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Article

Adjusting Sowing Date and Seeding Rate for Cultivated Lentil to Contrasting Rainfall Conditions in a Semi-arid Region

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Abstract: Adjusting the sowing date and seeding rate of lentils are important practices, which largely affect plant performance and need greater focus under semi-arid conditions. Our study aimed to optimize the sowing window and plant density specific to dry and wet conditions. A two-year field experiment was carried out under dry and wet cropping seasons (2016/2017 and 2017/2018). Two commercial lentil varieties (Syrie229 and Idleb2) were sown at early (late October/early November), normal (December), and late (January) sowing dates and with low (90 seeds/m^2), medium (120 seeds/m^2) and high (150 seeds/m^2) seeding rate. Several traits were recorded namely plant height at first filled pod (HFFP), plant height (PH), days to flowering (DTF), days to maturity (DTM), stem diameter (SD), weight of 100 seeds (100-SW) and seed yield (SY). Our results revealed that the dry year considerably reduced all trait values except the weight of 100 seeds compared to the wet year. Sowing date had a significant effect on most traits, with the highest values being found for early sowing date compared to normal and late dates, including seed yield (1.83 vs. 1.36 and 0.94 ton/ha, respectively). It is worth noting that the difference among sowing dates was detected only under wet years for most traits. The seeding rate affected only HFFP and stem diameter under a wet year, where a high seeding rate increased HFFP while a low seeding rate increased stem diameter. To conclude, cropping season was the main driver of growth and yield, and then the effect of sowing date was dependent on climatic conditions. Our results highlight the importance of adjusting the sowing window and seeding rate to cope with the future climatic change effects.

Keywords: *Lens culinaris; Syrie229*; Idleb2; early sowing; drought stress.

1. Introduction

Lentil (*Lens culinaris* Medikus) is the fourth most important pulse crop grown in many countries throughout the world [1]. It is one of the most important legumes, which provides protein, carbohydrates, calcium, phosphorus, iron, and B vitamins, and its consumption has increased, especially in developing countries [2,3]. Furthermore, lentil crops can maintain and improve soil fertility due to their high organic matter content and their ability to fix nitrogen symbiotically [4], which is profitable especially when included in rotation with cereals [5,6].

Lentil is usually grown as a winter crop, on marginal lands where rainfall is low and soil is poor [7]. It is moderately tolerant to drought stress [4], but its yield can greatly decrease from 6% to 54% under a range of drought stress conditions [8]. In Algeria, lentil is cultivated in small-scale farms as rainfed crops in different agro-climatic zones; however, their production is still low. In 2021, lentil crops occupied an area of 9098 ha producing 7998 tons; with an average yield of 879.1 kg/ha [9]. In the semi-arid environment, the growing season tends to be wet at the beginning and dry towards the end of the crop cycle [10, 11]. However, early winter rainfall is unpredictable, which often delays the sowing date. Moreover, the soil-stored water is depleted under the effect of early crop growth combined with the high rates of soil evaporation and increased vapor pressure deficit during subsequent crop reproductive growth in spring [12]. Accordingly, the low yield of the rainfed crops including lentils is mainly due to the effect of drought, which is the most limiting factor in the Mediterranean basin [13]. In addition, the use of traditional local cultivars, low plant density, weed infestation, and poor crop management practices could greatly affect the seed yield [14].

Adjusting the sowing date is an effective strategy to adapt the crop to the environmental conditions during the growth period and alleviate the adverse effects of climatic factors [15, 16], which can largely affect the growth, development, and yield of lentils [17]. An early sown lentil crop makes better use of seasonal precipitations than the crop from a later date of sowing [18] and allows the plants to achieve their reproductive growth as soon as possible before the terminal drought (water deficit and high temperatures) [18, 19]. This is true for a usual Mediterranean climate. However, in recent decades significant changes in the weather conditions have been observed throughout the year most likely related to climate change. These are mainly marked by scarce and irregular seasonal distribution of precipitations, global increases in temperature, and more frequent and severe drought periods [20]. In this situation, sowing dates may need to be reviewed to check whether these are still valid or need to be changed.

Besides that, the choice of seeding rate is an important agronomic practice influencing plant density and making substantial yield increase of lentils [21]. Plant density can affect seed yield through several traits like canopy development, radiation interception, dry matter production, and the evaporation of water from the soil under the crop and weed competition [22]. In Algeria, there is limited information available on the optimum sowing date and seeding rate for drought and wet conditions and their effect on the performance of lentils. In this regard, our study aimed to assess the field performance of two commercial lentil varieties in response to different sowing dates and seeding rates under different growing conditions to optimize the sowing window and plant density for specific rainfall conditions (drought and wet cropping season).

2. Materials and Methods

Site description

The field experiment was conducted during two consecutive cropping seasons of 2016 –2017 and 2017 – 2018, at the experimental station of a private seed company AXIUM at Chettaba locality, in Ain-Smara district, Constantine in northeastern Algeria (36° 19' 41'' N, 6° 27' 4'' E; elevated 752 m asl). The climate of the region is semi-arid with an average rainfall of 350 mm.

Treatments, experimental design, and crop management

Two commercial varieties of lentils (Syrie229 and Idleb2) were sown in fields with low, medium, and high seeding rates (90, 120, and 150 seeds /m^2, respectively). Seeds were sown on three different dates of sowing: early (November for 2016 and October for 2017), normal (December), and late (January). The experimental design was laid out in split-plot design with three replications, where the whole plots were assigned to sowing date and the subplots included the combinations of lentil varieties × seeding rates. Lentil seeds were sown at 20 cm row spacing in five-row plots of one m^2. One-meter space was left between main and sub-plots, and three meters between blocks. Nitrogen, phosphate, and potassium fertilizers were supplied, in a mixed formula (15/15/15), at 100 kg/ha and delivered during soil plowing. The crop was hand-weeded before flowering during the two cropping seasons.

Traits measurements

Days to flowering (DTF, days), calculated from sowing to 50% of plants reached flowering. Days to maturity (DTM, days), determined from sowing to the date of maturity of plants (80 % of plants are golden color). Plant height (PH, cm), height of first fertile pod (HFFP, cm), and stem diameter (SD, mm) were assessed at maturity based on three plants per plot. Seed yield (SY, ton/ha) was recorded after harvesting plots, and 100 seeds were weighed to determine the weight of 100 seeds (100-SW, g).

Statistical analysis

Analysis of variance was performed for all recorded traits using Genstat 12 [23], including the effect of the following treatments: year (cropping season), sowing date, seeding rate, lentil varieties, and their interactions. The block within a year was used as the blocking factor; therefore, the interaction block × year (first residual) was used to test the significant effect of year on the measured traits, while the remaining interactions including the blocking factor (second residual), were used to test the significant effect of other factors. Means were compared using the least significant difference (LSD) test at the 0.05 probability level. Principal component analysis was performed using the *FactoMiner* package [24] implemented in R4.1.3.

3. Results

3.1 Temperature and rainfall prevailed during lentil growth

The first cropping season (2016–2017), from September to June, had higher temperatures and less rainfall than the second one (2017–2018). Total rainfall (September to June) was 222 mm during the first cropping season (2016–2017), where the lowest values were observed in September (7 mm), December (5 mm) and March (0 mm). In contrast, the highest rainfall values were recorded in January (85 mm) and November (30 mm). Compared to the first cropping season, 2017–2018 was more favorable for crop growth with a total rainfall of 361 mm; most received in November (72 mm) and over the spring period (182 mm) (Figure 1) while the lowest rainfall values were observed during September, October, and June.

Overall, a similar temperature pattern was observed over the two cropping seasons, higher temperatures were recorded at the beginning and the end of the seasons whereas low temperatures were observed during winter. The winter of 2016–2017 was warmer than that of 2017–2018 except January (Figure 1). According to the weather data of the two cropping seasons, hereafter, the first cropping season (2016–2017) is referred to as the dry year, and the second cropping season (2017–2018) is referred to as the wet year.

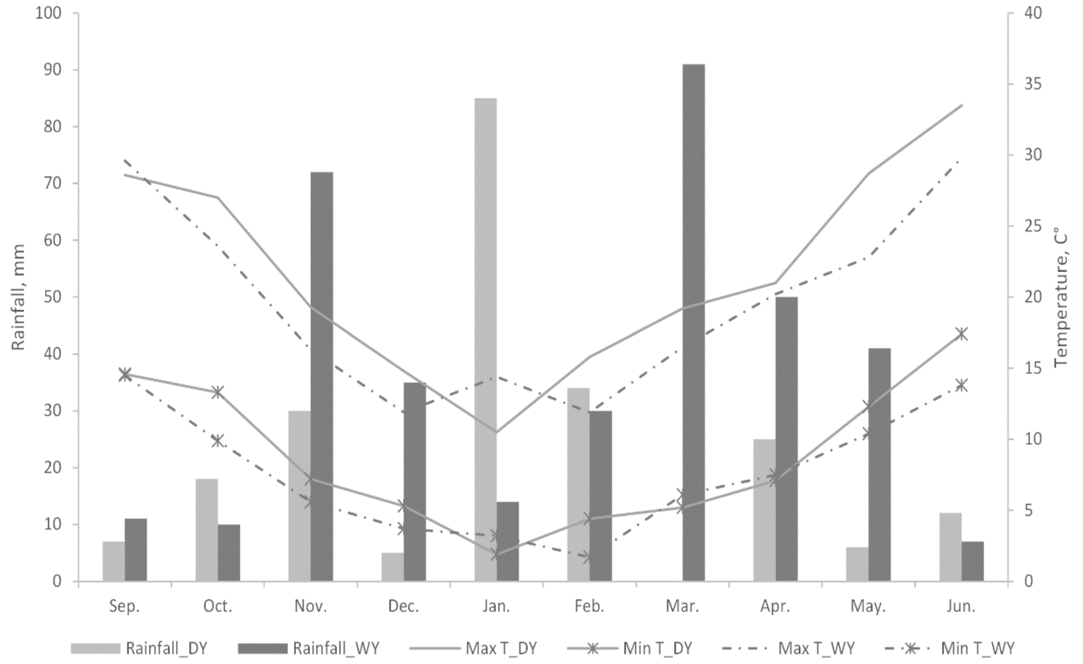

Figure 1. Monthly mean, maximum and minimum temperature (°C) and monthly total rainfall (mm) were recorded at Constantine station during the dry (DY; 2016/2017) and wet (WY; 2017/2018) cropping seasons.

3.2. Variability of the recorded traits

The analysis of variance showed highly significant differences (p<0.001) between the two growing seasons for all traits (Table 1). Similarly, the sowing date showed a highly significant effect (p<0.001) on all recorded traits except 100-seed weight. On the other hand, the applied seeding rate affected only plant height at the first filled pod and stem diameter (p<0.01) (Table 1). Regarding genotypes, our results revealed that differences among genotypes were highly significant (p<0.001) for the 100-seed weight over the two cropping seasons, and no difference was found for the remaining agronomic traits (Table 1). The interactions between the growing season (GS) and sowing dates (SD) had significant or highly significant effects on all traits except 100-seed weight. The interaction of growing season (GS) and seeding rate (SR) significantly influenced plant height at first filled pod and stem diameter (Table 1). No significant effect was detected for the remaining interactions on the recorded traits.

3.2.1. Effect of cropping season

The dry cropping season decreased significantly all the recorded traits except 100-SW (Table 1) compared to the wet year. The highest reductions were observed for seed yield, plant height, and stem diameter by 89.64, 51.40 and 46.43%, respectively. The weight of 100 seeds was the only trait that increased under drought by 16.28% (Table 2).

Table1. Analysis of variance of the effect of growing season, sowing date, seeding rate, variety, and their interactions on the recorded traits.

	d.f.	PH	HFFP	DTF	DTM	SD	100-SW	SY
Growing season (GS)	1	***	***	***	***	***	***	***
Sowing date (SD)	2	**	**	***	***	***	ns	**
Seeding rate (SR)	2	ns	**	ns	ns	*	ns	ns
Variety (Var)	1	ns	ns	ns	ns	ns	***	ns
GS x SD	2	**	***	***	***	***	ns	*
GS x SR	2	ns	*	ns	ns	***	ns	ns
SD x SR	4	ns	ns	ns	ns	ns	ns	ns
GS x Var	1	ns	ns	ns	ns	ns	ns	ns
SD x Var	2	ns	ns	ns	ns	ns	ns	ns
SR x Var	2	ns	ns	ns	ns	ns	ns	ns
GS x SD x SR	4	ns	ns	ns	ns	ns	ns	ns
GS x SD x Var	2	ns	ns	ns	ns	ns	ns	ns
GS x SR x Var	2	ns	ns	ns	ns	ns	ns	ns
SD x SR x Var	4	ns	ns	ns	ns	ns	ns	ns
GS x SD x SR x Var Var	4	ns	ns	ns	ns	ns	ns	ns

d.f: degree of freedom, PH (cm): plant height, HFFP (cm): plant height at the first filled pod, DTF (days): days to flowering, DTM (days): days to maturity, SD (mm): stem diameter, 100-SW (g): weight of 100 seeds, SY (ton/ha): seed yield. ns: difference no significant,, ** and *** indicate that the effect of the Corresponding factors is significant at 0.05, 0.001, and at >0.001, respectively.*

3.2.2. Effect of sowing date, seeding rate, and cultivar

Overall, when lentil cultivars were sown early (SD1), they exhibited the highest values for all traits compared to normal and late sowing dates (SD3 and SD2, respectively), resulting in higher seed yield (1.83 ton/ha vs. 0.94 to1.36 ton/ha, respectively) (Table 2). In addition, our results indicated that the values of all traits tended to decrease when the sowing date was delayed, except for HFFP. Regarding seeding rates (SR), with low seeding rates (SR1 and SR2), lentil plants had thicker stem diameters (2.3 and 2.2 mm, respectively), and tended to reach the flowering stage later (125 days) compared to the higher seeding rate (SR3, 124 days). For HFFP, SR1 presented higher values compared to SR2 and SR3.

3.2.3. Interaction of cropping season, seeding rate, and sowing date

The cropping season × sowing date interaction presented a significant effect on most traits except 100-SW (Table 1), indicating that the effect of sowing date depends strongly on the watering conditions of the year. The strongest interaction was noticed for the phenological traits (flowering and maturity). While early sowing extended the life cycle of the plant during the wet year (DTM = 227.11 days for SD1 against 154.61 days for SD3), the opposite effect was observed during the dry year (DTM = 174.78 days for SD1 against 193.54 days for SD3). Grain yield was significantly increased by early sowing during the wet year (3.37 ton/ha for SD1 against 1.81 ton/ha for SD3), however, during the dry year, the sowing date did not affect the yield. Similarly, plant height and stem diameter tend to be increased by early sowing during the wet year, however during the dry year, the sowing date affected only HFFP but in the opposite way (HFPP = 12.9 cm for SD3 against 10.9 cm for SD1).

The interaction cropping season × seeding rate showed a significant effect only for the plant height at first filled pod (HFFP) and stem diameter (Table 2). Under the dry year, the three seeding rates showed similar values for HFFP, however under the wet year, the medium (SR2) and high (SR3) seeding rates resulted in higher HFFP values compared to the low seeding rate (SR1). Regarding stem diameter, it was significantly different among seeding rates only under wet year, with the low seeding rate displaying the highest stem diameter (3 mm), significantly higher than that obtained under the high seeding rate (2.5 mm) (Table 2).

3.3. Relationships among traits

Under dry years, interesting correlations were found between seed yield and most traits except days to flowering. The highest positive correlation was detected with plant height (0.60) and weak ones were found with stem diameter (0.30) and 100-SW (0.29). In contrast, days to maturity and plant height to first filled pod were negatively associated with seed yield with the respective correlations -0.71 and -0.55 (Table 4). In addition, DTM was, negatively correlated with DTF, PH, and 100-SW and positively correlated to HFFP. The weight of 100 seeds presented correlations with PH (0.27) and HFFP (-0.35) (Table 4). On another hand, under wet years, relationships among traits are different from those found under dry years. Days to flowering became significantly correlated to SY and the correlations of the remaining traits with SY disappeared except stem diameter. Furthermore, the appearance of significant correlations of stem diameter with DTF and DTM. The correlations between the two series of traits of dry and wet years revealed a very high correlation for DTF (0.91) and a low correlation for DTM (-0.37) and 100-SW (0.38) (Table 3).

Table 2. Analysis of variance and mean comparison for the recorded traits as affected by sowing date, seeding rate, variety, and their interactions.

	PH	HFFP	DTF	DTM	SD	100-SW	SY
Sowing season (GS)							
Dry year	20.8 b	11.4 b	119.66 b	182.29 b	1.5 b	4.57 a	0.26 b
Wet year	42.8 a	15.5 a	130.48 a	188.86 a	2.8 a	3.93 b	2.51 a
Sowing date (SD)							
Early (SD1)	33.4 a	13.7 a	146.75 a	200.94 a	2.3 a	4.27 ab	1.83 a
Normal (SD2)	31.5 b	12.6 b	119.33 b	181.70 b	2.2 a	4.32 a	1.36 a
Late (SD3)	30.5 b	14.0 a	109.13 c	174.08 c	1.9 b	4.16 b	0.94 b
Seeding rate (SR)							
Low (SR1)	32.3 a	12.6 b	125.71 a	184.45 a	2.3 a	4.218 a	1.39 a
Medium (SR2)	31.6 a	13.7 a	124.81 a	185.72 a	2.2 a	4.289 a	1.33 a
High (SR3)	31.5 a	14.0 a	124.70 b	186.55 a	2.0 b	4.245 a	1.42 a
Cultivar							
IDLEB 2	31.9 a	13.6 a	125.23 a	187.01 a	2.2 a	4.49 a	1.37 a
Syrie 229	31.7 a	13.3 a	124.91 a	184.14 a	2.1 a	4.01 b	1.39 a
GS × SD							
Dry year							
SD1	21.5 c	10.9 d	134.89 b	174.78 e	1.5 c	4.63 a	0.30 c
SD2	22.1 c	10.5 d	112.06 d	178.56 d	1.7 c	4.70 a	0.39 c
SD3	18.8 c	12.9 c	112.03 d	193.54 b	1.4 c	4.38 a	0.08 c
Wet year							
SD1	45.2 a	16.5 a	158.61 a	227.11 a	3.1 a	3.91 a	3.37 a
SD2	40.9 b	14.7 b	126.61 c	184.85 c	2.7 b	3.95 a	2.34 b
SD3	42.3 ab	15.1 b	106.22 e	154.61 f	2.4 b	3.94 a	1.81 b
GS × SR							
Dry year							
SR1	20.8 a	11.2 c	120.03 a	181.45 a	1.5 c	4.55 a	0.25 a
SR2	21.5 a	11.3 c	119.33 a	181.56 a	1.6 c	4.60 a	0.29 a
SR3	20.1 a	11.8 c	119.62 a	183.87 a	1.5 c	4.57 a	0.24 a
Wet year							
SR1	43.8 a	14.0 b	131.39 a	187.46 a	3.0 a	3.89 a	2.54 a
SR2	41.7 a	16.1 a	130.28 a	189.89 a	2.7 ab	3.98 a	2.37 a
SR3	42.9 a	16.3 a	129.78 a	189.22 a	2.5 b	3.92 a	2.61 a

PH (cm): plant height, HFFP (cm): plant height at first filled pod, DTF (days): days to flowering, DTM (days): days to maturity, SD (mm): stem diameter, 100-SW (g): weight of 100 seeds, SY (ton/ha): seed yield.

Table 3. Pearson's correlation coefficients among the assessed traits under dry and wet years.

		Wet year						
		DTF	PH	HFFP	SD	DTM	100-SW	SY
Dry year	DTF	**0.91**	**0.36**	0.25	**0.66**	**0.47**	-0.06	**0.41**
	PH	0.16	0.12	0.08	**0.54**	0.01	-0.12	0.02
	HFFP	-0.24	-0.24	0.04	0.00	0.13	0.00	0.11
	SD	-0.05	0.24	-0.24	0.00	**0.27**	0.01	**0.36**
	DTM	**-0.47**	**-0.51**	**0.51**	-0.10	**-0.37**	-0.19	0.24
	100-SW	0.11	**0.27**	**-0.35**	0.16	**-0.30**	**0.38**	-0.08
	SY	0.13	**0.60**	**-0.55**	**0.30**	**-0.71**	**0.29**	0.10

PH (cm): plant height, HFFP (cm): plant height at first filled pod, DTF (days): days to flowering, DTM (days): days to maturity, SD (mm): stem diameter, 100-SW (g): weight of 100 seeds, SY (ton/ha): seed yield.

3.4. Classification of cropping season by sowing date combinations

Principal component analysis, including traits of sowing dates under dry and wet years, explained 93.72% of the total variability. The first principal component (PC1) explained most of the variability (73%) and was mainly formed by traits like seed yield, stem diameter, plant height to the first filled pod, and plant height (Figure 2). These traits were located on the positive side of PC1 in contrast position with the weight of 100 seeds. The distribution of sowing dates along the first PC was driven by the year effect (dry vs. wet), where the sowing dates under the wet year (WY-SD) increased all the traits except 100-SW, which was higher for the sowing dates under the dry year (Figure 2). The second principal component (PC2) was mainly loaded by plant phenology traits (flowering and maturity). The late sowing date under a wet year (WY-SD3) was the only treatment located on PC2, showing that this combination (wet year × late sowing date) had a short crop cycle including early flowering and maturity.

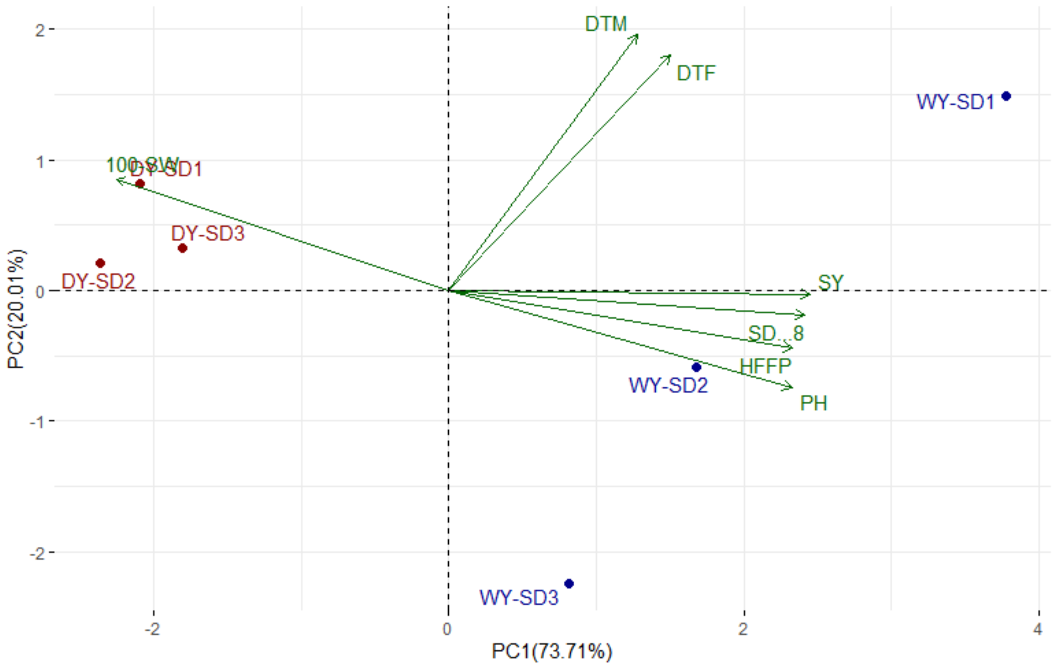

Figure 2. Principal component analysis based on traits recorded for early, normal, and late sowing dates (SD1, SD2, and SD3, respectively) under dry (DY) and wet (WY) years. DY-SD1 and WY-SD1 indicate the combination of early sowing date × dry year and early sowing date × wet year, respectively.

4. Discussion

Rainfall and temperature during the growing seasons of the current study were, overall, typical of the Algerian semi-arid regions, where the drought occurred around the period of flowering [25]. The total rainfall observed in our study varied from 222 mm, during the dry year, to 361 mm during the wet year. This indicates a considerable variation of rainfall across years, which characterizes the eastern high plateaus of Algeria, and led to a large grain yield variation for rainfed crops [26]. Furthermore, under climate change scenarios, climate forecasts suggest that variable annual rainfall patterns threaten the sustainability of lentil production by increasing the frequency of drought periods during the cropping season [27]. Our findings revealed that the dry year (drought) greatly reduced all the measured traits especially seed yield (by 89.64%) and plant height (51.40%). An exception was observed for seed weight, which increased by 16.28%. This should be explained by the compensation effect between yield components under stress conditions. In this case, the plant maintained or even increased seed size at the expense of seed number. These results follow several studies mentioning the negative effect of drought stress across the whole lentil cycle. For instance, drought reduced germination [28], shoot and root growth [29,30], leaf area [31,32], and relative water content [33] leading ultimately to a considerable reduction in biomass production and severe yield losses [29,34].

Sowing date (SD) is one of the most important factors that determine the yield of lentils, it greatly influences vegetative and reproductive growth stages including maturity date [30]. The present study revealed that lentils performed better with early sowing (November/October) in terms of growth and seed yield compared to late sowings (December and January). Similar results were reported in previous studies. When compared to late sowing, early sowing increased seed yield [35], days to flowering and maturity [36], plant height [37], and pod number per plant [38]. Regarding seed yield, our results were similar to those found in the Syrian lentil study [18], where seed yield in lentil was reduced in late sowings (January and February) by 26.6% and 32.5%, respectively, compared to the early sowing date. Furthermore, over three years, the highest lentil yield was achieved for sowings between October and November, and the lowest yield was found for later sowing [19]. The out-performance in terms of growth and yield of lentils sown at an early date appears to be the result of the best use of seasonal precipitation and the expression of their full growth potential compared to late sowing [18]. Furthermore, this could be also due to the longer growth period at the disposal of the early sown crop [7]. In addition, the low yield of a late-sown crop could be due to the effect of the drought and heat stress that most likely affect the advanced plant growth stage (flowering and grain filling) [19]. Nevertheless, our results demonstrated that the effect of sowing dates depends strongly on the growing season conditions. Under dry years, no difference was observed for seed yield among early, normal, and late sowing dates but under wet conditions, early sowing was advantageous over normal and late sowing dates. These findings could be in line with the typical strategy of lentils under Mediterranean environments (drought escape) where lentil plants start with vigorous growth when conditions are favorable and reach maturity early under the effect of high temperatures and drought stress in late spring or early summer [39]. Accordingly, based on the trait relationships under dry years, late maturity would penalize seed yield (Pearson correlation (-0.71), and this could be explained by the fact that late flowering places the seed filling and maturity under dry conditions, which ultimately reduces the seed yield. It is worth noting that the stem diameter was the only trait that was positively associated with seed yield under dry and wet years.

Unlike the sowing date, the effect of the seeding rate on the recorded traits in our study was less important, affecting only plant height at the first filled pod (HFFP) and stem diameter. We found that the high and medium seeding rates had the highest values for PHFFP and the lowest values for stem diameter, which was in agreement with the findings of [40] who reported that the higher sowing rate causes higher inter-plant competition and results in poor individual plants. In addition, [19] reported that increasing plant density caused an increase in plant height. According to [41], differences were found among four seeding rates of 200 to 350 seeds/m^2, where plant height, biomass, and yield were higher for the highest seed densities and the number of branches, pod, and seed per plant were higher for the lowest density. However, seed yield was not significantly different among seeding rates under dry and wet years. The three seeding rates (90, 12, and 150 seeds/m^2) used in the current study seem to be very close, and their effect on lentil performance was similar. Therefore, using a greater range of seeding rates would affect the growth and productivity of lentils.

5. Conclusions

Under semi-arid conditions, the dry year (222 mm) reduced all the recorded traits except the weight of seeds compared to the wet year (361 mm). The early sowing date (late October and November) improved the growth and yield of lentil cultivars compared to normal (December) and late (January) sowing dates. Furthermore, the effect of the sowing date, especially on seed yield, was dependent on the growing season conditions, with no effect under dry years. Seeding rates and cultivars did not show a significant effect on most traits. Overall, we can conclude that early sowing should be recommended regardless of the weather conditions of the growing season. Nevertheless, the current findings were based on a small number of lentil genotypes (two), and seeding rates during only two years, therefore, further works should be performed with a large number of diverse genotypes, seeding rates, and over several years to obtain reliable results under unpredictable semi-arid conditions.

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References

1. Delahunt, A.; Jason, Brand, J.; James, D; Nuttall, G. Field Screening of Lentil (Lens culinaris) forHigh-Temperature Tolerance. Agronomy **2023**, 13, (7): 1753. https://doi.org/10.3390/agronomy13071753
2. Giannakoula, A.; E.; Ilias, I. F.; Maksimovic, J. J. D.; Maksimović, V. M.; Zivanović, B. D. (2012). The effects of plant growth regulators on growth, yield, and phenolic profile of lentil plants. Journal of Food Composition and Analysis **2012**, 28(1), 46-53. https://doi.org/10.1016/j.jfca.2012.06.005
3. Sarker, A.; Rizvi, A.; H.; Singh, M.. Genetic variability for nutritional quality in lentil (*Lens culinaris* Medikus subsp. culinaris). Legume Research-An International Journal 2018, 41(3), 363-368. doi: 10.18805/LR-372.
4. Matny, O.N. Lentil (*Lens Culinaris* Medikus) current status and future prospect of production in Ethiopia. Adv Plants Agric Res. **2015**, 2 (2):45-53. doi: 10.15406/apar.2015.02.00040.
5. Quinn, M.A. Biological nitrogen fixation and soil health improvement. In The lentil—Botany, Production and Uses; Erskine, W.; Muehlbauer, F.J.; Sarker, A.; Sharma, B.; Eds.; CommAgric Bureau Int.: Wallingford, CT, USA 2009; pp. 229–247. https://doi.org/10.1079/9781845934873.0229

6. Erskine, W.; Sarker A.; Kumar, S. Crops that feed the world. Investing in lentil improvement toward a food secure world. Food Security **2009**, 3, 127-139. https://doi.org/10.1007/s12571-011-0124-5
7. Turk, M A.; Tawaha, A.M.; El- Shatnawi, M.K.J. Response of lentil (*Lens culinaris*Medik) to plant density, sowing date, phosphorus fertilization and ethephon application in the absence of moisture stress. J. Agron. Crop. Sci. **2003**, 189: 1-6. https://doi.org/10.1046/j.1439-037X.2003.00002.x
8. Siddique, K.H.M.; Loss, S.P.; Regan, K.L.; Jettner, R.L. Adaptation and seed yield of cool season grain legumes in Mediterranean environments of south-western Australia. Aust. J. Agric. Res.**1999**, 50: 375-387. https://doi.org/10.1071/A98096
9. FAOSTAT. Statistical databases of the Food and Agriculture Organization of the United Nations. Production: crops 2021. Available online: http://www.fao.org/faostat/en/#home (accessed on 02 October 2023).
10. Hunt, J. R.; Lilley, J. M.; Trevaskis, B.; Flohr, B. M.; Peake, A.; Fletcher, A. Early sowing systems can boost Australian wheat yields despite recent climate change. Nat. Climate Change 2009, 9, 244–247. https://doi.org/10.1038/s41558-019-0417-9
11. Flohr B. M.; Ouzman, J.; McBeath, T. M.; Rebetzke, G. J.; Kirkegaard, J. A.; Llewellyn, R. S. Redefining the link between rainfall and crop establishment in dryland cropping systems. Agric. Syst.**2021**, 190, 103-105. https://doi.org/10.1016/j.agsy.2021.103105
12. Rodriguez, D.; Sadras, V. O. The limit to wheat water use efficiency in eastern Australia in gradients in the radiation environment and atmospheric demand. Aust. J. Agric. Res. **2007**, 58, 287–302. https://doi.org/10.1071/AR06135
13. Royo, C.; Álvaro, F.; Martos, V.; Ramdani, A.; Isidro, J.; Villegas, D.; García-del-Moral, L.F. Genetic changes in durum wheat yield components and associated traits in Italian and Spanish varieties during the 20th century. Euphytica 2007, 155, 259–270. https://doi.org/10.1007/s10681-006-9327-9
14. Nabati, J.; Nezami, A.; Hasanfard, A.; ZareMehrjerdi, M.; Rastgoo, M. Selection of lentil (Lens culinarismedik.) genotypes by assessing phenological, morphological, yield and yield attributes. Iran Agricultural Research **2021**,40(1) 51-60.doi: 10.22099/IAR.2021.39466.1427
15. Coelho, A. E.; Sangoi, L.; Junior, A.; Fioreze, S. L.; Júnior, M. Growth patterns and yield of maize (Zea mays L.) hybrids as affected by nitrogen rate and sowing date in southern Brazil. Crop Pasture Sci. **2021**, 71, 976–986. https://doi.org/10.1071/CP20077.
16. Deng, F.; Zhang, C.; He L.; H.; Liao, S.; Li Q.; Li, B.; Zhu, S.; Gao, Y.; Tao Y.; Zhou, S.; Lei, X.; Wang, l.; Hu, J.; Chen, Y.; Ren, W. Delayed sowing date improves the quality of mechanically transplanted rice by optimizing temperature conditions during growth season. Field Crops Res. **2022**, 281:108493. https://doi.org/10.1016/j.fcr.2022.108493.
17. Sen S.; Ghosh, M.; Mazumdar, D.; Saha, B.; Doluid, S. Effect of sowing date and variety on phenology and yield of lentil during rabi season. Journal of Crop and Weed **2016**, 12(1):135-138. Available online at: https://www.cropandweed.com/archives/2016/vol12issue1/25.pdf (accessed September, 2023).
18. Saxena, M. C.; Murinda, M. V.; Turk, M.; Trabulsi, N. Productivity and water-use of lentil as affected by date of sowing. Lens **1983**, 10, 28—29.
19. Singh, H. and Saxena M. C. Response of lentil genotypes to date of planting. Lens 1982, 9, 30—31.
20. Mathbout, S. LopezBustins, J.A. Royé, D. Martin-Vide, J. Mediterranean-Scale Drought: Regional Datasets for Exceptional Meteorological Drought Events during 1975–2019. Atmosphere **2019**, 12, 941. https://doi.org/ 10.3390/atmos120.
21. Ball, DA.; Ogg, AG.; Chevalier, PM. The influence of seeding rate and weed control in small seeded lentils (Lens culinaris). Weed Sci. **1997**, 45 (2): 296-300. https://doi.org/10.1017/S0043174500092869
22. López-Bellido, F.J.; López-Bellido, L.; López-Bellido, R.J. Competition, growth and yield of faba bean (Viciafaba L.). Eur. J. Agron. **2005**, 23, 359-378. https://doi.org/10.1016/j.eja.2005.02.002.

23. Payne, RW, Murray, DA, Harding, SA, Baird, DB, Soutar, DM. GenStat for Windows 12thEdition. Introduction. VSN International **2009**. Hempel Hempstead, UK.
24. Lê, S.; Josse, J.; & Husson, F. FactoMineR: an R package for multivariate analysis. *Journal of statistical software* **2008**, *25*, 1-18.
25. Mekhlouf, A.; Bouzerzour, H.; Benmahammed, A.; HadjSahraoui, A.; Harkati, N. Adaptation des variétés de blé dur (*Triticum durum* Desf.) au climat semi-aride. Sécheresse **2006**, 4, 507-513. http://geoprodig.cnrs.fr/items/show/187775
26. Bahlouli, F.; Bouzerzour, H.; Benmahammed, A.; Hassous, K. L. Selection of high yielding and risk efficient durum wheat (*Triticum durum* Desf.) cultivars under semi-arid conditions. Pak. J. Agron. **2005**, 4, 360-365. https://scialert.net/abstract/?doi=ja.2005.360.365
27. Dai, A. (). Increasing drought under global warming in observations and models. Nat. Clim. Change **2013**,3, 52-58. https://doi.org/10.1038/nclimate1811
28. Muscolo, A.; Sidari, M.; Anastasi, U.; Santonoceto, C.; Maggio, A. Effect of PEG-Induced Drought Stress on Seed Germination of Four Lentil Genotypes. J. Plant Interact **2014**, 9, 354–363.https://doi.org/10.1080/17429145.2013.835880.
29. Idrissi, O.; Chafika, H.; Nsarellah, N. Comparaison de lignées avancées de lentille sous stress hydrique durant la phase de floraison et formation des gousses. Nat. Technol. **2013,** 10, 53–61.https://www.asjp.cerist.dz/en/article/41726.
30. Akter, S.; Jahan, I.; Hossain, M. A.; Hossain, M. A. (). Laboratory-and Field-Phenotyping for Drought Stress Tolerance and Diversity Study in Lentil (Lens culinarisMedik.). Phyton-International Journal of Experimental Botany **2021** 90(3), 949 970. https://doi.org/10.32604/phyton.2021.014411.
31. Gupta, D.; Dadu, R.H.; Sambasivam, P.;Bar I.; Azad, M.; Beera, N.; Ford, R.; Biju, S. Conventional and Biotechnological Approaches for Targeted Trait Improvement in Lentil. In Accelerated Plant Breeding **2020**, Volume 3; Springer: Berlin/Heidelberg, Germany, pp. 67–107. https://doi.org/10.1007/978-3-030-47306-8_3
32. Saha, M.; Bandyopadhyay, P.K.; Sarkar, A.; Nandi, R.; Singh, K.C.; Sanyal, D. Understanding the Impacts of Sowing Time and Tillage in Optimizing the Micro-Environment for Rainfed Lentil (*Lens culinaris* Medik) Production in the Lower Indo-Gangetic Plain. J. Soil Sci. Plant Nutr. **2020**, 20, 2536–2551. https://doi.org/10.1007/s42729-020-00319-6
33. Ben Ghoulam, S.; Zeroual, A.; Baidani, A.; Idrissi, O. Réponse au déficit hydrique progressif chez la lentille : Vers une différentiation morpho-physiologique entre des accessions sauvages (Lens orientalis), populations locales et lignées avancées (Lens culinaris). Botany **2022,** 100, 33–46. https://doi.org/10.1139/cjb-2020-0168.
34. Venugopalan, V.; Nath, R.; Sengupta, K.; Pal A. Banerjee, S.; Banerjee, P.; Chandran, M.; Roy, S.; Sharma, L.; Hossain, A.; Siddique, KH.M. Foliar Spray of Micronutrients Alleviates Heat and Moisture Stress in Lentil (Lens culinarisMedik) Grown under rainfed Field Conditions. Front. Plant Sci. **2022**, 13, 47743. https://doi.org/10.3389/fpls.2022.847743
35. Alemu, MA.; Fikre, A.; Negassa, TM.; Feyissa, T. Effects of Planting Time on Growth, Yield and Yield Related Traits of Lentil “Lens culinarisMedikus” at Central Ethiopia. ICRRD Journal, **2023**, 4(4), 140-152. https://doi.org/10.53272/icrrd
36. Nayeem, K.A. and Dalvi D.G. Stomata density aperture index and their differentials in wheat at low and high temperature. Ind. J. Agric. Sci. **1993**, 63: 215-219.
37. Tawaha, A.M. and Turk, MA. Effects of dates and rates of sowing on yield and yield components of lentil (Lens culinarisMedik.) under semi arid conditions. Pakistan J. Bio. Sci. **2002**, 5(5):531-532. 10. https://scialert.net/abstract/?doi=pjbs.2002.531.532
38. Ouji, A. and Mouelhi, M . Influence of Sowing Dates on Yield and yield components of lentil under semi-arid region of Tunisia. Journal of new sciences, Agriculture and Biotechnology **2017**, 38(2), 2077-2082.
39. Silim, S.N.; Saxena, M. C.; Erskine, W. Adaptation of lentil to the Mediterranean environment.II.Response to moisture supply. Experimental Agriculture **1993,** 29:21 28. https://doi.org/10.1017/S0014479700020366

40. Biçer, B.T.Some Agronomic Studies in Chickpea (Cicerarietinum L.) and Lentil (Lens culinarisMedik). Turkish J. of agricultural and Natural sciences **2014**, 1(1): 42–51.
41. Düzgün, E. Z. ; Toğay, N. The effects of different planting densities on lentil (Lens culinaris Medic.) yield and yield components in mardin conditions. ISPEC Journal of Agricultural Sciences **2021**, 5(3), 560-567. https://doi.org/10.46291/ISPECJASvol5iss3pp560-567.