	0.052	0.059	0.202	-0.279	-0.362	-0.116	-0.402	0.851
	0.902	0.889	0.631	0.503	0.379	0.784	0.323	**0.007****
TSW	0.875	-0.601	0.154	-0.880	-0.998	0.098	-0.731	0.054
	0.004**	0.115	0.716	**0.004****	**0.002****	0.817	**0.039***	0.899

(DE) Date of emergence; Autumn height (APH); Autumn width (APW); Winter height (WPH); Winter width (WPW); Autumn growth speed in height (AGS); Winter growth speed in height (WGS); Number of branches (NB); Date of first inflorescence (1F); Date end of flowering (EF); Duration of flowering (DF); Date of appearance of the first pod (P1); Date of full pod formation (FP); Date of total desiccation (TD); Number of seeds per pod (NSP); Pod length (LP); Pod width (WP); Seed length (LS); Seed width (WS); Number of pods per plant (NPP); Number of seeds per plant (NSPl); Thousand-seed weight (TSW); Cell content : Pearson correlation coefficient and probability: $p^{*} \leq 0.05$; $p^{**} \leq 0.01$; $p^{***} \leq 0.001$

Table 5. Relationships of morpho-phenological and biometrical characteristics with ecological factors of the origin environments within eight local populations of *Pisum sativum* in the South-Western Algeria during two years (2018/2019 and 2019/2020).

Ecological factors / Characteristics	Altitude		Rainfall		Temperature	
	Year 2018-2019	Year 2019-2020	Year 2018-2019	Year 2019-2020	Year 2018-2019	Year 2019-2020
DE	- 0.75	-0.10	-0.42	-0.26	0.50	0.22
	0.031*	0.821	0.301	0.528	0.204	0.599
APH	0.60	0.01	0.50	0.35	-0.48	-0.18
	0.117	0.978	0.204	0.399	0.230	0.662
WPH	0.05	0.11	-0.17	0.47	0.10	-0.39
	0.910	0.999	0.691	0.317	0.518	0.387
1F	0.23	0.04	-0.13	-0.28	0.06	0.27
	0.509	0.933	0.756	0.509	0.885	0.518
EF	0.12	-0.22	-0.05	-0.07	0.01	0.11
	0.778	0.555	0.910	0.866	0.999	0.795
DF	-0.06	-0.71	0.30	-0.37	-0.25	0.45
	0.888	**0.049***	0.471	0.365	0.558	0.258
P1	0.63	0.24	0.37	0.07	-0.42	-0.06
	0.091	0.568	0.365	0.866	0.304	0.885
FP	0.68	0.49	0.30	0.20	-0.41	-0.28
	0.062	0.217	0.471	0.629	0.319	0.498
NSP	-0.30	-0.54	-0.63	-0.49	0.63	0.58
	0.471	0.168	0.091	0.217	0.097	0.134
WP	0.29	0.23	-0.17	0.42	0.12	-0.43
	0.470	0.586	0.691	0.298	0.772	0.293
WS	0.34	0.19	0.02	0.01	-0.14	0.01
	0.414	0.658	0.955	0.989	0.748	0.988
NPP	0.42	0.02	-0.01	0.38	-0.11	-0.33
	0.301	0.955	0.978	0.349	0.795	0.423
NSPl	0.30	-0.38	-0.01	0.07	-0.14	0.09
	0.471	0.349	0.975	0.886	0.750	0.840
TSW	-0.14	-0.06	0.20	0.32	-0.16	-0.16
	0.744	0.888	0.637	0.435	0.704	0.706

(DE) Date of emergence; Autumn height (APH); Winter height (WPH); Date of first inflorescence (1F); Date end of flowering (EF); Duration of flowering (DF); Date of appearance of the first pod (P1); Date of full pod formation (FP); Number of seeds per pod (NSP); Pod width (WP); Seed width (WS); Number of pods per plant (NPP); Number of seeds per plant (NSPl); Thousand-seed weight (TSW); ecological factors of the environment of origin (Altitude, Rainfall, Temperature); cell content: Pearson correlation coefficient and probability: $p^* \leq 0.05$; $p^{**} \leq 0.01$; $p^{***} \leq 0.001$

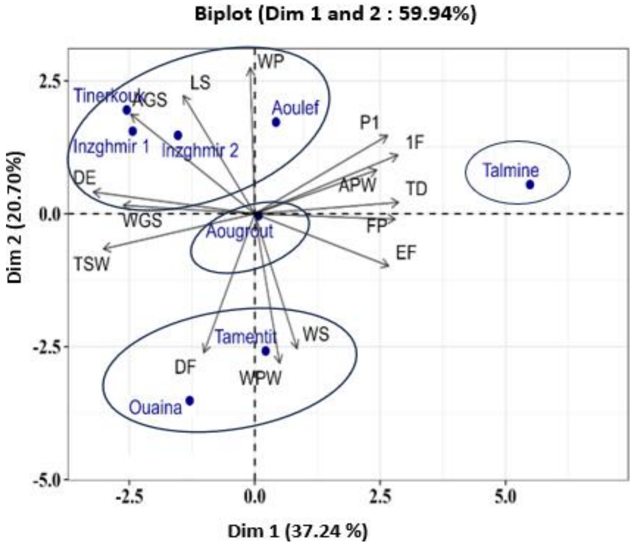

Fig. 1. Principal component analysis (PCA) of morpho-phenological and biometrical characteristics within Algerian populations of *Pisum sativum* L. in the South-Western of Algeria.

Principal component analysis: To better illustrate the relationships that exist between morpho-phenological and biometrical characteristics, within the eight local populations of *Pisum sativum*, a principal component analysis (PCA) was carried out on the basis of the twenty-two (22) variables (Fig. 1).

The principal component analysis (PCA) permitted to identify four (04) distinct population groups.

Axes 1 and 2 explain 59.24% of the observed total variation (Fig. 1). Axis 1 is positively associated with autumn height (APH), phenological variables related to flowering (1F, EF), pods formation (1P, FP), and total drying (TD). However, it was negatively correlated with the emergence date (DE), autumn growth speed in height (AGS), winter growth speed in height (WGS) and thousand-seed weight (TSW). Axis 2 is positively associated with width of the pods (WP), seed length (LS), and it was negatively associated with winter width (WPW), duration of flowering (DF) and seed width (WS).

The representation of populations on the factorial plane 1-2 (Fig.1) showed a contrast between two groups.

The group 1 (Talmine) is characterized by a population presenting vigorous vegetative development and a longer development cycle, with late flowering, pod formation and drying.

The group 2 (Tinerkouk, Inzghmir 1, Inzghmir 2 and Aoulef) comprises populations which are late at emergence (DE), have a good speed development in autumn (AGS) and winter (WGS), a high weight of seeds (TSW). Moreover, they stand out for their precocity concerning the flowering, pod formation and drying.

The group 3 (Tamentit and Aouina) is characterized by populations with a good winter width development (WPW), a relatively long flowering period (DF), small pods and seeds.

The group 4 (Aougrout) would be different and distinct from the others groups of populations without any specific characteristics.

Various studies carried out in different regions have reported that morphological, phenological (flowering) and production traits contribute to distinguishing genotypes (Wani *et al*., 2013; Gixhari *et al*., 2014; Ouafi *et al*., 2016; Aman *et al*., 2021; Aybegün *et al*., 2022). In the same context, Mohamed *et al*., (2019) reported the same findings on several local accessions of *Pisum sativum* from arid regions in southern Tunisia.

Tar'an *et al*., (2005) indicated that the majority of cultivars (*Pisum sativum*) intended for human or animal consumption formed a distinct group from cultivars for silage or specific purposes. Within *Pisum sativum* L., the results of correlation and principal component analysis showed that the number of seeds per plant, height, biomass, length and area of tendrils, date of emergence and date of flowering, can be decisive in the selection criteria of high yields (Mani & Hannachi, 2015).

In the same family (*Fabaceae*), Chabouni *et al*., (2024) reported that good yields are associated with the earliness of *Medicago sativa* L. populations. In *Vicia* genus, Mahmah *et al*., (2023) found that early-flowering ecotypes of *Vicia narbonensis* L. produced better yields than late-flowering ecotypes in the semi-arid region of Setif (Algeria).

Conclusion

This study identified several local populations of the species *Pisum sativum* L. in South-Western Algeria.

The analysis of variance revealed significant differences, for most of the characteristics. Significant variation was recorded in the phenological stages linked to vegetative development, flowering and pod formation, as well as in the biometrical characteristics relating to production.

Interaction analysis indicates a strong influence of the environment (Year) on all the morpho-phenological characteristics of the local pea populations, whereas this influence would be lesser on biometrical characteristics, which seem to be relatively more stable.

The correlation matrix revealed also several significant correlations between morphological, phenological and biometrical characteristics.

In addition, the results of this study revealed the existence of significant relationships between some phenological traits (emergence date and flowering duration) and an ecological factor (altitude) characterizing the provenance environments of populations. Thus, the local populations of pea, coming from high altitude areas, showed an early date of emergence and a short duration of flowering.

Principal component analysis (PCA) revealed a wide morpho-phenological and biometrical variation within local populations and permitted to distinguish four (04) groups of local populations (G1: Talmine / G2: Inzghmir 1, Inzghmir 2, Aoulef, Tinerkouk/G3: Tamentit, Ouaina/G4: Aougrout).

The group 2 (Inzghmir 1, Inzghmir 2, Aoulef, Tinerkouk) and 3 (Tamentit, Ouaina) present, each one, some local populations with similar behaviour and characteristics whereas the others two groups contain only one population (Talmine / G1 and Aougrout / G4).

The group 4 (Aougrout) would be totally different and distinct from the other populations without any specific characteristics.

This finding would enable farmers and stockbreeders to choose one or more local pea populations, depending on the targeted characteristics and objectives.

The characteristics of these populations constitute a very valuable database with a view to facilitating the exploitation of the observed variation in a subsequent breeding programme. The obtained results permit to know more about the diversity of fodder in the southern region of Algeria, which is essentially based on perennial alfalfa (*Medicago sativa*).

Developing local populations of *Pisum sativum* would contribute to the diversification and development of legumes for both human and animal consumption, thus enabling the development of livestock farming and its products and consequently improving the standard of living of local populations in this hyper-arid region of the country.

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(Received for publication 10 June 2024)