Research Article

Evaluation and Adaptation of Cameline (*Camelina sativa*) Crantz L in Semi-Arid Algeria

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Abstract | *Camelina sativa* L., is a species of oilseed plant in the Brassicaceae family, recently introduced in Algeria. *Camelina* has been the subject of several research studies and should be proposed as an alternative crop. The trials were carried out during the 2021/2022 agricultural campaign; the objective of which was to evaluate the varietal diversity of *Camelina sativa* in Setif (Eastern Algeria). The trials were carried out in a completely randomized block design with four replicates. Mean differences in emergence, number of days to 50% flowering, number of siliques, number of seeds per silique, thousand kernel weight, seed and oil yield, and oil content between the seven varieties were significant (p<0.05). The results of Principal Component Analysis (PCA) show that variety V7 (Alba) performs best of the agronomic parameters: It produces 344 plants per square meter and is the earliest, lasting 104 days from sowing flowering, it produced the highest seed yield, at 1.8 t/ha. Analysis of variance showed that Alba (V7) was the best variety in terms of oil yield and oil content, with 345g/kg and 34.5%, respectively.

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Introduction

Algeria is currently calling for intensified efforts to improve and increase the production of vegetable oils for food and industrial use as an alternative to oil, given that over 45% of the country's used edible oils are imported. This would solve the problem by promoting the cultivation of oilseeds.

Oilseed production in Algeria is very limited in terms of cultivated area and choice of species and varieties adapted to the soil and climate conditions of each region. This calls for a search for new, better-performing varieties to ensure satisfactory, high-quality production. One of the main problems in arid and semi-arid regions is the fluctuation and insufficiency of rainfall (Lobell *et al*., 1980). As a result, drought, salinity and low temperatures have become critical problems that seriously threaten the agricultural production of many oilseed crops (Mohammed *et al*., 2017). These disadvantages call for the introduction of resistant and drought-tolerant crops that can perform better in environments with low water availability, in order to guarantee food security. Over the past decade, *Camelina sativa* has emerged as an alternative species for diversifying vegetable oil production. Plants of this species can tolerate temperatures as low as -2 °C, which can cause serious damage to other oilseed crops (Robinson, 1987). This species should therefore be adapted to semi-arid and arid zones, as it is resistant to cold, drought and insufficient water (Zanetti *et al*., 2017). *Camelina sativa* is a winter annual that develops a taproot. The plant is erect and reaches a height of 30 to 90 cm (Putnam *et al*., 1993; Francis and Warwick, 2009).

Vollmann *et al*. (2007) indicate that species is an early crop due to its rapid vegetative growth. The seeds of this plant contain between 28% and 40% oil, making it a promising crop in view of the growing demand for vegetable oils (Eidhin *et al*., 2003). *Camelina sativa* oil is a valuable source of omega-3 fatty acids essential for human well-being. Several studies have shown that *Camelina sativa* meal can be used as an ingredient in livestock and poultry feed (Francis and Warwick, 2009). *Camelina sativa* oil is used not only in the food industry. But also in the cosmetics industry, due to its high levels of antioxidant activity. The resulting products include face and body creams, shampoos and other cosmetics (Lonescu *et al*., 2015; Quéro *et al*., 2016; El-Bassam, 2010).

Camelina sativa can be grown successfully with supplemental irrigation in semi-arid conditions, giving respectable seed yields (Lohaus *et al*., 2020). It requires less water than other oilseed crops matures early and can grow in both cool and dry climates. The aim of this study is to determine and evaluate the agronomic performance and adaptation of seven varieties of winter *Camelina sativa* in the high-altitude semi-arid zone of Algeria.

Experimental

Description and location of experimental site: The experimental site has been set up for the period 2021/2022 at the National Institute of Agronomic Research of Algeria, Setif unit; the trial is characterized by the following geographical coordinates: 36°09'55"N and 5°22'15"E, with an altitude of 983 meters. the site soil is aridisol with a low organic matter content (<1%) and an alkaline pH of 8.40 in the first 40 cm. Soil analysis was carried out at the Sidrra Fertial agronomic laboratory. The soil has a very low phosphorus concentration (0.8 ppm), low nitrogen content (0.08%) and a normal potassium concentration (0.6 meq/ 100 g).

The region's climate is semi-arid, characterized by hot summers and cold winters. Infoclimat, 2022 presents average monthly temperatures and rainfall during the crop cycle (varieties are studied under rain-fed systems) (Table 1).

Rainfall and temperature fluctuations were generally in line with historical data throughout the semi-arid zone. However, during the emergence stage, a frost storm hit all the treatments (microplots) in the crop, resulting in a reduction of around 30% in the number of plants emerging, with a consequent drop in yield. Nevertheless, the experimental site benefited from a cumulative amount of precipitation (>300 mm), capable of satisfying the water requirements of the *Camelina sativa* crop, as indicated by Hergert and al. (2016).

Plant material and experimental setup: Seven varieties of *Camelina sativa* were the subject of this study. *Camelina sativa* was first introduced to Algeria through the 4CEMED project as part of the PRIMA program. The experimental setup used was a completely randomized block design with four replicates. The surface area of the individual plots was 6 m^2. The inter-block spacing was 2 m, while the inter-plot spacing was 0.4 m.

The previous crop was winter barley (*Hordeum vulgare* L.), grown as seed. The conventional technique was used for tillage, where the plot was ploughed deeply

Table 1: *Average monthly temperatures and precipitation for the 2021-2022 crop year (Infoclimat, 2022).*

Month	Sep	Oct	Nov	Dec	Jan	Feb	March	April	May	June	Total
Temperature (°c)	24.2	15.1	8.8	7	4.8	7.5	9	11.8	17.8	26.8	
Precipitation (mm)	38	8.2	83.8	20.6	11.8	28.2	47.8	78.8	6	0.4	323.6

in autumn, using a disc plough, followed by two overlaps of a cover-crop. Ground fertilization was carried out before sowing, using Monoammonium Phosphate, (MAP) (12.52.0); and NPK (4.20.20). Sowing was carried out in 28 December 2021 using an experimental six-row drill, with a sowing density of 600 seeds/m^2.

Eight parameters were studied during the trial: Number of plants emerged per square meter (in January), number of days to flowering (in April), and number of siliques per plant (late April and beginning may), number of seeds per silique (in May), and thousand kernel weight (TKW) (July), actual seed yield and oil yield, and oil extraction rate (September 2022).

Statistical analysis

Data were analyzed statistically using COSTAT version 6.4 and Statistica version 8software. Cultivated varieties were compared by Analysis of Variance (ANOVA), Correlation Analysis and Principal Component Analysis (PCA). The comparison of significant means was recorded by the Least Significant Difference (LSD) test at the 5% probability threshold (Steel *et al*., 1997).

Results and Discussion

A descriptive analysis was carried out to evaluate the results obtained. The highest coefficient of variation was recorded for the grain yield parameter at 32.5%, followed by the number of siliques/plant with a coefficient of variation of 26.66%. The other parameters showed coefficients of variation medium to low.

The ANOVA results indicate significant to highly significant variety effects for the parameters studied. The ANOVA results reveal significant variability between the different varieties tested, which justifies the analysis of varieties for selection with a view to improving productivity and appreciating the degrees of adaptation of *Camelina* cultivation in semi-arid zones (Table 2).

Camelina sativa varietal characteristics

The results concerning the number of emerged plants per square meter show significant differences for the variety factor studied. Although the LSD test and the comparison at a 5% threshold reveal the appearance of four homogeneous groups, Average values show that the variety Alba (V 7) has a high number of emerged plants with 344 plants/m^2, followed by the variety V3 with 300 plants /m^2, while the varieties V1, V5, V6, V2 and V4 have fewer than 260 plants m^{-2}.

The means for the effect of variety on the 50 % flowering period are shown in the comparison diagram. Analysis of variance revealed highly significant differences at 50 % flowering.

For the number of siliques per plant parameter, the results showed highly significant statistical effects. The variety Alba (V7) showed the highest value in terms of number of siliques, with over 297 siliques per plant. In contrast, V6 showed a low value of around 139 siliques. The other varieties recorded intermediate averages. Duncan's post-hoc test clearly separated the varieties into six homogeneous groups.

Table 2: *Mean values, coefficient of variation and probability at the 5% threshold for the parameters studied.*

Coded	Variety	NPE/m^2	NDF50 %	NS/P	NSe/S	TKW (g)	Seed yield (kg/ha)	Oil yield (g/kg)	Oil content (%)
CCE26	V1	256	110.5	146.5	16.75	0.81	1158	230	23
CCE29	V2	219	109.75	178.25	7.5	0.98	1126	265	26.5
CCE42	V3	300	110.5	232.5	10.75	0.97	778	285	28.5
CCE43	V4	194	128	225.5	13.25	0.84	654	250	25
CCE44	V5	245	108.5	207	12	0.9	803	285	28.5
CCE117	V6	241	107.25	139.25	9	0.98	1178	240	24
Alba	V7	344	104.25	297.45	7.25	1.05	1820	345	34.5
	CV (%)	20.36	0.72	26.66	9.81	9.52	32.7	13.4	13.4
	P < 0.05	0.01*	0.000***	0.009**	0.000***	0.089*	0.0038**	0.0058**	0.0058**
	Variety mean	257	111,25	203.77	10.93	0.93	75.17	1900	190

: significant, **: highly significant, *: very highly significant. NPE/ m^2/number of plants emerging per m^2, NDF50 % number of days to 50% flowering, NSe/S : number of seeds per silique, NS/P : number of siliques per plant, TKW : Thousand kernel Weight. CV: coefficient of variation P < 0.05: probability at the 5% threshold.*

These results on the number of grains per silique express very highly significant differences for the variety factor studied. Although the Duncan test and the 5% threshold comparison revealed the appearance of seven overlapping homogeneous groups, the mean values of the effect of the variety factor studied on the number of grains per silique are illustrated on the comparison diagram in Figure 1.

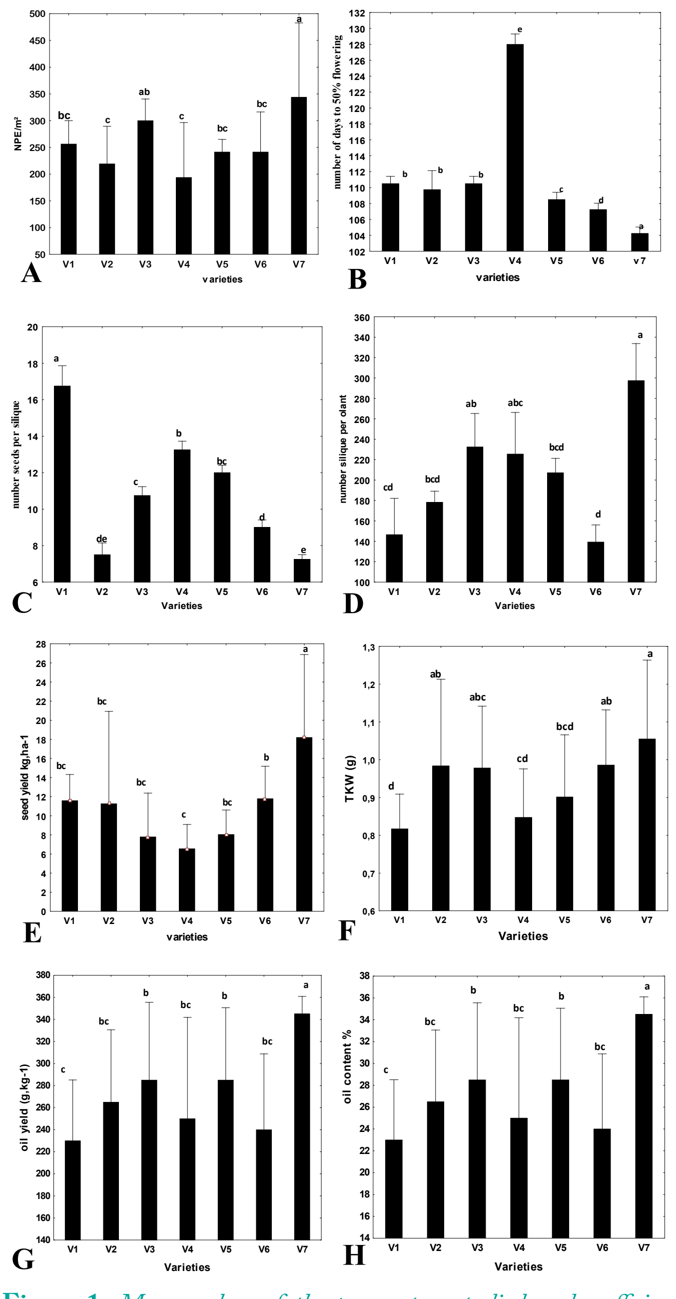

Figure 1: *Mean values of the parameters studied and coefficient of variation for the seven varieties of Camelina. (A) varieties for number plants emergence/m^2; (B) varieties for number of days to 50% flowering; (C) varieties for number seeds per silique; (D) varieties for number silique per plant; (E) varieties for seed yield; (F) varieties for thousand-seed weight (TKW g); (G) varieties for oil yield (g/kg); (H) varieties for oil content.*

Grain yield variation

Observation of the behavior of plants of the seven varieties for the variety factor revealed heterogeneity in the final grain yield parameter of *Camelina*. Analysis of variance (ANOVA) showed a highly significant difference. Among the different varieties, CCE43 (V4) had the lowest average grain yield at maturity, at 654kg per hectare, while Alba (V7) had the highest, at 1820 kg per hectare. The rest of the varieties gave intermediate averages. This effect was explained by the clear separation of the different homogeneous groups of the factor studied. Duncan's post-hoc test revealed the appearance of four homogeneous groups.

Analysis of variance (ANOVA) of the thousand kernel weight (TKW) parameter showed a significant difference. In the light of the results obtained, we note that the highest average was recorded for the variety Alba with 1.05 g, while the other varieties gave intermediate averages. Duncan's post-hoc test clearly separates the varieties in our trials into six distinct homogeneous groups.

The results of the analysis of variance and the mean values of the effect of the varietal factor studied on yield and oil extraction rate are shown in the comparison diagrams in Figure 1E, G. The variety Alba showed the highest oil yield and the highest oil extraction rate, with 345g/kg and 34.5%, respectively. Variety V4, on the other hand, showed only low values, with 230g/kg and 23%, respectively. The other varieties showed intermediate averages. Duncan's post-hoc test revealed the existence of four overlapping homogeneous groups for both parameters.

Correlation analysis and principal component analysis (PCA)

Analysis of Table 3 correlations shows that most of the traits exhibit significant associations. The emergence trait showed a positive correlation with number of siliques per plant, thousand grain weight, seed yield, oil yield and oil content, with correlation coefficients of r= 0.60, r= 0.60, r= 0.66 and r= 0.76, respectively. Thus, this parameter showed a negative correlation with earliness (r=-0.66). The number of days to 50% flowering showed a positive correlation with number of seeds/silique (r=0.44), and negative correlations with TKW (-0.62), seed yield (r=-0.65), yield and oil rate with a correlation of r=-0.42. Number of siliques/plant gave positive correlations with TKW, oil yield and oil rate at r= -0.44, r= -0.89, r= -0.89, respectively. For number of seed/silique showed negative correlations with TKW, seed yield,

Table 3: *Means, minima, maxima, coefficient of variation and standard error for the parameters studied.*

Variables	NPE/m^2	NDF50%	NS/P	NSe/S	TKW (g)	Seed yield (kg/ha)	Oil yield (g/kg)	Oil content (%)
NPE/m^{22}		-0.66	0.60	-0.32	0.60	0.66	0.76	0.76*
NDF50%	-0.66		0.006	0.44	-0.62	-0.65	-0.42	-0.42
NS/P	0.60	0.006		-0.37	0.44	0.29	0.89	0.89
NSe/S	-0.32	0.44	-0.37		-0.94	-0.48	-0.59	-0.59
TKW (g)	0.60	-0.62	0.44	-0.94		0.60	0.69	0.69
seed yield (kg/ha)	0.66	-0.65	0.29	-0.48	0.60		0.54	0.54
oil yield (g/kg)	0.76	-0.42	0.89	-0.59	0.69	0.54		1.00
oil content (%)	0.76	-0.42	0.89	-0.59	0.69	0.54	1.00	

NPE/ m^2/number of plants emerging per m^2, NDF50%: number of days to 50% flowering, NSe/S: number of seeds per silique, NS/P: number of siliques per plant, TKW: thousand kernel weight.

oil yield and oil content with correlation coefficients of r=-0.94, r=-0.48, r=-0.59 and r=-0.59.

Principal component analysis (PCA) is used to study the relationship between measured parameters and *Camelina* varieties. The 2 PCA axes studied account for 82.5% of the total variance, which is highly significant. The first axis, with 65.17% of variance, correlates positively with number of days to flowering and number of seeds/silique, and negatively with number of silique/plant, oil content, oil yield and number of emerged plants/m^2. Along this axis, the varieties V4 and V1 are opposed to the Alba variety V7 and V3. Axis 2 is negatively correlated with thousand kernel weight (TKW) and seed yield (Figure 2).

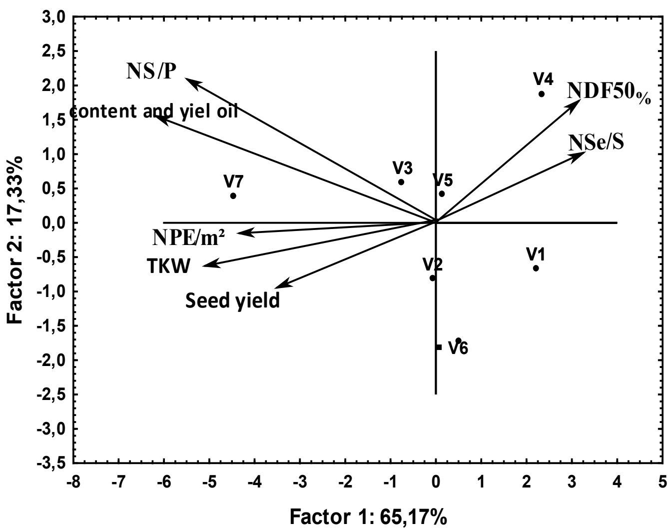

Figure 2: *Principal component analysis of measured variables and the factor studied (varieties). Factor 1, correlates positively with NDF 50$_{\%}$ and NSe/S, and negatively with NS/P, content and yield oil, along this factor, V4 and V1 are opposed to the variety Alba and V3. is negatively correlated TKW and seed yield.*

The V4 variety showed a shorter period with 128 days, while the Alba variety showed a shorter period with 104 days. Duncan's post-hoc test revealed five homogeneous groups. According to research by Lily *et al.* (2021), similar values were found for the flowering period (85 to 125 days) and it was noted that flowering is significantly affected by seed type. Thus, environmental and genetic factors can influence the flowering period. Early flowering is essential for local adaptation and to maximize *Camelina* yield (Lily *et al.*, 2021). Flowering is also strongly influenced by temperature and genotype (Angelini *et al.*, 2020).

According to the work of Czarnik *et al.* (2018), the number of siliques per plant can range from 60 to 115 siliques per plant. This result was consistent with the general principle stated by Bradshaw (1965), according to which stable parameters are often associated with the number of siliques on the main branch. Furthermore, results obtained by Czarnik *et al.* (2018) indicate that the aforementioned parameter changes are positively and negatively correlated with nitrogen fertilization as well as with an increase in sowing density and date (Angelini *et al.*, 2020). For the number of grains per silique. Variety V1 produced the highest number of seeds, with more than 16 seeds per silique, while varieties V2 and Alba had less than 8 seeds per silique. This finding is in line with the body of research on fruits, also known as siliques, which contain up to 25 seeds per silique (Schuster and Friedt, 1998).

Field trials carried out by Agegnehu and Honermeier (1997) in Austria revealed average yields of 1440 kg/ha, varying between 820 and 1950 kg/ha. This research confirms our findings on the effects of variety on grain yield at maturity. In fact, camelina had a yield potential comparable to that of other cruciferous oil seeds (Putnam *et al.*, 1993; Budin *et al.*, 1995).

Differences observed between varieties for oil yield and oil content, are probably due to the genetic potential of each variety. According to research by Berti *et al.* (2011), seed oil yield varied between 420 and 457 g/kg. Krzyżaniak *et al.* (2019), found lower oil contents for *Camelina* varieties oscillating between 39.3 and 42.2%.

Thousand kernel weight (TKW) showed positive correlations with seed yield and oil yield. Zanetti *et al.* (2021) reported that in new improved *Camelina* lines, characterized by increased seed weight, seed yield was higher compared to lines with average seed weight.

Principal component analysis (PCA), the distribution of variables along the two axes along the two axes makes it possible to characterize the varieties tested and to assign to groups individuals that are more or less similar on the basis of the variables measured. The results reported on axis 1, confirm that the fourth variety V4 and V1 are characterized by high numbers of days to flowering and higher values for the number of seeds/silique. On the same axis, Alba V7 and V3 are characterized by good plant emergence m^{-2} and good productivity: high siliques/plant, oil yield and oil content. Axis 2, which features the varieties V5, V2 and V6, can be interpreted as they are closer to axis 2.

This variability between varieties can be interpreted as due to two effects:

- Environmental interaction effect
- Genetic effect of different varieties tested

Conclusions

Camelina sativa is proving to be of crucial importance. A study evaluating seven varieties in the agroecological conditions of the wilaya of Sétif produced very encouraging results, due to its high oil extraction capacity. These results underline the importance of varietal selection of *Camelina sativa* to optimize productivity in semi-arid zones.

They also highlight the role of environmental and genetic factors in the development of the species' crops. The most striking correlations concern the number of plants, which is positively related to yield components and negatively to precocity (-0.66). This means that a long cycle induces an increase in productivity. The number of pods per plant was negatively correlated with the number of seeds/pod (-0.37), positively correlated with the weight of a thousand grains (0.44), and strongly correlated with yield and oil content (0.89).

Among the varieties studied, V7 (Alba) performed best in terms of grain and oil yield, as it is characterized by a high number of plants. Analysis of variance and PCA revealed that the Alba (V7) and V3 varieties exhibited high performance and adaptability for most of the parameters studied.

The study of the varietal behavior of seven varieties revealed a very interesting diversity of agronomic factors, likely to play a decisive role in promoting sustainable agricultural development, while providing economic opportunities for farmers and contributing to food security. The integration of this species into agricultural systems represents a promising alternative, which could not only improve crop resilience but also offer concrete solutions to the challenges posed by climate change.

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Novelty Statement

The objective of the study is to assess the adaptation of Camelina cultivation in the semi-arid highlands region. The introduction of a new oilseed crop not only provides significant agronomic benefits to the cropping system but also improves the economic position of farmers.

Author's Contribution

Dahbia Izountar: Conceptualized the study, monitored the culture (fieldwork, sowing, harvesting); wrote abstract, introduction, data collection, data entry in SPSS and analysis, results and discuddion, conclusion and references.
Hafidha Boucherit: Editing of draft, Supervised the research, Analyzed data, reviewed the manuscript, proofread, reviewed the manuscript, Overall Management of the article, performed proof-reading, and revised the manuscript.
Ramdane Benniou: Conceptualized and revised the

manuscript, analyzed data, reviewed and proofread the manuscript.

Abderrahmane Hannachi: Conceived the idea, Supervised the research.

Mohamed Seddik Benattia: Technical Input.

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Conflict of interest

The authors have declared no conflict of interest.

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