PAN

JOURNAL OF WATER AND LAND DEVELOPMENT

e-ISSN 2083-4535

ITP-PIB

Polish Academy of Sciences (PAN) Institute of Technology and Life Sciences – National Research Institute (ITP – PIB)

JOURNAL OF WATER AND LAND DEVELOPMENT
DOI: 10.24425/jwld.2022.141553
2022, No. 54 (VII–IX): 39–49

Climate change necessitates a change in the cultivation date of caraway (*Carum carvi* L.)

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RECEIVED 13.04.2022 ACCEPTED 13.05.2022 AVAILABLE ONLINE 04.07.2022

Abstract: By 2050, global crop demand is projected to rise by 60–110%. Crop yields have also been impacted by climate change in some nations, and these impacts are likely to continue. To prevent the influence of climate change on crop output, it is critical to adjust planting times in weather-related open fields to meet food security concerns. Present study was carried out at Experimental Farm of Faculty of Agriculture, Al-Azhar University, Assiut, Egypt, during two successive seasons, 2019 and 2020. It was aimed to study the effect of different sowing times (1st and 15th October, 1st and 15th November), and plant spacings (25, 20, and 15 cm) on growth, fruit yield, and oil production of caraway (*Carum carvi* L.) plants. The results showed that sowing caraway plants on 15th October with plant spacing of 25 cm gave the highest dry weight (72.6 g·plant^{-1}), fresh weight (266.15 g·plant^{-1}), seed yield (37.43 g·plant^{-1}), and oil yield (0.659 cm^3·plant^{-1}). The maximum umbels (50.83 number per plant) and essential oil (1.78%) were also recorded in the plants receiving same treatment. On the other hand, plants sown at 15th November with spacing of 15 cm exhibited the minimum values of recorded traits. While the highest value of plant height gave with sowing caraway plants on 15th October with plant spacing of 15 cm (135.35 cm). In conclusion, the plants sowed on October 15th with a maximum plant spacing of 25 cm had the highest values of the evaluated morphological, biochemical, and yield attributes of caraway.

Keywords: climate change, condiments, leafy vegetables, sowing time, vegetative growth, volatile oil

INTRODUCTION

Caraway (*Carum carvi* L.) belongs to the family Umbelliferae (Apiaceae), is an annual winter herb [PETER (ed.) 2006]. It is one of the drugs and condiment crops and has a particular importance among the medicinal plants in some parts of the world [SACHAN *et al.* 2016]. It occurs both wild and domesticated in central and northern Europe, Egypt, Morocco, Australia, and China [RUBATZKY *et al.* 1999]. Caraway fruits were known to Arabian physicians and probably came into use in Europe in the thirteenth century [EVANS 2009]. The dried fruit, commonly called seeds, contains 2–8% essential oil [LAWLESS 2013]. Carvone and limonene are the principal components, besides, trace amounts of other constituents (such as acetaldehyde, furfural, carveol, pinene, thujone, camphene, phellandrene, hydrocarbons, y-terpinene, etc.) are also present. Caraway seeds also contain lipids (13–21%), nitrogenous compounds (25–35%), fibers (13–19%), and water (9–13%) [EZZ EL-DIN *et al.* 2010].

The best way to achieve the economical goal is to increase yield by using the proper cultivars, best sowing date and optimum plant density [BEGNA, ANGADI 2016]. Plant density depends on the growth cycle, time and method of cultivation, soil conditions, sunlight and allelopathic surroundings of the plant [ALVES SOUZA *et al.* 2020]. Selection of suitable sowing date has advantages concerning assembling the raw material and other productions. Some studies of planting dates in *Hibiscus sabdariffa* found that the early planting dates gave the highest plant height, branches, biomass, sepals, seeds as well as increased N, P, K, and total carbohydrates percentage, acidity, anthocyanins and fixed oil [FUTULESS *et al.* 2010; OYEWOLE, MERA 2010]. On the other hand, some previous authors conducted experiments to determine the appropriate row spacing in fennel (*Foeniculum vulgare* Mill.) crop, indicating that plant seeding at the nearest distance had a positive effect on plant growth, seed yields, oil production and plant chemical components, and produced the highest seed yield compared to control plants [KHORSHIDI *et al.* 2009; MENARIA, MALIWAL 2011].

The effect of sowing time and seed spacing was studied by many investigators on fennel plants. In this respect, the studies of EL-KHAYYATT and GOUDA [2005], KUMAR *et al.* [2006], AYUB *et al.* [2008], SINGH *et al.* [2009] and SELIM *et al.* [2013] verified that early sowing had a positive impact on plant growth, seed yield, oil production, and phytochemical components of fennel plants from the beginning of October to mid-October.

Optimum sowing date and plant spacing had positive effects on growth, yield and chemical composition of different plant species as emphasised by many authors (THALJI and SHALALDEH [2006] on faba bean (*Vicia faba*) and SAJJAD *et al.* [2014] on quinoa (*Chenopodium quinoa*)). However, BHARGAVA *et al.* [2007] and SIEF *et al.* [2015] found that the best growth and yield of quinoa was obtained when plant were sown at 15th October with spacing of 25 cm, while late sowing (1st December) gave the lowest yield regardless of plant spacing. Similarly, EISA *et al.* [2018] reported that, quinoa plant sown at low density (56,000 plant·ha^{-1}) showed significant increase in seed weight as compared to control, and 100 dm^3 were obtained due to differences in temperature, rainfall and radiation over the year.

Sowing time is a key factor in the flowering phase of plants; delayed sowing can reduce the number of flowers [NLEYA *et al.* 2020]. By changing day length, maximum and minimum temperatures, relative humidity, and other environmental conditions during the growing season, changing the sowing date can impair plant fertility [SHRESTHA *et al.* 2018]. The length of the growth cycle, phenological processes, and finally the quantitative and qualitative yield of plants can also be influential [DADKHAH *et al.* 2010].

The goal of the present study was to explore the effects of different sowing times and plant spacings on morphological characteristics and yield of caraway plants, and to define the best treatment for maximum quantitative and qualitative crop output.

MATERIALS AND METHODS

EXPERIMENTAL SITE

During two consecutive growing seasons (2018/2019 and 2019/2020), field experiments were performed at the Experimental Farm of the College of Agriculture, Al-Azhar University, Assiut, Egypt to evaluate the impact of sowing time and plant spacing on the morphological and biochemical traits of caraway (*Carum carvi* L.). Soil (30 cm upper layer) from both experimental locations was analysed according to YANCEY *et al.* [1982] and KLUTE [1986] (Tab. 1).

Table 1. The initial physio-chemical properties of the experimental soil during both growing seasons

Parameter		Value in years	
		2018/2019	2019/2020
Particle size distribution	sand (%)	20.0	18.3
	silt (%)	56.5	59.6
	clay (%)	23.5	22.1
Texture grade		silty loam	silty loam
pH of soil water suspension (1:2.5) (w/v)		7.5	7.3
EC_e (dS·m^{-1}) soil paste		2.2	2.0
OM (%)		0.50	0.60
Total $CaCO_3$ (%)		2.53	2.43
HCO_3^- (cmol kg^{-1} of soil)		2.9	3.2
Cl^- (cmol kg^{-1} of soil)		2.2	2.1
SO_4^{2-} (cmol kg^{-1} of soil)		6.6	6.4
Ca^{2+} (cmol kg^{-1} of soil)		3.4	3.6
Mg^{2+} (cmol kg^{-1} of soil)		1.9	2.3
K^+ (cmol kg^{-1} of soil)		3.5	3.35
Na^+ (cmol kg^{-1} of soil)		22.72	18.07

Explanations: each value represents a mean of three replicates, *EC* = electrical conductivity, OM = organic matter.
Source: own study.

EXPERIMENTAL DESIGN AND TREATMENTS

The study was carried out as a bifactorial experiment based on a randomised complete block design with three replications. The factors included "sowing time" (main plot) i.e., 1st Oct, 15th Oct, 1st Nov and 15th Nov, and "plant spacing" (subplot) i.e., 15, 20 and 25 cm. Caraway seeds were obtained from the Medicinal and Aromatic Plant Research Department, El-Kanater El-Khairia, El-Kaliobia, Egypt. The soil was prepared by plowing twice orthogonally, flattening, and dividing the experimental units. The experimental area was 2 × 3 m containing four rows (the distance between rows was 60 cm). Plants were thinned (two plants per hole) after 21 days of planting. The plants were irrigated monthly, according to the needs of the plant and the type of soil. At 25 and 55 days after sowing (DAS) in both growing seasons, weeds were removed manually. The prescribed basal dose of P_2O_5 i.e., 107 kg·ha^{-1} (15.5% $CaH_6O_9P_2$) was incorporated into the soil. While 159.46 kg N·ha^{-1} (33.5% NH_4NO_3) and 119 kg·ha^{-1} K_2O (50% potassium sulphate) were divided into two equivalent splits at 30 and 60 DAS, as recommended by the Ministry of Agriculture, Egypt [HASSAN 2011].

WEATHER CONDITIONS DURING THE EXPERIMENT

According to Köppen–Geiger climate map, the climate of the experimental region (Assiut city, Egypt) is described as very hot and dry in summer and as cold in winter [BECK *et al.* 2018]. Maxi-minimum temperatures and relative humidity during the two growing seasons are shown in Figure 1.

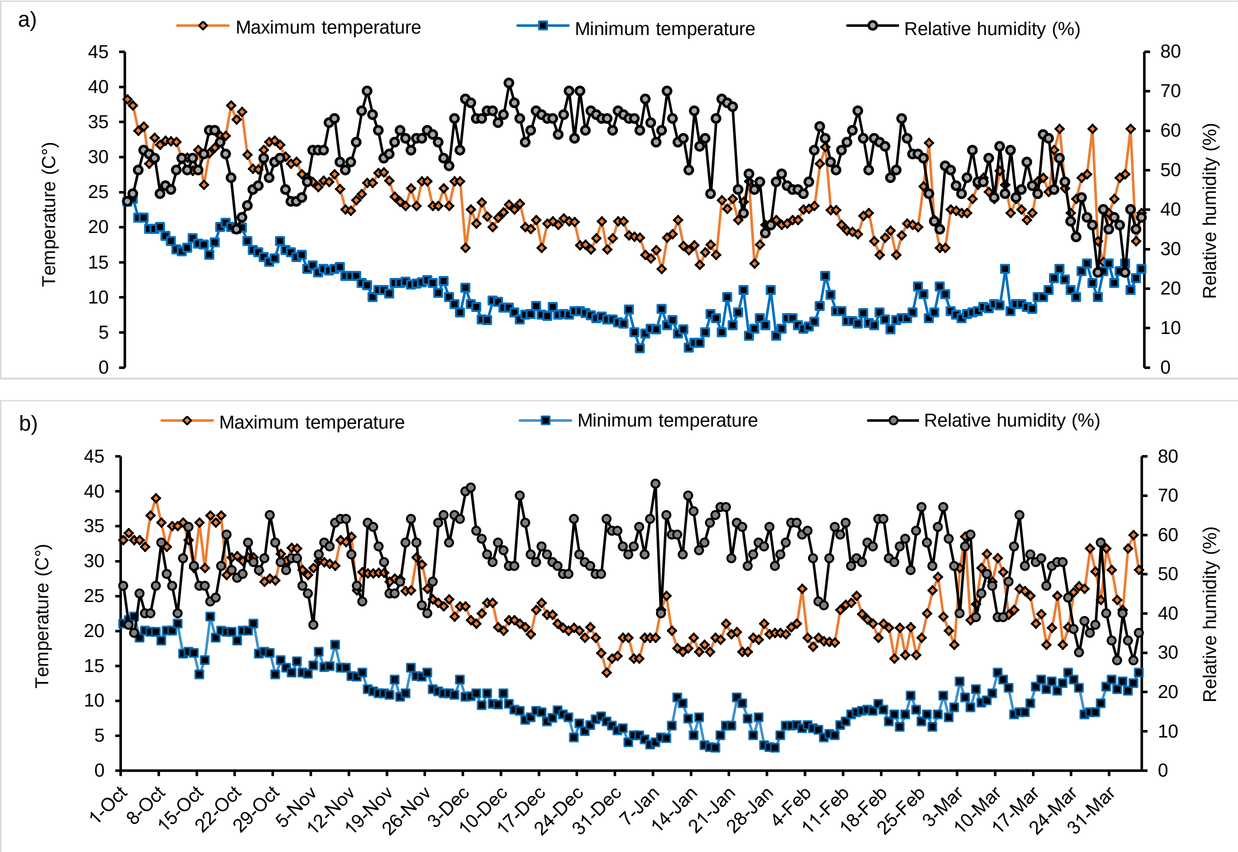


Fig. 1. Weather conditions during the two growing seasons of caraway cultivation: a) growing season 2018/2019, b) growing season 2019/2020; source: own study

DATA COLLECTION

In both growing seasons, data regarding growth parameters were collected after 152, 154, 152 and 140 days of 1st, 2nd, 3rd and 4th sowing, respectively. Plant height was measured at the end of the experiment from the soil surface to the top of each plant for the different treatments. Plant height was taken using a ruler from the base of the rhizome to the top of the plant, whereas the average was calculated and recorded just before harvesting. The fresh and dry weights of the plants and seed yield weight were weighed using an electronic balance (MJ-W176P). In all treatments, the dry weight of the plant was obtained by oven drying at 75°C until a constant weight was obtained [SORGONÀ *et al.* 2011]. The oil production was determined at the end of experiment for the both seasons according to BPC 2009, by water distillation of 100 g of seed for 1.5–2.0 h to extract the essential oil. Finally, the essential oil yield was determined by the formula of FARAHANI *et al.* [2008], where volatile oil yield ($cm^3 \cdot plant^{-1}$) was calculated by multiplying volatile oil (% in seed weight, $g \cdot plant^{-1}$).

STATISTICAL ANALYSIS

Collected data were subjected to two-way ANOVA (sowing time·plant spacing) using statistical software package "Statistics 8.1" [GOMEZ, GOMEZ 1984; SNEDECOR, COCHRAN 1989]. The treatments' means were compared using Fisher's Least significant difference (*LSD*) test at the significance level of 5% ($p \leq 0.05$) [DADKHAH *et al.* 2010].

RESULTS

MORPHOLOGICAL TRAITS

The results revealed that the sowing time and plant spacing exhibited significant impact on morphology of caraway plants. During 1st growing season (2019), plants sown on 15th Oct showed maximum height (132.83 cm) among those were sown on other dates, late sowing on 15th Nov caused (6.5%) reduction. Concerning the plant spacing, 15 cm was the best treatment with respect to plant height (131.51 cm). The maximum plant height (135.2 cm) was reported in the plants seeded on the 15th of Oct with plant spacing of 15 cm, when the cumulative impact of sowing time and plant spacing was considered. Similarly, in 2nd season, the maximum height was observed in caraway plants sown at 15th Oct (135.5 cm) with plant spacing of 25 cm. In case of number of branches, the plants sown earlier (15th Oct and 1st Nov) showed the highest number (25.98 and 25.05, respectively) during 1st growing season. Plant spacing also influenced this trait significantly, showing the highest average number of branches (26) in the plants sown at 25 cm spacing. In both growth seasons, the interplay between sowing time and plant spacing had a significant influence on the quantity of caraway branches (Tab. 2). Based on the results shown in Table 2,

Table 2. Effect of sowing time and plant spacing on plant height, number of branches and number of umbels per plant of caraway during two growing seasons

Sowing time			Plant height (cm) at plant spacing			Mean (A)	Number of branches per plant at plant spacing			Mean (A)	Number of umbels per plant at plant spacing			Mean (A)
			25 cm	20 cm	15 cm		25 cm	20 cm	15 cm		25 cm	20 cm	15 cm	
2019	1st Oct		126.6 def	130.3 bcd	132.4 ab	129.75 b	26.0 bcd	25.2 bcd	22.9 def	24.68 a	42.7 cd	40.5 cd	37.5 d	40.22 b
	15th Oct		131.3 abc	132.0 abc	135.2 a	132.83 a	28.4 a	26.2 abc	23.4 bcd	25.98 a	48.5 a	44.9 ab	43.3 bc	45.56 a
	1st Nov		128.3 bc	132.2 abc	133.5 ab	131.33 ab	26.5 ab	25.5 a-d	23.2 bcd	25.05 a	45.4 ab	43.3 bc	41.8 bc	43.5 a
	15th Nov		125.1 efg	123.3 fg	121.6 g	123.32 c	22.9 c-f	21.3 ef	19.7 f	21.3 b	42.3 bc	39.9 cd	37.4 d	39.84 b
	mean (B)		126.95 c	129.45 b	131.51 a	–	26.0 a	25.2 a	22.9 b	24.68 a	44.72 a	42.15 b	39.97 c	–
	LSD ($p \le$ 0.05)	A	2.16				1				1.5			
		B	1.24				1.058				1.0			
		A×B	2.4				1.8				1.9			
2020	1st Oct		128.2 b	133.4 a	135.1 a	132.21 b	27.5 b	26.1 bc	24.8 cd	26.11 b	46.9 b	43.6 bc	40.1 c	43.52 c
	15th Oct		133.9 a	134.8 a	135.5 a	134.72 a	29.3 a	27.3 abc	24.7 cd	27.07 a	53.2 a	47.5 ab	45.3 bc	48.65 a
	1st Nov		133.8 a	134.6 a	134.7 a	134.36 a	28.7 ab	27.1 abc	25.2 bcd	26.96 a	48.5 ab	45.3 bc	43.0 bc	45.62 b
	15th Nov		124.9 c	127.8 bc	128.5 b	127.05 c	24.4 cde	22.3 de	21.1 e	22.61 c	43.7 bc	41.1 c	39.6 c	41.47 d
	mean (B)		130.19 b	132.65 a	133.42 a	–	27.46 a	25.68 b	23.91 c	–	48.07a	44.38 b	42.0 c	–
	LSD ($p \le$ 0.05)	A	1.18				1.2				2.2			
		B	0.86				0.87				1.5			
		A×B	2.9				1.8				3.0			

Explanations: A = plant spacing, B = sowing time; values shown in the table are the means of three replicates; different letters indicate significant differences among treatments according to Duncan's multiple range test when $p \le 0.05$.
Source: own study.

the highest number of umbels per plant (45.56 and 48.65) were recorded in the plants sown on 15th Oct in both growing seasons, respectively. Plant spacing also had significant impact on number of umbels. Maximum umbels were recorded in the plants sown at the distance of 25 cm (44.72 and 48.07 during 2019 and 2020, respectively). Because of the interaction between sowing time and spacing, the quantity of umbels per plant varied significantly. The maximum number of umbels per plant was observed in the plants sown on 15th Oct with planting distance of 25 cm during 1st and 2nd growing season.

The results in Table 3 demonstrated that sowing time and plant spacing had a substantial influence on biomass of caraway plants. During 1st growing season (2019), plants sown on 15th Oct showed maximum dry weight per plant (67.90 g·plant^{-1}) among those were sown on other dates, while the late sowing on 15th Nov showed minimum of dry weight (60.32 g·plant^{-1}). Referring to the plant spacing, 25 cm was the best treatment with relevance to dry weight (67.66 g·plant^{-1}). The maximum dry weight (72.1 g·plant^{-1}) was obtained in the plants seeded on the 15th of Oct with a 25 cm spacing, taking into account the interaction impact of sowing time and plant spacing. Similarly, in 2nd season, the maximum dry weight per plant was observed in caraway plants sown at 15th Oct (73.1 g·plant^{-1}) with plant spacing of 25 cm. In case of fresh weight, the plants sown earlier (15th Oct) showed the highest weight (248.91 g·plant^{-1}) during 1st growing season. Plant spacing also influenced this trait significantly, showing the highest average fresh weight (247.16 g·plant^{-1}) in the plants sown at 25 cm spacing. In both growth seasons, the combination between sowing time and plant spacing had a significant influence on fresh weight of caraway per plant (Tab. 3). Based on the results shown in Table 3, the highest weight of 1000 seeds (9.41 and 9.65 g) were recorded in the plants sown on 15th Oct in both growing seasons, respectively. Plant spacing also had significant impact on 1000-seeds weight (g). Maximum weight was recorded in the plants sown at the distance of 25 cm (9.00 and 9.25 g during 2019 and 2020, respectively). The interaction of sowing time and spacing resulted in significant weight fluctuations in 1000 seeds. During the first and second growth seasons, plants seeded on 15th Oct with a planting spacing of 25 cm had the highest weight of 1000 seeds.

YIELD AND BIOCHEMICAL TRAITS

The sowing time and plant spacing exhibited significant impact on seeds yield of caraway plants. Plants seeded on the 15th of Oct had the highest seed weight per plant (31.47 g·plant^{-1}) among those sown on other dates during the first growing season (2019), while late sowing on the 15th of Nov had the lowest seed weight per plant (22.02 g·plant^{-1}). Concerning the plant spacing, 25 cm was the best treatment with respect to seed weight (30.85 g·plant^{-1}). Considering the cumulative effect of sowing time and plant spacing, the maximum seed weight (36.2 g·plant^{-1}) was recorded in the plants sown on 15th Oct with plant spacing of 25 cm (Fig. 2a). Similarly, in 2nd season, the maximum seeds weight per plant was observed in caraway plants sown at 15th Oct (38.7 g·plant^{-1}) with plant spacing of 25 cm. In case of seed weight per hectare, the plants sown earlier (15th Oct) showed the highest weight (2291.72 kg·ha^{-1}) during 1st growing season.

Table 3. Effect of sowing time and plant spacing on dry weight, fresh weight and 1000-seeds weight of caraway during two growing seasons

Sowing time			Dry weight (g plant^{-1}) at plant spacing			Mean (A)	Fresh weight (g plant^{-1}) at plant spacing			Mean (A)	1000-seeds weight (g) at plant spacing			Mean (A)
			25 cm	20 cm	15 cm		25 cm	20 cm	15 cm		25 cm	20 cm	15 cm	
2019	1st Oct		68.6 b	63.0 de	60.1 f	63.92 c	248.2 bc	231.0 de	220.5 f	233.23 c	8.97 bc	8.75 bcd	8.12 d	8.61 c
	15th Oct		72.1 a	68.0 bc	63.6 d	67.90 a	264.4 a	249.3 bc	233.1 d	248.91 a	9.73 a	9.35 ab	9.16 abc	9.41 a
	1st Nov		68.8 b	66.6 c	61.2 ef	65.52 b	252.1 b	244.1 bc	224.5 ef	240.23 b	9.13 abc	9.04 bc	8.67 cd	8.94 b
	15th Nov		61.1 ef	59.9 f	59.7 f	60.23 d	224.0 ef	219.6 f	218.8 f	220.77 d	8.16 d	7.08 e	6.85 e	7.36 d
	Mean (B)		67.66 a	64.36 b	61.15 c	–	247.16 a	235.98 b	224.21 c	–	9 a	8.55 b	8.19 c	–
	LSD (*p* ≤ 0.05)	A	1.1				4.7				4.7			
		B	1.7				5.88				5.88			
		A×B	3.4				11.6				11.6			
2020	1st Oct		69.8 b	66.4 cd	61.5 f	65.91 b	250.5 bc	237.9 d	225.5 ef	237.95 c	9.07 bcd	8.92 cde	8.36 e	8.78 c
	15th Oct		73.1 a	69.1 bc	65.3 de	69.14 a	267.9 a	253.3 bc	239.3 d	253.48 a	9.96 a	9.64 ab	9.37 abc	9.65 a
	1st Nov		69.4 b	67.3 bcd	62.8 de	66.51 b	254.6 b	246.7 c	230.1 e	243.78 b	9.32 a-d	9.16 bcd	8.95 cde	9.14 b
	15th Nov		62.2 f	61.0 f	60.1 f	65.9 c	228.1 e	223.8 e	220.5 ef	224.13 d	8.68 de	7.25 f	6.99 f	7.64 d
	Mean (B)		68.63 a	65.96 b	62.425 c	–	250.27 a	240.40 b	228.84 c	–	9.25 a	8.74 b	8.41 c	–
	LSD (*p* ≤ 0.05)	A	1.6				4.3				4.3			
		B	1.4				4.4				4.4			
		A×B	2.8				8.9				8.9			

Explanations as in Tab. 2.
Source: own study.

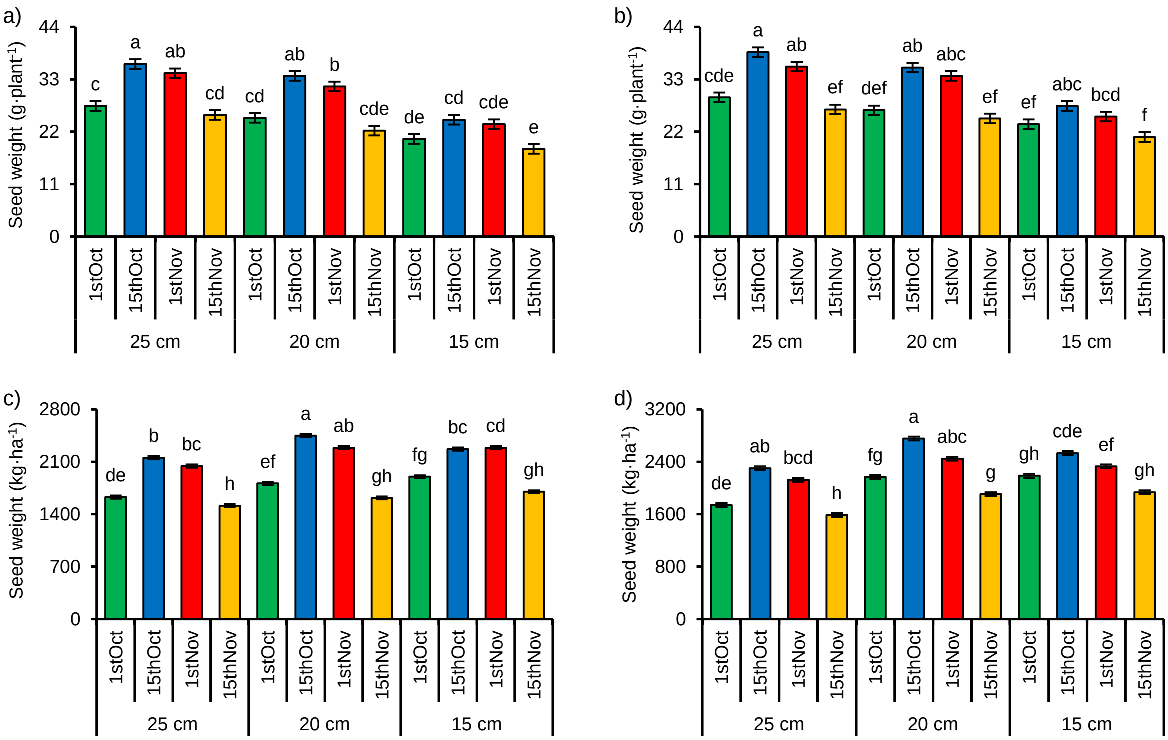


Fig. 2. Effect of sowing time and plant spacing on seed weight of caraway during two growing seasons: a) seed weight (g·plant^{-1}) season 2019, b) seed weight (g·plant^{-1}) season 2020, c) seed weight (kg·ha^{-1}) season 2019, d) seed weight (kg·ha^{-1}) season 2020; different letters indicate significant differences among treatments according to Duncan's Multiple Range test when $p \leq 0.05$; source: own study

Plant spacing had a substantial impact on this feature, with 20 cm spacing producing the greatest average seed weight per hectare (2041.56 g·plant^{-1}). The interaction between sowing time and plant spacing had also a remarkable impact seed weight of caraway per hectare in both growing seasons (Fig. 2b).

During 1st growing season (2019), plants sown on 15th Oct showed maximum value of volatile oil (1.51%) among those were sown on other dates. When it came to plant spacing, 25 cm was the greatest option for volatile oil (1.60%). The most volatile oil (1.70%) was obtained in the plants seeded on the 15th of Oct with a plant spacing of 25 cm, when the cumulative impact of sowing time and plant spacing was considered (Fig. 3a). While, in 2nd season, the maximum volatile oil percentage was observed in caraway plants sown at 1st Nov and 15th Oct (1.90 and 1.86%, respectively) with plant spacing of 25 cm (Fig. 3b). In case of volatile oil yield cm^3·plant^{-1}), the plants sown earlier (15th Oct) showed the highest yield (0.478 cm^3·plant^{-1}) during 1st growing season. Plant spacing also influenced this trait significantly, showing the highest average of volatile oil yield (0.497 cm^3·plant^{-1}) in the plants sown at 25 cm spacing. In both growth seasons, the interaction between sowing time and plant spacing had a significant influence on volatile oil output per plant; the greatest volatile oil yields (0.599 and 0.719 cm^3·plant^{-1}) were reported during the first and second growing seasons, respectively (Fig. 3c, d).

The highest value of volatile oil yield expressed in cubic decimeters per hectare (34.32 and 40.29 dm^3·ha^{-1}) were recorded in the plants sown on 15th Oct in both growing seasons, respectively. The amount of volatile oil output in cubic decimeters per hectare was similarly affected by plant spacing. The plants seeded at a distance of 25 cm had the highest value (29.51 and 34.27 dm^3·ha^{-1} during 2019 and 2020, respectively). Significant differences in volatile oil yield expressed in cubic decimeters per hectare emerged from the

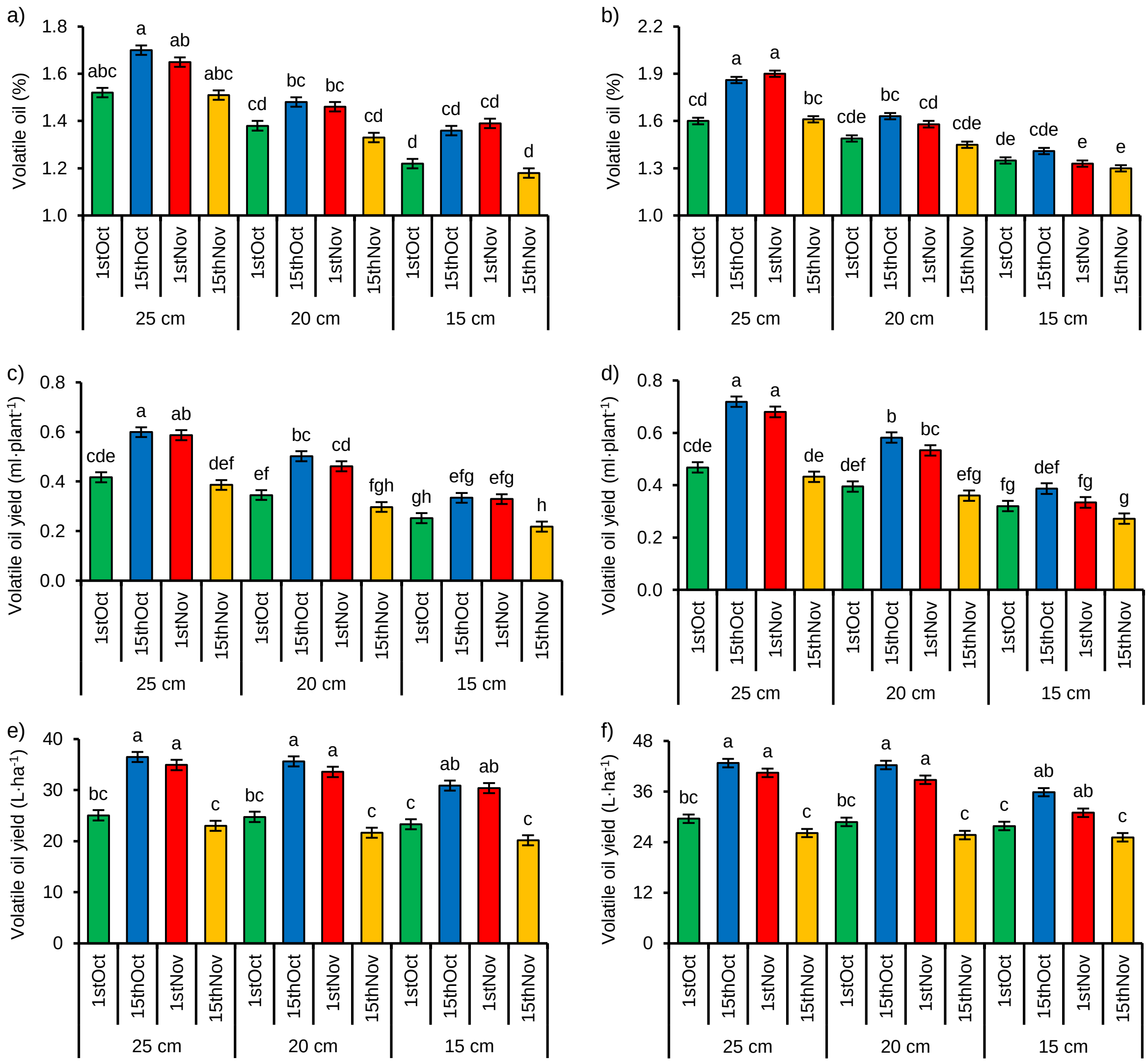


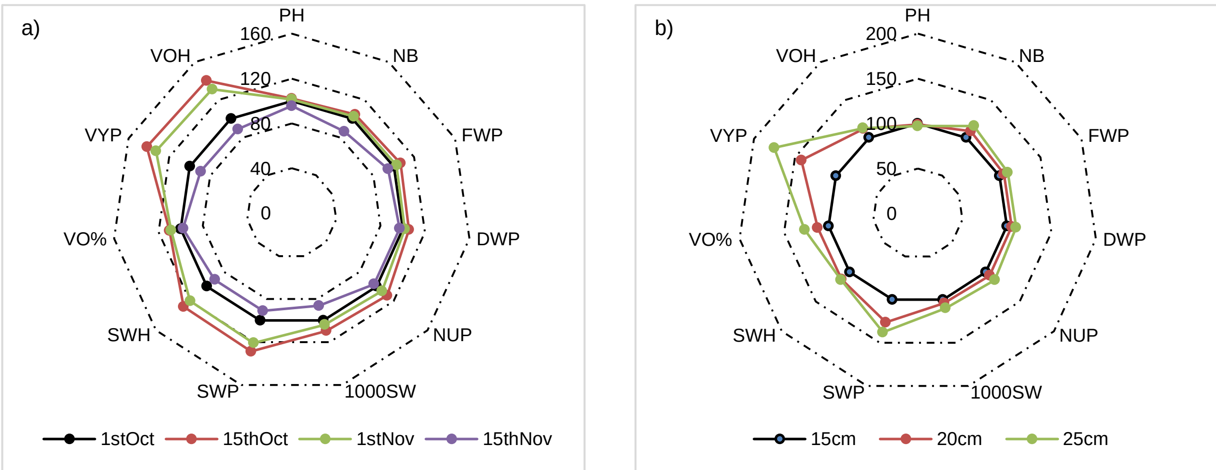
Fig. 3. Effect of sowing time and plant spacing on volatile oil (%) and oil yield (cm^3·plant^{-1} and dm^3·ha^{-1}) of caraway during two growing seasons: a) volatile oil (%) season 2019, b) volatile oil (%) season 2020, c) volatile oil yield (cm^3·plant^{-1}) season 2019, d) volatile oil yield (cm^3·plant^{-1}) season 2020, e) volatile oil yield (dm^3·ha^{-1}) season 2019, f) volatile oil yield (dm^3·ha^{-1}) season 2020; different letters indicate significant differences among treatments according to Duncan's multiple range test when $p \leq 0.05$; source: own study

interaction of planting timing and spacing. The maximum average of volatile oil yield in cubic decimeters per hectare was observed in the plants sown on 15th Oct with planting distance of 25 cm (36.48 and 42.76 $dm^3 \cdot ha^{-1}$) during 1st and 2nd growing season, respectively (Fig. 3e, f).

DISCUSSION

Genetic and agronomic variables impact the development and output of medicinal plants [YUAN *et al.* 2020]. One of the most important success factors in agriculture is choosing the most acceptable sowing time and planting density [MARESMA *et al.* 2019; MOOSAVI *et al.* 2015]. The increase in plant height following the increase in plant density tends to cause the rise in inter-plant light rivalry and the disturbance of the balance of growth regulators [CRAINE, DYBZINSKI 2013]. The reduction in light penetration into the middle and lower layers of the canopy reduces auxin decomposition [CASAL 2013], thus, under these conditions, if other environmental factors such as moisture and soil fertility restrict the growth of plants, plant height increases [IMAM, RANJBAR 2000]. For each crop, there is an idealistic sowing time, further delay can typically reduce the yield [PATEL *et al.* 2019]. Experts in agriculture believed that the cornerstone of a successful agronomic system is the establishment of an acceptable density of healthy plants at farm level [SHEKARA *et al.* 2016]. The increase in the number of plants per unit area causes fierce competition between plants over environmental variables such as light, nutrients, and humidity. Similarly, the decrease of the number of plants per unit area causes to the lack of economic return from the crop [CRAINE, DYBZINSKI 2013]. In current study, the plants sown in mid-October with planting distance of 25 cm showed dominant growth and development among other treatments (Fig. 4).

Our results provide light on the importance of plant spacing and sowing time in boosting the caraway plant's qualitative and quantitative production, as well as the effectiveness of combining these treatments to change the features evaluated in these plants. The maximum yield is understood to derive from the most favourable environmental conditions for each crop [LILIANE, CHARLES 2020]. In our present experience, the plants seeded on 15th Oct were exposed to the optimal short-day period, optimum low temperature, and optimum high moisture availability, as



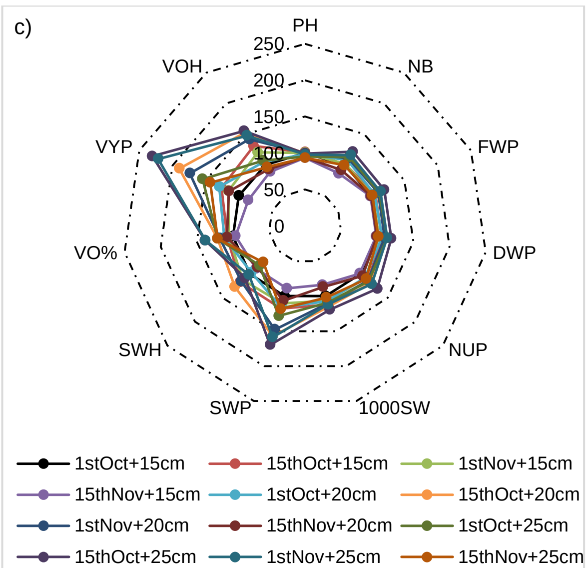


Fig. 4. A radar diagram illustrating relative deviations from the control (a black circle of the relative value of 100%) of all studied traits for a given variant (%) under the effect of: a) sowing time, b) plant spacings, c) interaction between sowing time and plant spacings; PH = plant height, NB = number of branches, FWP = fresh weight per plant, DWP = dry weight ($g \cdot plant^{-1}$), NUP = no. of umbels per plant, 1000 SW = 1000 seed weight, SWP = seed weight per plant, SWH = seed weight per hectare, VO% = volatile oil %, VYP = volatile oil yield per plant, VOH = volatile oil yield per hectare; source: own study

shown in Figure 1. This might explain the higher yield. They had greater vegetative growth and cell division, which contributed to increased stem elongation, particularly in the stems. SINGH *et al.* [2005] found a reduction in plant height in fenugreek plants (*Trigonella foenum-graecum*) whose seeding was postponed from October to November. Late-sown safflowers had smaller plant diameters, resulting in a drop in sap production, according to AMIRI [2003]. This was due to the conjunction of the long day period and higher temperatures, according to AMIRI [2003]. The appropriate climatic circumstances and surroundings of components may boost biosynthetic processes and photosynthesis to produce excellent plants, which might explain the findings [HIRICH *et al.* 2014; SAJJAD *et al.* 2014; WANG *et al.* 2020]. The low below and above ground competition between plants for light, water, and nutrients may explain the rise in these features with increased plant spacing between caraway plants. These results are in accordance with those obtained by BADRAN *et al.* [2007] on fennel plants, and BHARGAVA *et al.* [2007] and SIEF *et al.* [2015] on quinoa plants, they reported that plant density is one of the important factors that affect the final yield. Increased planting distances up to 15 cm wide resulted in a drop in grain output. Growth and yield were reduced due to changes in radiation, daylight hours, and an unfavourable seed temperature. The importance of the proper season and time of sowing is irreplaceable in all other agronomic managements, and the advantage of adequate sowing time has been recorded in numerous agricultural settings [KADHUM 2009; MOHAMMADGHASEMI *et al.* 2021]. The lower fixed oil output with crops planted after 1st Nov might be attributed to the crops' poor environment for oil biosynthesis. Early seeding increased essential oil yields, perhaps due to favourable climatic inputs that boosted essential oil production, resulting in more plant metabolites. According to EL-MEKAWY [2012], essential oil content is always higher when the crop is sown early.

Abiotic stress factors such as heat, soil salinity, drought, tropospheric ozone, and excessive UV radiation are already causing major agricultural yield declines, and due to the impact of global climate change, they will become even more pronounced in the coming decades – Figure 5 [ASHMORE 2006; FENG, KOBAYASHI, 2009; WASSMANN *et al.* 2009a]. Climate change is the incidence of unfavourable environmental conditions and has prompted efforts around the world to adjust agricultural activity to these stresses [ELSHEERY, CAO 2008; ELSHEERY *et al.* 2020a, b, c; HELALY *et al.* 2017; LOBELL *et al.* 2008; NASER *et al.* 2016; WASSMANN *et al.* 2009b]. Physiological shifts in crop plants as a result of exposure to abiotic stresses entail changes in photosynthetic gas exchange and assimilate translocation [MORGAN *et al.* 2004], altered water absorption and evapotranspiration, impacts on nutrient uptake and translocation [SÁNCHEZ-RODRÍGUEZ *et al.* 2010], antioxidant reactions [BRAY 2000], programmed cell death [KANGASJÄRVI 2005], and altered gene expression and enzyme activity [DURRETT *et al.* 2007; FREI *et al.* 2010]. These exposures are expected to have a variety of impacts on seed chemical composition and, as a result, agricultural product content.

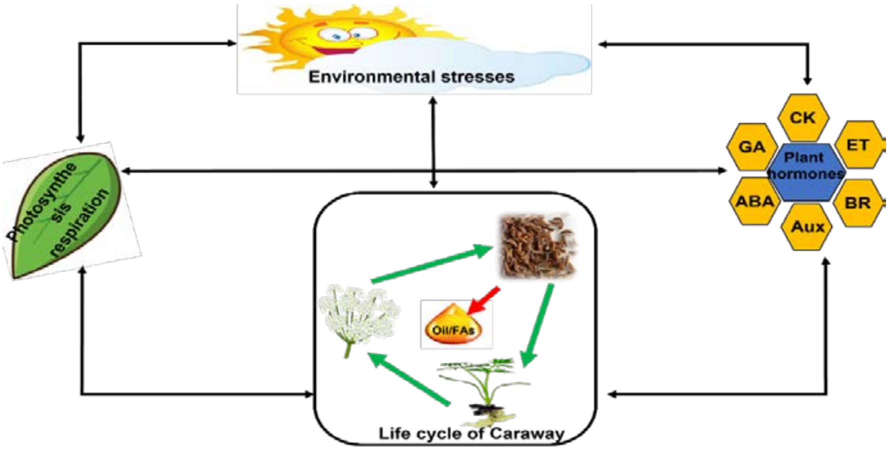


Fig. 5. Seed development and accumulation in caraway seeds and the regulation network; CK = cytokine, GA = gibberellic acid, ABA = abscisic acid, AUX = auxin, BR = brassinosteroid, ET = ethylene; source: own elaboration

CONCLUSIONS

In present study, the effect of different sowing times and plant spacings on the growth, yield, and oil production of caraway plants were investigated. Under semi-arid conditions (Egypt), the findings revealed that seeding caraway plants on the 15th of October with a plant spacing of 25 cm produced the maximum dry weight (72.6 g·plant^{-1}), fresh weight (266.15 g·plant^{-1}), seed yield (37.43 g·plant^{-1}), and oil yield (0.659 cm^3·plant^{-1}) and oil yield (0.659 cm^3·plant^{-1}). The plants receiving the same treatment had the most umbels (50.83 number per plant) and essential oil (1.78%). Plants seeded on the 15th of November with a spacing of 15 cm, on the other hand, had the lowest values of reported features. While planting caraway plants on the 15th of October with a 15 cm plant spacing yielded the maximum value of plant height (135.35 cm). Finally, the plants sown on 15th October with a maximum plant spacing of 25 cm exhibited the best morphological, biochemical, and yield properties of caraway.

ACKNOWLEDGMENTS

Thanks to all field technicians at College of Agriculture, Al-Azhar University branch Assiut, Egypt.

REFERENCES

ALVES SOUZA S., HIGINO VIEIRA J., BISPO DOS SANTOS FARIAS D., DA SILVA G.H., CABRAL ALEMAN C. 2020. Impact of irrigation frequency and planting density on bean's morpho-physiological and productive traits. Water. Vol. 12(9), 2468. DOI 10.3390/w12092468.

AMIRI H. 2003. Effect planting date and plant density on forage and seed of corn in Gorgan Iran region. MSc Thesis. Islamic Azad University, Birjand Branch, Iran.

ASHMORE M., TOET S., EMBERSON L. 2006. Ozone: A significant threat to future world food production? New Phytologist. Vol. 170(2) p. 201–204. DOI 10.1111/j.1469-8137.2006.01709.x.

AYUB M., NADEEM M., TANVEER A., TAHIR M., SAQIB M., NAWAZ R. 2008. Effect of different sowing methods and times on the growth and yield of fennel (*Foeniculum vulgare* Mill.). Pakistan Journal of Botany. Vol. 40(1) p. 259–264.

BADRAN F., ABDALLA N.M., ALY M., IBRAHIM S.M. 2007. Response of fennel plants to seeding rate and partial replacement of mineral NPK by biofertilization treatments. [8th African Crop Science Society Conference]. [27–31.10.2007. Egypt: El-Minia].

BECK H.E., ZIMMERMANN N.E., MCVICAR T.R., VERGOPOLAN N., BERG A., WOOD E.F. 2018. Present and future Köppen-Geiger climate classification maps at 1-km resolution. Science Data. Vol. 5(1) p. 1–12. DOI 10.1038/sdata.2018.214.

BEGNA S.H., ANGADI S.V. 2016. Effects of planting date on winter canola growth and yield in the southwestern US. American Journal of Plant Sciences. Vol. 7(1) p. 201–217. DOI 10.4236/ajps. 2016.71021.

BHARGAVA A., SHUKLA S., OHRI D. 2007. Effect of sowing dates and row spacings on yield and quality components of quinoa (*Chenopodium quinoa*) leaves. Indian Journal of Agriculture Science. Vol. 77(11) p. 748–751.

BPC 2009. British pharmacopoeia. London. British Pharmacopoeia Commission. ISBN 011322799X pp. 5.

BRAY E.A. 2000. Response to abiotic stress. Biochemistry molecular biology of plants. Annual Review of Plant Biology. Vol. 55 p. 373–399. DOI 10.1146/annurev.arplant.55.031903.141701.

CASAL J.J. 2013. Canopy light signals and crop yield in sickness and in health. International Scholarly Research Notices. Vol. 2013. DOI 10.1155/2013/650439.

CRAINE J.M., DYBZINSKI R. 2013. Mechanisms of plant competition for nutrients, water and light. Functional Ecology. Vol. 27(4) p. 833–840. DOI 10.1111/1365-2435.12081.

DADKHAH A., KAFI M., RASAM G. 2010. The effect of planting date and plant density on growth traits, yield quality and quantity of Matricaria (*Matricaria chamomilla*). International Journal of Horticultural Science Vol. 23(2) DOI 10.22067/JHORTS4.V1388I2.2592.

DURRETT T.P., GASSMANN W., ROGERS E.E. 2007. The FRD3-mediated efflux of citrate into the root vasculature is necessary for efficient iron translocation. Plant Physiology. Vol. 144(1) p. 197–205. DOI 10.1104/pp.107.097162.

EISA S.S., ABD EL SAMAD E.H., HUSSIN S.A., ALI E.A., EBRAHIM M., GONZÁLEZ J.A., ..., ABDEL-ATI A.A. 2018. Quinoa in Egypt-plant density effects on seed yield and nutritional quality in marginal regions. Middle East Journal of Applied Sciences. Vol. 8(2) p. 515–522.

EL-KHAYYATT A.-A. S., GOUDA H.A. 2005. Effect of sowing date and potassium fertilization on growth, yield and chemical composition of *Foeniculum vulgare* Mill plants. Annals of Agricultural Science, Moshtohor. Vol. 43(3) p. 1246–1269.

EL-MEKAWY M. 2012. Growth and yield of *Niglla sativa* L. plant influenced by sowing date and irrigation treatments. American-Eurasian Journal of Agricultural & Environmental Sciences. Vol. 12(4) p. 499–505.

ELSHEERY N.I., CAO K.-F. 2008. Gas exchange, chlorophyll fluorescence, and osmotic adjustment in two mango cultivars under drought stress. Acta Physiologiae Plantarum. Vol. 30(6) p. 769–777. DOI 10.1007/s11738-008-0179-x.

ELSHEERY N.I., HELALY M.N., EL-HOSEINY H.M., ALAM-ELDEIN S.M. 2020a. Zinc oxide and silicone nanoparticles to improve the resistance mechanism and annual productivity of salt-stressed mango trees. Agronomy. Vol. 10(4), 558. DOI 10.3390/agronomy10040558.

ELSHEERY N.I., HELALY M.N., OMAR S.A., JOHN S.V.S., ZABOCHNICKA-ŚWIĄTEK M., KALAJI H.M., RASTOGI A. 2020b. Physiological and molecular mechanisms of salinity tolerance in grafted cucumber. South African Journal of Botany. Vol. 130 p. 90–102. DOI 10.1016/j.sajb.2019.12.014.

ELSHEERY N.I., SUNOJ V.S.J., WEN Y., ZHU J.J., MURALIDHARAN G., CAO K.F. 2020c. Foliar application of nanoparticles mitigates the chilling effect on photosynthesis and photoprotection in sugarcane. Plant Physiology and Biochemistry. Vol. 149 p. 50–60. DOI 10.1016/j.plaphy.2020.01.035.

EVANS W.C. 2009. Trease and Evans' pharmacognosy [e-book]. Elsevier Health Sciences. ISBN 9780702041891 pp. 616.

EZZ EL-DIN A.A., HENDAWY S., AZIZ E.E., OMER E. 2010. Enhancing growth, yield and essential oil of caraway plants by nitrogen and potassium fertilizers. International Journal of Academic Research. Vol. 2(3) p. 192–197.

FARAHANI H.A., LEBASCHI M.H., HAMIDI A. 2008. Effects of arbuscular mycorrhizal fungi, phosphorus and water stress on quantity and quality characteristics of coriander. Advances in Natural and Applied Sciences. Vol. 2(2) p. 55–60.

FENG Z., KOBAYASHI K. 2009. Assessing the impacts of current and future concentrations of surface ozone on crop yield with meta-analysis. Atmospheric Environment. Vol. 43(8) p. 1510–1519. DOI 10.1016/j.atmosenv.2008.11.033.

FREI M., TANAKA J.P., CHEN C.P., WISSUWA M. 2010. Mechanisms of ozone tolerance in rice: characterization of two QTLs affecting leaf bronzing by gene expression profiling and biochemical analyses. Journal of Experimental Botany. Vol. 61(5) p. 1405–1417. DOI 10.1093/jxb/erq007.

FUTULESS K., KWAGA Y., CLEMENT T., ANEJA K.R., JOSHI R., SHARMA C., ..., AHAOTU N. 2010. Effect of sowing date on calyx yield and yield components of roselle (*Hibiscus sabdariffa* L.) in Nothern Guinea Savanna. New York Science Journal. Vol. 3(11) p. 1–4.

GOMEZ K.A., GOMEZ A.A. 1984. Statistical procedures for agricultural research. 2nd ed. John Wiley & Sons. ISBN 978-0-471-87092-0 pp. 680.

HASSAN A.A. 2011. Post harvest technology and physiology of fruit vegetables. Egypt: Al-Dar Al-Arabiah Lil Nashr Wa Al-Tawsia Cairo. [In Arabic].

HELALY M.N., EL-HOSEINY H., EL-SHEERY N.I., RASTOGI A., KALAJI H.M. 2017. Regulation and physiological role of silicon in alleviating drought stress of mango. Plant Physiology and Biochemistry. Vol. 118 p. 31–44. DOI 10.1016/j.plaphy.2017.05.021.

HIRICH A., CHOUKR-ALLAH R., JACOBSEN S.E. 2014. Quinoa in Morocco – effect of sowing dates on development and yield. Journal of

Agronomy and Crop Science. Vol. 200(5) p. 371–377. DOI 10.1111/jac.12071.

IMAM Y., RANJBAR G. 2000. Effect of plant density and drought stress at vegetative growth stage on yield, yield components and water use efficiency in grain corn. Iranian Journal of Agricultural Researches. Vol. 2(3) p. 118–129.

KADHUM M. 2009. Evaluation yield of some varieties of *Nigella sativa* L. under different climatic conditions. Anbar Journal of Agricultural Sciences. Vol. 7(1) p. 255–261.

KANGASJÄRVI J., JASPERS P., KOLLIST H. 2005. Signalling and cell death in ozone-exposed plants. Plant, Cell Environment. Vol. 28(8) p. 1021–1036. DOI 10.1111/j.1365-3040.2005.01325.x.

KHORSHIDI J., TABATABAEI M. F., OMIDBAIGI R., SEFIDKON F. 2009. Effect of densities of planting on yield and essential oil components of fennel (*Foeniculum vulgare* Mill. var. *Soroksary*). Journal of Agricultural Science. Vol. 1(1) p. 152–157. DOI 10.5539/jas.v1n1p152.

KLUTE A. 1986. Water retention: laboratory methods. Methods of soil analysis: Part 1. Physical and mineralogical methods. Vol. 5 p. 635–662.

KUMAR A., SINGH R., CHHILLAR R. 2006. Nitrogen requirement of fennel (*Foeniculum vulgare*): based cropping systems. Indian Journal of Agricultural Science. Vol. 76(10) p. 599–602.

LAWLESS J. 2013. The encyclopedia of essential oils: the complete guide to the use of aromatic oils in aromatherapy, herbalism, health, and well being. Newburyport. Conari Press. ISBN 157324614X pp. 226.

LILIANE T.N., CHARLES M.S. 2020. Factors affecting yield of crops. In: Agronomy climate change food security. Chapt. 2 p. 1–16. DOI 10.5772/intechopen.90672.

LOBELL D.B., BURKE M.B., TEBALDI C., MASTRANDREA M.D., FALCON W.P., NAYLOR R.L. 2008. Prioritizing climate change adaptation needs for food security in 2030. Science. Vol. 319(5863) p. 607–610. DOI 10.1126/science.1152339.

MARESMA A., BALLESTA A., SANTIVERI F., LLOVERAS J. 2019. Sowing date affects maize development and yield in irrigated Mediterranean Environments. Agriculture. Vol. 9(3), 67. DOI 10.3390/ agriculture9030067.

MENARIA B., MALIWAL P. 2011. Maximization of seed yield in transplanted fennel (*Foeniculum vulgare* Mill.). Journal of Spices Aromatic Crops. Vol. 16(1) p. 46–49.

MOHAMMADGHASEMI V., MOGHADDAM S.S., RAHIMI A., POURAKBAR L., POPOVIĆ-DJORDJEVIĆ J. 2021. Morpho-biochemical traits and macro-elements of *Lallemantia iberica* (MB) Fischer & Meyer, as affected by winter (late autumn) sowing, chemical and nano-fertilizer sources. Acta Physiologiae Plantarum. Vol. 43(2) p. 1–19. DOI 10.1007/s11738-020-03169-y.

MOOSAVI G., SEGHATOLESLAMI M., EBRAHIMI A., FAZELI M., JOUYBAN Z. 2015. The effect of nitrogen rate and plant density on morphological traits and essential oil yield of coriander. Journal of Ornamental Plants. Vol. 3(2) p. 95–103.

MORGAN P.B., BERNACCHI C.J., ORT D.R., LONG S.P. 2004. An in vivo analysis of the effect of season-long open-air elevation of ozone to anticipated 2050 levels on photosynthesis in soybean. Plant Physiology. Vol. 135(4) p. 2348–2357. DOI 10.1104/pp.104.043968.

NASER H.M., HANAN E.-H., ELSHEERY N.I., KALAJI H.M. 2016. Effect of biofertilizers and putrescine amine on the physiological features and productivity of date palm (*Phoenix dactylifera* L.) grown on reclaimed-salinized soil. Trees. Vol. 30(4) p. 1149–1161. DOI 10.1007/s00468-016-1353-1.

NLEYA T., SCHUTTE M., CLAY D., REICKS G., MUELLER N. 2020. Planting date, cultivar, seed treatment, and seeding rate effects on soybean growth and yield. Agrosystems, Geosciences Environment. Vol. 3(1), e20045. DOI 10.1002/agg2.20045.

OYEWOLE C., MERA M. 2010. Response of roselle (*Hibiscus sabdariffa* L.) to rates of inorganic and farmyard fertilizers in the Sudan savanna ecological zone of Nigeria. African Journal of Agricultural Research. Vol. 5(17) p. 2305–2309. DOI 10.5897/AJAR.9000600.

PATEL A., PATEL M., PATEL R., MOTE B. 2019. Effect of different sowing date on phenology, growth and yield of rice–a review. Plant Archives. Vol. 19(1) p. 12–16.

PETER K.V. (ed.) 2006. Handbook of herbs and spices. Vol. 3. 1st ed. Sawstone. Woodhead Publishing. ISBN 9780081016268 pp. 145.

RUBATZKY V.E., QUIROS C.F., SIMON P.W. 1999. Carrots and related vegetable Umbelliferae: Wallingford. CABI Publishing. ISBN 9780851991290 pp. 175.

SACHAN A.K., DAS D.R., KUMAR M. 2016. *Carum carvi* – An important medicinal plant. Journal of Chemical Pharmaceutical Research. Vol. 8(3) p. 529–533.

SAJJAD A., MUNIR H., AHMED ANJUM S., TANVEER M., REHMAN A. 2014. Growth and development of *Chenopodium quinoa* genotypes at different sowing dates Journal of Agricultural Research. Vol. 52(4) p. 535–546.

SÁNCHEZ-RODRÍGUEZ E., DEL MAR RUBIO-WILHELMI M., CERVILLA L.M., BLASCO B., RIOS J.J., LEYVA R., ROMERO L., RUIZ J.M. 2010. Study of the ionome and uptake fluxes in cherry tomato plants under moderate water stress conditions. Plant Soil. Vol. 335(1) p. 339–347. DOI 10.1007/s11104-010-0422-2.

SELIM S., EBTSAM M., TAWFIK M., ABOU-SREEA A. 2013. Effect of sowing date, sow spacing and bio-fertilizer on yield and oil quality of fennel plant (*Foeniculum vulgare* Mill.). Australian Journal of Basic Applied Sciences. Vol. 7(2) p. 882–894.

SHEKARA C., BALASUBRAMANI N., SHARMA R., SHUKLA C., KUMAR A., CHAUDHARY B.C., BAUMANN M. 2016. Farmer's handbook on basic agriculture. Navsari, Gujarat India. Desai Fruits & Vegetables Pvt. Ltd. ISBN 8085199129097 pp. 154.

SHRESTHA J., KANDEL M., CHAUDHARY A. 2018. Effects of planting time on growth, development and productivity of maize (*Zea mays* L.). Journal of Agriculture Natural Resources. Vol. 1(1) p. 43–50. DOI 10.3126/janr.v1i1.22221.

SIEF A., EL-DEEPAH H., KAMEL A., IBRAHIM J.F. 2015. Effect of various inter and intra spaces on the yield and quality of quinoa (*Chenopodium quinoa* Willd.). Journal of Plant Production. Vol. 6(3) p. 371–383. DOI 10.21608/jpp.2015.49331.

SINGH S., BUTTAR G., SINGH S., BRAR D. 2005. Effect of different dates of sowing and row spacings on yield of fenugreek (*Trigonella foenum gracum*). Journal of Medicinal Aromatic Plant Sciences. Vol. 27(4) p. 629–630.

SINGH S.K., TRIPATHI S., DWIVEDI A. 2009. Effect of planting dates, sowing methods and row spacing on yield of fennel. Annals of Horticulture. Vol. 2(2) p. 249–250.

SNEDECOR G.W., COCHRAN W.G. 1989. Statistical methods. 8th ed. Ames. Iowa State University Press. ISBN 0813815614 p. 503.

SORGONÀ A., ABENAVOLI M.R., CACCO G., GELSOMINO A. 2011. Growth of tomato and zucchini seedlings in orange waste compost media: pH and implication of dosage. Compost Science & Utilization. Vol. 19(3) p. 189–196. DOI 10.1080/1065657X.2011.10736999.

THALJI T., SHALALDEH G. 2006. Effect of planting date on faba bean (*Vicia faba* L.) nodulation and performance under semiarid conditions. World Journal of Agricultural Sciences. Vol. 2(4) p. 477–482.

WANG N., WANG F., SHOCK C.C., MENG C., QIAO L. 2020. Effects of management practices on quinoa growth, seed yield, and quality. Agronomy. Vol. 10(3), 445. DOI 10.3390/agronomy 1003 0445.

WASSMANN R., JAGADISH S., HEUER S., ISMAIL A., REDONA E., SERRAJ R., …, SUMFLETH K. 2009a. Climate change affecting rice production: The physiological and agronomic basis for possible adaptation strategies. Advances in Agronomy. Vol. 101 p. 59–122. DOI 10.1016/S0065-2113(08)00802-X.

WASSMANN R., JAGADISH S., SUMFLETH K., PATHAK H., HOWELL G., ISMAIL A., …, HEUER S. 2009b. Regional vulnerability of climate change impacts on Asian rice production and scope for adaptation. Advances in Agronomy. Vol. 102 p. 91–133. DOI 10.1016/ S0065-2113(09)01003-7.

YANCEY P.H., CLARK M.E., HAND S.C., BOWLUS R.D., SOMERO G.N. 1982. Living with water stress: evolution of osmolyte systems. Science. Vol. 217(4566) p. 1214–1222.

YUAN Y., TANG X., JIA Z., LI C., MA J., ZHANG J. 2020. The effects of ecological factors on the main medicinal components of *Dendrobium officinale* under different cultivation modes. Forests. Vol. 11(1), 94. DOI 10.3390/f11010094.