# ANISE YIELD AND YIELD COMPONENTS WITH VARYING SOWING DATES, PLANT DENSITIES, AND NITROGEN FERTILIZERS IN SULAIMANI REGION- IRAQ

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## ABSTRACTS

**To improve both the quantity and quality of anise *(Pimpinella anisum L.)* seeds, a field experiment was conducted in the fall season of 2021-2022 at two locations: Qlyasan Agricultural Research Station and Kanipanka Research Station. The experiment was designed as factorial experiments (2×2×3) within Randomized Complete Block Design (RCBD) using 3 replicates, the first factor was two sowing dates (20$^{th}$ Oct. and 20$^{th}$ Nov), the second factor was plant density (50 and 100 plants m$^{-2}$), and the third factor was the application of Nitrogen (15 and 30 kg ha$^{-1}$ as well as control). The mean results of the both locations indicated that the highest seed yield of 2759 kg ha$^{-1}$ gained by the combination of the Oct. 20 sowing date within 100 plants m$^{-2}$ density and the application of 30 kg ha$^{-1}$ as urea 46% nitrogen, while the highest essential oil yield of 31 kg ha$^{-1}$ occurred with the combination of the sowing date of Oct. 20 with 100 plants m$^{-2}$ and 15 Kg ha$^{-1}$ nitrogen. The Kanipanka location outperformed the Qlyasan location by 91.50% and 46.60% for the characters' seeds yield and essential oil yield, respectively.**

**Keywords: Medicinal plant, *Pimpinella anisum L.*, Seed yield, Essential oil%, and Essential oil yield.**

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## حاصل اليانسون ومكوناته مع اختلاف مواعيد الزراعة، الكثافات النباتية والأسمدة النيتروجينية في منطقة السليمانية

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## المستخلص

من أجل زيادة كمية وجودة بذور اليانسون، أجريت تجربة حقلية في خريف 2021-2022 في موقعين مختلفين هما محطة أبحاث قليسان الزراعية ومحطة أبحاث كاني بانكة. صممت التجربة كتجربة عاملية (2 × 2 × 3) طبقت بإستخدام تصميم القطاعات الكاملة العشوائية (RCBD) وبثلاث مكررات. العامل الأول عبارة عن موعدين للزراعة (20 أكتوبر و20 نوفمبر)، والعامل الثاني كان كثافتين نباتيتين (50 و100 نبات م$^{2}$) والعامل الثالث كان إضافة النيتروجين بمستوين (15 و30 كغم هكتار$^{-1}$) بالإضافة الى المقارنة. أشارت نتائج متوسط كلا الموقعين إلى أن أعلى محصول للبذور كان 2759 كغم هكتار$^{-1}$ تم الحصول عليه عن طريق الجمع بين موعد الزراعة 20 أكتوبر ضمن كثافة نباتية 100 نبات م$^{2}$ واستخدام 30 كغم هكتار$^{-1}$ من النيتروجين، بينما كان أعلى حاصل الزيت العطري الذي كان 31 كغم هكتار$^{-1}$ نتج من التداخل بين موعد الزراعة 20 أكتوبر و الكثافة النباتية 100 نبات م$^{2}$ مع 15كغم هكتار$^{-1}$ نيتروجين. تفوق موقع كانيبانكا في الأداء على موقع قليسان بنسبة 91.50٪ و46.60٪ في كل من انتاج البذور وانتاج حاصل الزيت العطري على التوالي.

الكلمات المفتاحية: النبتات الطبي. *Pimpinella anisum* L. ، انتاج البذور، نسبة الزيت العطري، حاصل الزيت العطري.

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## INTRODUCTION

Traditional medical systems worldwide have long utilized medicinal plants to treat a range of illnesses. Medicinal plants contain various bioactive compounds that possess therapeutic properties and can be used to treat several diseases (20). In recent years, medicinal plants have gained significant attention in modern medicine due to their accessibility, affordability, widespread acceptance, and safety, making herbal remedies highly valued globally (8). Anise (*Pimpinella anisum* L.) is an annual herb with white flowers and green to yellow small seeds. It is a member of the Apiaceae family (33), which is recognized for the unique flavors derived from its essential oils. The plant is native to the Mediterranean area (38) and grows successfully in the countries neighboring the Kurdistan region. It produced a seed yield of 562.1 kg ha-1 and 15.1 kg ha-1 of essential oil in Turkey (14). Anise seed contains around 1.5–5.0% essential oil (31), and it is characterized by a higher amount of trans-anethole (90%) and methyl chavicol (estragole), 0.19 (33). The essence of the plant is contained in these oils, which are a mixture of aromatic, volatile substances. Anise is a fragrant and significant medicinal plant that is extensively grown for its seeds. Because these seeds have a high concentration of essential oils and antioxidants, they are utilized in a variety of industries, including food, pharmaceuticals, and cosmetics. However, the yield and quality of these seeds are influenced by various environmental factors and cultural practices, such as sowing dates, plant density, and nitrogen fertilizer (19, 40). The date of sowing is a crucial factor in crop productivity. Better use of time, light, temperature, precipitation, and other elements is made possible by the ideal sowing date (32). Sowing dates for anise crops can significantly affect plant growth, yield, and essential oil content. Earlier sowing dates generally result in higher yields and essential oil content, while later sowing dates can lead to reduced growth and yield (2). The microenvironment of an anise field is largely determined by plant spacing and seed rate. The narrower sowings, anise branches, and umbels decreased (32). Sowing at 20 × 10 cm could be the optimum row space for higher productivity in anise (17). For optimum crop production, it's important to control nitrogen fertilizer application. It influences photosynthetic efficiency and leaf development, which results in the generation of dry matter, making it one of the most crucial nutrients for crop production (7). The use of fertilizer nitrogen (N) for crop production primarily influences soil health through changes in organic matter content, microbial life, and soil acidity (29). According to certain supporting studies, nitrogen fertilization has an impact on the yield quantity and quality of medicinal plants (25). The impact of climate change on natural and managed systems is a major concern, particularly the effect of warming on major agricultural crop production (36). By optimizing these factors, a high yield can be achieved by improving nutrient absorption and light exposure in the crop (30). This research aims to identify the optimum combinations of sowing dates, plant densities, and nitrogen fertilizer to increase anise seed yield and quality. The results of this study could provide valuable information to farmers and researchers for optimizing cultural practices in anise cultivation.

## MATERIALS AND METHODS

The methods of the investigation were performed at two different locations: Qlyasan agricultural research station, College of Agricultural Engineering Sciences, University of Sulaimani (Lat. 35$^{o}$ 34' 307"; N, Long. 45$^{o}$ 21' 992"; E, 765 m.a.s.l.), and Kanipanka research station, Ministry of Agriculture (Lat. 35$^{o}$ 22' 37"; N, Long. 45$^{o}$ 43' 33"; E, 545 m.a.s.l.) in Shahrazoor, in season 2021-2022. Each location includes the study of two sowing dates of anise (20$^{th}$ Oct. and 20$^{th}$ Nov.) using two plant densities (50 and 100 plants m$^{-2}$) and the application of nitrogen fertilizer (15 and 30 kg ha$^{-1}$ as well as control); hence experiment was designed as a (2×2×3) factorial experiment within RCBD using 3 replicates. In both locations of the study, the area of a plot within replications was (1×1) m²; each plot contained 5 rows, the length of each row was 1 m, and the distance between the rows was 20 cm. The plants in each row were 10 cm apart to represent the density of 50 plants m$^{-2}$, while for the density of 100 plants m$^{-2,}$ the distance between the rows was 10 cm. They are harvested when they mature. The meteorological data for the experimental season are shown in Table 1. The soil's chemical and physical properties are shown in Table 2. Some growth, yield, and yield components of anise were studied in both locations, which were Plant height (cm), No. of branches plant$^{-1}$, Root depth (cm), No. of umbels plant$^{-1}$, No. of seeds umble$^{-1}$, 1000 Seeds weight (g), Seed yield (kg ha$^{-1}$), Essential oil (%), and Essential oil yield (kg ha$^{-1}$) (28).

**Table 1. Metrological data of growing season 2021-2022 at Qlyasan and Kanipanka locations**

| Period | Qlyasan | | | Kanipanka | | |
|---|---|---|---|---|---|---|
| | Temp. C° | | Rainfall | Temp. C° | | Rainfall |
| | Max. | Min. | Mm | Max. | Min. | Mm |
| Oct. | 24.8 | 23.0 | 0.0 | 30.4 | 15.6 | 18.5 |
| Nov. | 16.3 | 14.9 | 36.8 | 22.8 | 10.2 | 17.2 |
| Dec. | 10.6 | 9.3 | 29.1 | 15.9 | 5.1 | 72.1 |
| Jan. | 5.4 | 4.3 | 141.0 | 9.0 | 1.0 | 153.5 |
| Feb. | 11.2 | 9.8 | 54.3 | 15.2 | 5.4 | 57.5 |
| Mar. | 11.9 | 10.6 | 22.7 | 15.3 | 6.4 | 58.9 |
| Apr. | 21.1 | 19.3 | 15.7 | 26.2 | 14.6 | 42.7 |
| May | 24.6 | 22.9 | 10.9 | 28.3 | 17.3 | 15.4 |
| Jun. | 34.0 | 32.2 | 0.0 | 37.8 | 23.3 | 0.9 |
| Total | | | 310.5 | | | 436.7 |

**Table 2. Soil analysis of both locations of the studies**

| Soil properties | Qlyasan | Kanipanka |
|---|---|---|
| % Sand | 10.64 | 3.34 |
| % Silt | 45.15 | 65.69 |
| % Clay | 44.21 | 30.97 |
| Texture | Clay | Clay |
| EC dS m-1 at 25°C | 0.7 | 0.11 |
| PH | 7.85 | 7.45 |
| N % | 0.14 | 0.15 |
| Organic matter % | 1.13 | 1.139 |

**Essential oil determination**

The Clevenger apparatus was used to quantify essential oils. For each treatment, 100 g of dried and cleaned mixed seed samples were ground up, combined with 1 liter of distilled water, and put into a 2 L round-bottom flask. The flask was then connected to Clevenger equipment to extract the essential oil using hydrodistillation for 120 minutes. After being extracted, the essential oil was dried with anhydrous sodium sulfate and stored at 4°C in a dark glass bottle (25, 26).

$$\textbf{Essential oil }(\%) = \frac{\textbf{weight of the vessel with oil (g)} - \textbf{weight of the empty vessel(g)}}{\textbf{Weight of the seed sample (g)}} \times \mathbf{100} \qquad \textbf{Eq. (1)}$$

$$\textbf{Essential oil yield }(\mathbf{Kg\ ha^{-1}}) = \textbf{ Seeds yield }(\mathbf{Kg\ ha^{-1}}) \times \textbf{ Essential oil}(\%) \qquad \textbf{Eq. (2)}$$

## RESULTS AND DISCUSSIONS

### 1- Effect of sowing dates on studied traits

The means of some growth, yield, and essential oil characters of anise as affected by sowing dates in both locations and their means are presented in Table 3. In the first location, most of the studied characters showed a highly significant effect ($p \leq 0.01$). However, the essential oil yield was found to be significant ($p \leq 0.05$), while the root depth and 1000-seed characters showed no significant differences. Sowing on 20$^{th}$ Nov. resulted in a significant increase of 30.76% in plant height, 9.83% in the number of branches per plant, and 34.99% in the amount of essential oil, compared to sowing on October 20$^{th}$. Conversely, sowing on 20$^{th}$ Oct. led to a significant increase of 22.91% in the number of umbels plant$^{-1}$, 25.79% in the number of seeds umbel$^{-1}$, 63.91% in seeds yield, and 16.70% in essential oil yield. Regarding the second location and the means of both locations, all the studied characteristics showed highly significant responses ($p \leq 0.01$) to the sowing dates, except for the number of branches per plant and root depth, which did not exhibit significant differences. Sowing on 20$^{th}$ Nov. resulted in a significant increase of 40.44% in plant height and 14.00% in the essential oil for the second location, and 5.37% and 25.26% respectively for the means of both locations. On the other hand, sowing on 20$^{th}$ Oct. led to a significant increase of 40.80% in the number of umbels plant$^{-1}$, 12.14% in the number of seeds umbel$^{-}$

$^{1}$, 16.25% in 1000 seed weight, 89.85% in seeds yield, and 55.74% in essential oil yield for the second location, and 33.05%, 17.94%, 7.21%, 80.40%, and 38.33% for the means of both locations, respectively. These results suggest that the growth, yield traits, and essential oil quality of the anise plant are significantly influenced by the date of sowing. Plant height, branching, umbel and seed production, seed weight, and essential oil content may all be impacted by different sowing dates. As shown in Table 3, the first sowing date had a significant influence on most of the characters in comparison with the second sowing date. The shortening of the development period could reduce the vegetative growth of plants and cause smaller plants with a lower number of branches and umbels, and lead to lower fruit numbers. Lower anise fruit yield due to delayed sowing was found to be related to the reduction of vegetative growth (39). It was found that anise umbel buds developed when the air temperature was above 4°C (5). The flowering stage was delayed due to the delayed sowing date because of the high temperature and low humidity, which may have inhibited the development of the plant's reproductive organs and seed sets (12). The earlier sown crops during the fall season are exposed to higher temperatures and day lengths compared to later sowing dates (23). This could be because the lower fruit number is observed in plant$^{-1}$ or, per unit area, for this treatment (Table 1). The results are consistent with the widely recognized observation that anise plants are vulnerable to unfavorable weather conditions when they are in flower (37). The thousand-seed weight was not affected by sowing dates in the Qlyasan location. Likewise, Ullah and Honermeier (34) found no impact of different sowing dates on the weight of a thousand seeds. This suggests that the growth of anise is primarily influenced by environmental conditions, particularly temperature. In a study conducted by Maheshwari *et al*. (14), it was observed that sowing anise on either October 25 or November 5 resulted in higher yields of fruit, essential oil, and trans-anethole compared to sowing on November 30. Another investigation by Fazecas *et al.* (11) found that anise fruits sown at the end of November have produced positive fruit yields.

**Table 3. Means of some growth, yield, and essential oil characters of Anise affected by sowing date**

| Sowing date | Plant height (cm) | No. of branches plant$^{-1}$ | Root depth (cm) | No. of umbels plant$^{-1}$ | No. of seeds umbel$^{-1}$ | 1000 seeds wt. (g) | Seeds yield (kg ha$^{-1}$) | Essential oil (%) | Essential oil yield (kg ha$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Qlyasan Location | | | | | |
| 20th Oct. | 35.297 | 7.621 | 10.963 | 9.269 | 74.067 | 2.248 | 1187.879 | 1.552 | 18.305 |
| 20th Nov. | 46.157 | 8.370 | 10.891 | 7.541 | 58.882 | 2.287 | 724.719 | 2.095 | 15.685 |
| LSD $_{0.05}$ | 1.881 | 0.516 | n.s | 0.528 | 2.160 | n.s | 98.998 | 0.068 | 1.976 |
| LSD $_{0.01}$ | 2.556 | 0.702 | n.s | 0.717 | 2.936 | n.s | 134.556 | 0.092 | n.s |
| | | | | Kanipanka Location | | | | | |
| 20th Oct. | 45.037 | 9.176 | 12.314 | 13.950 | 89.193 | 2.632 | 2399.041 | 1.329 | 30.345 |
| 20th Nov. | 63.251 | 9.094 | 12.275 | 9.908 | 79.539 | 2.264 | 1263.635 | 1.515 | 19.485 |
| LSD $_{0.05}$ | 3.177 | n.s | n.s | 0.574 | 5.520 | 0.150 | 218.072 | 0.043 | 3.653 |
| LSD $_{0.01}$ | 4.318 | n.s | n.s | 0.779 | 7.503 | 0.204 | 296.397 | 0.058 | 4.965 |
| | | | | Average of both Locations | | | | | |
| 20th Oct. | 40.167 | 8.398 | 11.639 | 11.609 | 81.630 | 2.440 | 1793.460 | 1.441 | 24.325 |
| 20th Nov. | 54.704 | 8.732 | 11.583 | 8.725 | 69.211 | 2.276 | 994.177 | 1.805 | 17.585 |
| LSD $_{0.05}$ | 1.794 | n.s | n.s | 0.379 | 2.880 | 0.101 | 116.367 | 0.039 | 2.018 |
| LSD $_{0.01}$ | 2.396 | n.s | n.s | 0.506 | 3.848 | 0.135 | 155.452 | 0.052 | 2.696 |

**n.s: not significant**

## 2- Effect of plant densities on studied traits

Results in Table 4 indicate the effects of plant density on the growth, yield, and essential oil characteristics. Concerning the first location, highly significant effects ($p \leq 0.01$) were observed of plant density on the no. of umbels plant$^{-1}$, seed yield, essential oil %, and essential oil yield. However, the effect was significant ($p \leq 0.05$) on the no. of seeds umbel$^{-1}$, and was not significant on the other characters. The 50 plants m$^{-2}$ exceeded the 100 plants m$^{-2}$ in no. of umbels plant$^{-1}$ by 10.28 %, while for no. of seeds umbel$^{-1}$, seed yield, essential oil %, and essential oil yield, the 100 plants m$^{-2}$ exceeded the 50 plants m$^{-2}$ by 3.50%, 89.53%,14.03%, and 96.12 % respectively. Regarding the second location, the effect of plant density was highly significant ($p \leq 0.01$) on the characters, no. of umbels plant$^{-1}$, no. of seeds umbel$^{-1}$, seed yield, and essential oil yield. However, it was not significant for the other characters. The 50 plants m$^{-2}$ showed a significant increase of 23.00% and 10.65% in the umbels per plant and the number of seeds per umbel, respectively, compared to the 100 plants m$^{-2}$. Conversely, for seed yield and essential oil yield, the density of 100 plants m$^{-2}$ exhibited a higher value of 53.81% and 34.87%, respectively. The means of both locations, a highly significant effect ($p \leq 0.01$) of plant density was observed for the characters, no. of umbels plant$^{-1}$, seed yield, essential oil%, and essential oil yield. However, it was only significant ($p \leq 0.05$) for no. of seeds umbel$^{-1}$, and not significant for the other characters. The results indicated that the 50 plants m$^{-2}$ outperformed the 100 plants m$^{-2}$ by 16.99% and 4.23% in terms of the no. of umbels plant$^{-1}$ and no. of seeds umbel$^{-1}$. Conversely, for seeds yield, essential oil%, and essential oil yield, the 100 plants m$^{-2}$ significantly surpassed the 50 plants m$^{-2}$ by 65.02%, 6.23%and 56.37% respectively. Results in Table 4 show that the plant density had a significant impact on anis growth, yield, and oil. The best possible plant density has a positive impact on the plant's ability to absorb nutrients and receive light. It can be explained by the fact that anise plants utilize water, light, and nutrients more effectively when there is less rivalry among plants at a higher plant density, which lowers the components that contribute to production (32, 37). According to a study by Maheshwari *et al.* (14), it was found that the amount of anise seeds harvested showed a positive correlation with increased spacing between the plants. In another study, the sowing of anise at 30 cm spacing resulted in higher yields compared to narrower and wider spacing (22). Ullah and Honermeier (34) found that an increase in planting density led to a decrease in the fruit yield of anise. Yan *et al.* (37) stated that narrow planting had a negative impact on the seed yield of anise. The study conducted over two years revealed that plants cultivated with a row spacing of 15 cm and a plant density of 200–300 plants m$^{-2}$ produced the best fruit production since there was less competition among the plants (35). Nevertheless, Tuncturk and Yıldırım (32) found that narrower sowing resulted in higher crop yields and taller plant height. These differences might be due to climatic characteristics. Another investigation by Meena *et al.* (17) stated that sowing at 20×30 cm could be the optimum row space for higher productivity in anis.

**Table 4. Means of some growth, yield, and essential oil characters of Anise affected by plant density**

| Plant density (m$^2$) | Plant height (cm) | No. of branches plant$^{-1}$ | Root depth (cm) | No. of umbels plant$^{-1}$ | No. of seeds umbel$^{-1}$ | 1000 seeds wt. (g) | Seeds yield (kg ha$^{-1}$) | Essential oil (%) | Essential oil yield (kg ha$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| **Qlyasan Location** | | | | | | | | | |
| 50 | 41.602 | 8.121 | 10.715 | 8.816 | 65.331 | 2.279 | 660.589 | 1.704 | 11.478 |
| 100 | 39.852 | 7.870 | 11.139 | 7.994 | 67.618 | 2.256 | 1252.008 | 1.943 | 22.511 |
| LSD $_{0.05}$ | n.s | n.s | n.s | 0.528 | 2.160 | n.s | 98.998 | 0.068 | 1.976 |
| LSD $_{0.01}$ | n.s | n.s | n.s | 0.717 | n.s | n.s | 134.556 | 0.092 | 2.686 |
| **Kanipanka Location** | | | | | | | | | |
| 50 | 53.546 | 8.947 | 12.775 | 13.111 | 88.632 | 2.438 | 1443.101 | 1.443 | 21.216 |
| 100 | 54.742 | 9.323 | 11.814 | 10.747 | 80.101 | 2.459 | 2219.575 | 1.401 | 28.614 |
| LSD $_{0.05}$ | n.s | n.s | n.s | 0.574 | 5.520 | n.s | 218.072 | n.s | 3.653 |
| LSD $_{0.01}$ | n.s | n.s | n.s | 0.779 | 7.503 | n.s | 296.397 | n.s | 4.965 |
| **Means of both Locations** | | | | | | | | | |
| 50 | 47.574 | 8.534 | 11.745 | 10.963 | 76.981 | 2.359 | 1051.845 | 1.574 | 16.347 |
| 100 | 47.297 | 8.597 | 11.477 | 9.371 | 73.859 | 2.357 | 1735.792 | 1.672 | 25.562 |
| LSD $_{0.05}$ | n.s | n.s | n.s | 0.379 | 2.880 | n.s | 116.367 | 0.039 | 2.018 |
| LSD $_{0.01}$ | n.s | n.s | n.s | 0.506 | n.s | n.s | 155.452 | 0.052 | 2.696 |

n.s: not significan

**3- Effect of nitrogen on studied traits**

Data in Table 5 illustrates the effect of nitrogen fertilizer on growth, yield, and essential oil of anise in both locations and their means. The effect of nitrogen fertilizer was highly significant ($p \leq 0.01$) for the plant height, no. of seeds per umbel, seed yield, and essential oil %. However, it was significant ($p \leq 0.05$) for no. of branches plant$^{-1}$, no. of umbels plant$^{-1}$, and essential oil yield, and was not significant for the other characters in the first location. Applying 30kg N ha$^{-1}$ outyielded other treatments for the plant height by 15.51%, 7.99% no. of branches plant$^{-1}$ by11.14%, 2.22%, no. of umbels plant$^{-1}$ by 10.30%, 4.68%, seeds yield by 25.04%, 14.89%, essential oil by 1.41%, 7.45% and essential oil yield by13.47%, 23.81% respectively. The no. of seeds umbel$^{-1}$ applying 15 kg N ha$^{-1}$ predominated both control and 30kg N ha-1 by 7.25% and 4.82% respectively. Regarding the second location, the effect of nitrogen fertilizer was highly significant ($p \leq 0.01$) for the characters no. of umbels per plant and essential oil %. However, it was significant ($p \leq 0.05$) for root depth and no. of seeds umbel$^{-1}$, and not significant for the other characters. The application of 15kg N ha$^{-1}$ exceeded other treatments for the characters root depth and essential oil % significantly by 15.11 %, 15.22%, and 6.53%, 10.10% respectively. However, for no. of umbels plant$^{-1}$ applying 30kg N ha$^{-1}$ predominated both control and 15kg N ha$^{-1}$ significantly by 11.81% and 16.43. Control outyielded both 15 kg N ha$^{-1}$ and 30kg N ha-1 for the no. of seeds umbel$^{-1}$ by 0.09% and 9.62% respectively. At the means of both locations, the effect of nitrogen fertilizer was highly significant ($p \leq 0.01$) on the no. of umbels plant$^{-1}$, while it was significant ($p \leq 0.05$) on plant height, root depth, and the number of seeds umbel$^{-1}$. The effect was not significant on the other characters. Applying 30kg N ha$^{-1}$ predominated control and 15kg N ha$^{-1}$ for plant height by 6.30%, 3.57%. The root depth and no. of umbels plant$^{-1}$, 15kg N ha$^{-1}$ outyielded other treatments by 9.39%, 4.14% for root depth, and by 3.03%, 7.39% for no. of umbels plant$^{-1}$, respectively. The treatment of 30kg N ha$^{-1}$ predominated control and 15kg N ha-1 by 11.21%, 11.39% for no. umbels plant$^{-1}$ respectively. An important factor in the growth and development of plants is nitrogen fertilizer. Applying nitrogen to medicinal plants will encourage growth and the production of essential oils and other active ingredients (4, 40). Conversely, inadequate soil organic matter and imbalanced nitrogen fertilization have a detrimental effect on plant output and chemical content. Excessive nitrogen fertilizer inputs also have an adverse effect on plant structure, the surrounding soil, and irrigation water. Generally speaking, every element that affects photosynthesis may have an impact on seed output (27). The results in Table 3 were consistent with earlier findings by Jevđović and Maletić (13), demonstrating that fertilizer application had a major impact on anise seed yield and quality. Fertilizer application showed a significant effect on anise yield characters such as: plant height, No. branches plant $^{-1}$, no. of umbel plant $^{-1}$, no. of seeds umbels$^{-1}$, seeds yield, and 1000 seed wt. (6). According to a related study by Nabizadeh *et al.* (18), fertilizer application produced the maximum oil content and seed production. A study by Abdullah (1) reported that the highest seed yield and oil content, respectively, were achieved (1286 and 179 Kg ha$^{-1}$) by the chemical nitrogen (60 kg ha$^{-1}$) with a density of 25 plant m$^{-2}$. In contrast to the other types of fertilizers under investigation, another study by Ahmed *et al.* (3) showed that anise plants treated with chemical fertilization often produced the highest values in plant growth (plant height, number of branches plant$^{-1,}$ and herb fresh and dry weights plant$^{-1}$).=

**Table 5. The means of some growth, yield, and essential oil characters of Anise affected by nitrogen fertilizer**

| Nitrogen Fertilizer (kg ha$^{-1}$) | Plant height (cm) | No. of branches plant$^{-1}$ | Root depth (cm) | No. of umbels plant$^{-1}$ | No. of seeds umbel$^{-1}$ | 1000 seeds wt. (g) | Seeds yield (kg ha$^{-1}$) | Essential oil (%) | Essential oil yield (kg ha$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Qlyasan Location | | | | | |
| 0 | 37.889 | 7.499 | 10.743 | 7.988 | 64.419 | 2.284 | 859.258 | 1.850 | 16.710 |
| 15 | 40.528 | 8.153 | 11.098 | 8.417 | 69.091 | 2.178 | 935.192 | 1.746 | 15.314 |
| 30 | 43.764 | 8.334 | 10.940 | 8.811 | 65.913 | 2.340 | 1074.446 | 1.876 | 18.960 |
| LSD $_{0.05}$ | 2.303 | 0.633 | n.s | 0.646 | 2.645 | n.s | 121.247 | 0.083 | 2.420 |
| LSD $_{0.01}$ | 3.131 | n.s | n.s | n.s | 3.596 | n.s | 164.796 | 0.113 | n.s |
| | | | | Kanipanka Location | | | | | |
| 0 | 54.237 | 9.194 | 11.413 | 11.625 | 86.936 | 2.532 | 1883.831 | 1.334 | 24.594 |
| 15 | 54.028 | 9.418 | 13.138 | 11.164 | 86.854 | 2.467 | 1784.054 | 1.537 | 27.550 |
| 30 | 54.167 | 8.793 | 12.333 | 12.998 | 79.308 | 2.347 | 1826.128 | 1.396 | 22.601 |
| LSD $_{0.05}$ | n.s | n.s | 1.257 | 0.702 | 6.761 | n.s | n.s | 0.052 | n.s |
| LSD $_{0.01}$ | n.s | n.s | n.s | 0.955 | n.s | n.s | n.s | 0.071 | n.s |
| | | | | Means of both Locations | | | | | |
| 0 | 46.063 | 8.347 | 11.078 | 9.806 | 75.678 | 2.408 | 1371.545 | 1.592 | 20.652 |
| 15 | 47.278 | 8.785 | 12.118 | 9.790 | 77.973 | 2.323 | 1359.623 | 1.641 | 21.432 |
| 30 | 48.965 | 8.563 | 11.636 | 10.905 | 72.611 | 2.343 | 1450.287 | 1.636 | 20.780 |
| LSD $_{0.05}$ | 2.197 | n.s | 0.698 | 0.464 | 3.528 | n.s | n.s | n.s | n.s |
| LSD $_{0.01}$ | n.s | n.s | n.s | 0.620 | n.s | n.s | n.s | n.s | n.s |

**n.s: not significant**

**4- Interaction of sowing dates and plant densities:** Data present in Table 6 illustrate the interaction effect between sowing dates and plant density on some growth, yield, and essential oil characters of anise in both locations and their means. In the first location, the interaction effect was highly significant ($p \leq 0.01$) on the no. of seeds umbel$^{-1}$, seed yield, essential oil %, and essential oil yield, while non-significant effects were observed on the other characters. The interaction of 20$^{th}$ Oct. and 100 plants m$^{-2}$ resulted in the highest values for the no. of seeds umbel$^{-1}$, seed yield, and essential oil yield. Specifically, the number of seeds umbel reached 79.126 seeds, the seed yield was 1644.787 kg ha$^{-1}$, and the essential oil yield was 25.374 kg ha$^{-1}$. On the other hand, the interaction between 20$^{th}$ Nov. and 100 seeds m$^{-2}$ resulted in the minimum value for no. seeds umbel$^{-1,}$ which was 56.11 seeds. Additionally, the lowest seeds yield of 590.208 kg h$^{-1}$ was recorded with the interaction of 20$^{th}$ Nov. and 50 plants m$^{2}$. Conversely, the interaction between 20$^{th}$ Nov. and 100 plants m$^{-2}$ yielded the highest essential oil%, reaching 2.295. Furthermore, the essential oil % and essential oil yield produced the minimum values of 1.513% and 11.235 kg h$^{-1}$, respectively, when the interaction occurred between the 20$^{th}$ Oct and the 50 plants m$^{-2}$ interaction. Concerning the second location, the effect of the interaction between sowing date and plant density was examined, and the results were found to be highly significant ($p \leq 0.01$) on the no. of umbels plant$^{-1}$, seed yield, and essential oil %. The interaction between 20$^{th}$ Oct. with 50 plants m$^{-1}$ resulted in a higher no. of umbels plant$^{-1}$ with the value of 14.443 umbels. Conversely, the lowest number of umbels (8.038) was observed when the crop was sown on the 20$^{th}$ of November with a plant density of 100 plants m$^{2}$. When examining the seed yield, it was found that the interaction between 20$^{th}$ Oct. with 100 plants m$^{2}$ produced a maximum value for seed yield of 3032.430 kg ha$^{-1}$. On the other hand, the minimum yield of 1120.55 kg ha$^{-1}$ was observed when the crop was sown on the 20$^{th}$ of November with a plant density of 50 plants m$^{2}$. The highest percentage of essential oil, reaching 1.668%, was observed with the interaction of the sowing date on the 20$^{th}$ Nov. and 100 plants m$^{2}$. In contrast, the lowest value of essential oil percent (1.135%) was obtained when the crop was sown on the 20$^{th}$ October with a plant density of 100 plants m$^{2}$. At the means of both locations, the interaction between the 20$^{th}$ Oct. and 50 plants m$^{-2}$ showed a maximum no. of umbels reaching 11.944 umbels. Conversely, the interaction between the 20$^{th}$ Nov. and 100 plants m$^{-2}$ exhibited a minimum no. of umbels, with a value of 7.467. However, the interaction of the 20$^{th}$ Oct. and 100 plants m$^{-2}$ resulted in the maximum no. of seeds umbel$^{-1}$ with 83.328 seeds, and seed yield of 2338.608 kg ha$^{-1}$. On the other hand, the interaction between the 20$^{th}$

Nov. and 100 plants m² yielded the lowest number of seeds umbel$^{-1}$, with a mean of 64.39. The lowest value of seed yield, amounting to 855.379 kg h$^{-1}$, was recorded by the interaction between 20$^{th}$ Nov. and 50 plants m$^{2}$. Furthermore, the interaction of 20$^{th}$ Nov., coupled with 100 seeds m$^{-2}$, exhibited a maximum percentage of essential oil, with a value of 1.981%. Conversely, the interaction between 20$^{th}$ Oct and 100 plants m$^{2}$ resulted in the minimum oil percent of 1.363. Current findings are partially in agreement with (34).

**Table 6. Means of some growth, yield, and essential oil characters of Anise affected by the interaction of sowing date and plant density**

| Sowing Dates | Plant Density (m$^{2}$) | Plant height (cm) | No. of branches plant$^{-1}$ | Root depth (cm) | No. of umbels plant$^{-1}$ | No. of seeds umbel$^{-1}$ | 1000 seeds wt. (g) | Seeds yield (kg ha$^{-1}$) | Essential oil (%) | Essential oil yield (kg ha$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **Qlyasan Location** | | | | | |
| 20$^{th}$ Oct. | 50 | 35.630 | 7.538 | 10.908 | 9.444 | 69.008 | 2.224 | 730.970 | 1.513 | 11.235 |
| | 100 | 34.963 | 7.703 | 11.019 | 9.093 | 79.126 | 2.271 | 1644.787 | 1.591 | 25.374 |
| 20$^{th}$ Nov. | 50 | 47.574 | 8.703 | 10.522 | 8.187 | 61.654 | 2.334 | 590.208 | 1.896 | 11.721 |
| | 100 | 44.740 | 8.037 | 11.259 | 6.896 | 56.110 | 2.240 | 859.230 | 2.295 | 19.648 |
| LSD $_{0.05}$ | | n.s | n.s | n.s | n.s | 3.055 | n.s | 140.004 | 0.096 | 2.795 |
| LSD $_{0.01}$ | | n.s | n.s | n.s | n.s | 4.152 | n.s | 190.290 | 0.130 | 3.799 |
| | | | | | **Kanipanka Location** | | | | | |
| 20$^{th}$ Oct. | 50 | 43.721 | 8.630 | 12.797 | 14.443 | 90.856 | 2.684 | 1765.651 | 1.524 | 26.954 |
| | 100 | 46.352 | 9.722 | 11.832 | 13.457 | 87.531 | 2.580 | 3032.430 | 1.135 | 33.737 |
| 20$^{th}$ Nov. | 50 | 63.370 | 9.263 | 12.753 | 11.779 | 86.408 | 2.191 | 1120.550 | 1.363 | 15.479 |
| | 100 | 63.131 | 8.924 | 11.797 | 8.038 | 72.670 | 2.338 | 1406.720 | 1.668 | 23.491 |
| LSD $_{0.05}$ | | n.s | n.s | n.s | 0.811 | n.s | n.s | 308.400 | 0.061 | n.s |
| LSD $_{0.01}$ | | n.s | n.s | n.s | 1.102 | n.s | n.s | 419.169 | 0.082 | n.s |
| | | | | | **Means of both Locations** | | | | | |
| 20$^{th}$ Oct. | 50 | 39.676 | 8.084 | 11.852 | 11.944 | 79.932 | 2.454 | 1248.311 | 1.518 | 19.094 |
| | 100 | 40.658 | 8.713 | 11.426 | 11.275 | 83.328 | 2.426 | 2338.608 | 1.363 | 29.555 |
| 20$^{th}$ Nov. | 50 | 55.472 | 8.983 | 11.638 | 9.983 | 74.031 | 2.263 | 855.379 | 1.629 | 13.600 |
| | 100 | 53.936 | 8.481 | 11.528 | 7.467 | 64.390 | 2.289 | 1132.975 | 1.981 | 21.570 |
| LSD $_{0.05}$ | | n.s | n.s | n.s | 0.536 | 4.073 | n.s | 164.568 | 0.055 | n.s |
| LSD $_{0.01}$ | | n.s | n.s | n.s | 0.715 | 5.442 | n.s | 219.842 | 0.073 | n.s |

**n.s: not significant**

**5- Interaction of sowing dates and nitrogen fertilizer:** The data presented in Table 7 shows the interaction between sowing date and nitrogen fertilizer on the growth, yield, and essential oil percentage of anise in both locations and their means. In the first location, this interaction had a highly significant effect ($p \leq 0.01$) on the no. of umbels plant$^{-1}$, essential oil %, and essential oil yield. However, it had a significant effect ($p \leq 0.05$) on plant height and no. of seeds umbel$^{-1}$, and no significant effects were recorded on the other characters. Sowing on 20$^{th}$ Nov. under 30kg N ha$^{-1}$ resulted in the highest plant height of 51.083cm. Conversely, the lowest plant height of 33.362 was observed with the interaction of 20$^{th}$ Oct and control treatment. Sowing on 20$^{th}$ Oct. with 0kg N ha$^{-1}$ showed the highest number of umbels plant$^{-1}$ and essential oil yield with the values of 9.362 umbels and 21.061 kg h$^{-1,}$ respectively. The lowest no. umbels plant$^{-1}$ and essential oil yield of 6.613 umbels and 12.359 kg h$^{-1,}$ respectively, were obtained with the interaction between 20$^{th}$ Nov. and control treatment. The interaction between 20$^{th}$ Oct. and 15kg N ha$^{-1}$ had a maximum number of seeds umbel$^{-1}$ (78.597 seeds). On the other hand, the lowest number of seed umbel$^{-1}$ (56.847 seeds) was recorded with the interaction between 20$^{th}$ Nov and control. The maximum essential oil % of 2.356 was exhibited by the interaction between the 20$^{th}$ No. under 15 kg N ha$^{-1}$. However, a minimum oil % of 1.136% was observed with the interaction between 20$^{th}$ Oct. and 15 kg N ha$^{-1}$. Regarding the second location, the no. of umbels plant$^{-1}$ and essential oil % showed a significant increase ($p \leq 0.01$) in response to this interaction, and no significant effects were observed for the other characters. The combination of 20$^{th}$ Oct. and 30kg N ha$^{-1}$ resulted in the highest number of umbels plant$^{-1}$, reaching 15.330 umbels. Conversely, the lowest value of 9.252 umbels per plant was recorded when the interaction occurred between the 20$^{th}$ Nov. and the control treatment. Additionally, the combination of 20$^{th}$ Nov. with 30 kg N ha$^{-1}$ exhibited the maximum percentage of essential oil at 1.645%, while the minimum percentage of essential oil at 1.147% was observed when the interaction took place between 20th Oct. with 30 kg N ha$^{-1}$. Regarding the means of both locations, the interaction effect between sowing date and nitrogen fertilizer was highly significant ($p \le 0.01$) for the no. of umbels plant$^{-1}$ and essential oil %. Still, it was only significant ($p \le 0.05$) for essential oil yield and not significant for other characteristics. Sowing on 20th Oct. and 30kg N ha$^{-1}$, showed the maximum number of umbels plant$^{-1}$, reaching 12.221 umbels. However, the minimum number of umbels plant$^{-1}$, 7.933 umbels, was recorded for the interaction between 20th Nov. under the control treatment. The interaction between 20th Nov. with 15 kg N ha$^{-1}$, the maximum essential oil % was observed, reaching 1.944%. Conversely, the lowest values were obtained from the interaction between 20th Oct. and 30 kg N ha$^{-1}$, resulting in 1.338% essential oil. Sowing on the 20th Oct. with control resulted in the maximum essential oil yield of 26.233 kg ha$^{-1}$. In contrast, the lowest values were recorded for the interaction between 20th Nov. and control treatment, with an essential oil yield of 15.071kg ha$^{-1}$. The results were in partial agreement with the study conducted by Fatemeh *et al*. (10).

**Table 7. The means of some growth, yield, and essential oil characters of Anise are affected by the interaction effect of sowing date and nitrogen fertilizer**

| Sowing Dates | Nitrogen Fertilizer (kg ha$^{-1}$) | Plant height (cm) | No. of branches plant$^{-1}$ | Root depth (cm) | No. of umbels plant$^{-1}$ | No. of seeds umbel$^{-1}$ | 1000 seeds wt. (g) | Seeds yield (kg ha$^{-1}$) | Essential oil (%) | Essential oil yield (kg ha$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|
| **Qlyasan Location** | | | | | | | | | | |
| 20th Oct. | 0 | 33.362 | 7.222 | 10.583 | 9.362 | 71.992 | 2.207 | 1055.796 | 1.992 | 21.061 |
| | 15 | 36.083 | 7.417 | 11.028 | 9.333 | 78.597 | 2.170 | 1192.335 | 1.136 | 14.430 |
| | 30 | 36.445 | 8.223 | 11.278 | 9.112 | 71.612 | 2.367 | 1315.505 | 1.529 | 19.423 |
| 20th Nov. | 0 | 42.417 | 7.777 | 10.903 | 6.613 | 56.847 | 2.362 | 662.720 | 1.708 | 12.359 |
| | 15 | 44.972 | 8.888 | 11.167 | 7.500 | 59.585 | 2.187 | 678.050 | 2.356 | 16.198 |
| | 30 | 51.083 | 8.445 | 10.602 | 8.510 | 60.215 | 2.313 | 833.388 | 2.223 | 18.497 |
| LSD $_{0.05}$ | | 3.257 | n.s | n.s | 0.914 | 3.741 | n.s | n.s | 0.117 | 3.423 |
| LSD $_{0.01}$ | | n.s | n.s | n.s | 1.243 | n.s | n.s | n.s | 0.159 | 4.652 |
| **Kanipanka Location** | | | | | | | | | | |
| 20th Oct. | 0 | 45.223 | 9.445 | 11.333 | 13.998 | 91.472 | 2.743 | 2513.571 | 1.300 | 31.405 |
| | 15 | 44.332 | 9.555 | 13.500 | 12.522 | 87.680 | 2.707 | 2162.826 | 1.542 | 33.021 |
| | 30 | 45.555 | 8.528 | 12.110 | 15.330 | 88.428 | 2.447 | 2520.725 | 1.147 | 26.610 |
| 20th Nov. | 0 | 63.250 | 8.943 | 11.493 | 9.252 | 82.400 | 2.320 | 1254.091 | 1.368 | 17.784 |
| | 15 | 63.723 | 9.282 | 12.777 | 9.807 | 86.028 | 2.227 | 1405.282 | 1.533 | 22.080 |
| | 30 | 62.778 | 9.057 | 12.555 | 10.667 | 70.188 | 2.247 | 1131.532 | 1.645 | 18.591 |
| LSD $_{0.05}$ | | n.s | n.s | n.s | 0.993 | n.s | n.s | n.s | 0.074 | n.s |
| LSD $_{0.01}$ | | n.s | n.s | n.s | 1.350 | n.s | n.s | n.s | 0.101 | n.s |
| **Means of both Locations** | | | | | | | | | | |
| 20th Oct. | 0 | 39.293 | 8.333 | 10.958 | 11.680 | 81.732 | 2.475 | 1784.684 | 1.646 | 26.233 |
| | 15 | 40.208 | 8.486 | 12.264 | 10.928 | 83.138 | 2.438 | 1677.580 | 1.339 | 23.725 |
| | 30 | 41.000 | 8.376 | 11.694 | 12.221 | 80.020 | 2.407 | 1918.115 | 1.338 | 23.017 |
| 20th Nov. | 0 | 52.833 | 8.360 | 11.198 | 7.933 | 69.623 | 2.341 | 958.405 | 1.538 | 15.071 |
| | 15 | 54.348 | 9.085 | 11.972 | 8.653 | 72.807 | 2.207 | 1041.666 | 1.944 | 19.139 |
| | 30 | 56.931 | 8.751 | 11.578 | 9.588 | 65.202 | 2.280 | 982.460 | 1.934 | 18.544 |
| LSD $_{0.05}$ | | n.s | n.s | n.s | 0.656 | n.s | n.s | n.s | 0.067 | 3.496 |
| LSD $_{0.01}$ | | n.s | n.s | n.s | 0.876 | n.s | n.s | n.s | 0.090 | n.s |

n.s: not significant

**6- Interaction of plant densities and nitrogen fertilizer:** The interaction between plant density and nitrogen fertilizer on growth and yield characters of anise in both locations and their means is shown in Table 8. In the first location, the effect of this interaction was highly significant ($p \le 0.01$) on the following characters: no. of umbel plant$^{-1}$, no. of seeds umbel$^{-1}$, seed yield, and essential oil %. However, it was only significant ($p \le 0.05$) for no. of branches plant$^{-1}$, and was not significant for the other characters. The maximum number of branches, plant$^{-1}$ (9.002 branches), was observed in the interaction of 50 plants m$^{-2}$ under 30kg N ha$^{-1}$, while the interaction of 50 plants m$^{-2}$ coupled with the control treatment showed a minimum height of 7.443 cm. In terms of the no. of umbels per plant$^{-1}$, the highest value of 9.778 umbels was exhibited by the interaction of 50 plants m$^{-2}$ coupled with 15kg N ha$^{-1}$, whereas the minimum value of 7.055 umbels was recorded in the interaction of 100 plants m$^{-2}$ and 15kg N ha$^{-1}$. The maximum number of seeds umbel$^{-1}$ (78.105 seeds), was produced by 100 plants m$^{-}$

$^{2}$ under 15kg N ha$^{-1}$ interaction, while the interaction of 100 plants m$^{-2}$ coupled with control treatment showed the lowest number of seeds plant$^{-1}$ (58.892 seeds). Regarding seed yield, the highest value of 1491.040 kg ha$^{-1}$ was observed in the interaction of 100 Plants m$^{-2}$ with 30 kg N ha$^{-1}$, while the minimum value of seed yield (657.852 kg ha$^{-1}$) was recorded in the interaction of 50 plants m$^{-2}$ under 30kg N ha$^{-1}$. The maximum percentage of oil (2.082%) was observed in the interaction of 100 seeds m$^{-2}$ with the control treatment, whereas the interaction between 50 plants m$^{-2}$ and 15kg N ha$^{-1}$ showed a minimum essential oil percentage of 1.528%. In the second location, the effect of this interaction was highly significant ($p \leq 0.01$) for essential oil %, while it was significant($p \leq 0.05$) for no. of umbels plant$^{-1}$ and essential oil yield, and was not significant on the other characters. The maximum number of umbels plant$^{-1}$ was 14.497, exhibited by the interaction of 50 plants m$^{-2}$ with 30kg N ha$^{-1}$, while the interaction of 100 plants m$^{-2}$ and control treatment produced a minimum no. umbels plant$^{-1}$ of 10.107. The highest values for essential oil % and essential oil yield were 1.572% and 35.070 kg ha$^{-1,}$ respectively, recorded using 100 plants m$^{-2}$ under 15 kg N ha$^{-1}$. The lowest value for essential oil % 1.287, was recorded for the interaction between 100 plants m$^{-2}$ and 30 kg N ha$^{-1}$. The lowest value for essential oil yield, of 20.020 kg h$^{-1}$ was observed for the interaction between 50 plants m$^{-2}$ under 15 kg N ha$^{-1}$. At the means of both locations, the number of seeds umbel$^{-1}$ and essential oil responded significantly ($p \leq 0.01$) to this effect, while the essential oil yield showed a significant response ($p \leq 0.05$). No significant effects were observed on the other characters. The maximum values for no. of seeds umbel$^{-1}$, essential oil %, and essential oil yield were 81.919 seeds, 1.768%, and 28.018 kg ha$^{-1}$, respectively, recorded by the interaction of 100 plants m$^{-2}$ under 15kg N ha$^{-1}$. The lowest value of the no. seeds umbel$^{-1}$ were 69.60 seeds, produced by the interaction of 100 plants m$^{-2}$ and 30 kg N ha$^{-1}$, while the minimum essential oil % was 1.470%, recorded by 50 plants m$^{-2}$ under the control treatment. The interaction between 50 plants m$^{-2}$ under 15 kg N ha$^{-1}$ exhibited the lowest value of 14.846 kg h$^{-1}$ essential oil yield. Optimal plant spacing plays a significant role in determining the microenvironment within an anise field and has the potential to enhance crop productivity by positively influencing nutrient absorption and light exposure for the plants. An experiment by Faravani *et al.* (9) showed that applying fertilizer and maintaining the optimum plant density combination produced the highest yields of anise seeds and essential oil. Likewise, Ram *et al*. (21) observed that the integrated use of plant density and fertilizer resulted in higher percentages of essential oil and increased essential oil yield in their study.

**Table 8. The means of some growth and yield characters of Anise are affected by the interaction effect of plant density and nitrogen fertilizer**

| Plant density ($m^2$) | Nitrogen Fertilizer (Kg $ha^{-1}$) | Plant height (cm) | No. of branches $plant^{-1}$ | Root depth (cm) | No. of umbels $plant^{-1}$ | No. of seeds $umbel^{-1}$ | 1000 seeds wt. (g) | Seeds yield (kg $ha^{-1}$) | Essential oil (%) | Essential oil yield (kg $ha^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|
| **Qlyasan Location** | | | | | | | | | | |
| | 0 | 38.028 | 7.443 | 10.250 | 8.002 | 69.947 | 2.315 | 662.886 | 1.618 | 11.539 |
| 50 | 15 | 41.195 | 7.917 | 10.917 | 9.778 | 60.077 | 2.250 | 661.029 | 1.528 | 9.662 |
| | 30 | 45.583 | 9.002 | 10.978 | 8.667 | 65.970 | 2.273 | 657.852 | 1.967 | 13.234 |
| | 0 | 37.750 | 7.555 | 11.237 | 7.973 | 58.892 | 2.253 | 1055.630 | 2.082 | 21.881 |
| 100 | 15 | 39.860 | 8.388 | 11.278 | 7.055 | 78.105 | 2.107 | 1209.355 | 1.963 | 20.966 |
| | 30 | 41.945 | 7.667 | 10.902 | 8.955 | 65.857 | 2.407 | 1491.040 | 1.784 | 24.687 |
| $LSD_{0.05}$ | | n.s | 0.895 | n.s | 0.914 | 3.741 | n.s | 171.470 | 0.117 | n.s |
| $LSD_{0.01}$ | | n.s | n.s | n.s | 1.243 | 5.085 | n.s | 233.057 | 0.159 | n.s |
| **Kanipanka Location** | | | | | | | | | | |
| | 0 | 52.917 | 9.388 | 11.577 | 13.143 | 92.647 | 2.493 | 1568.904 | 1.323 | 22.055 |
| 50 | 15 | 53.610 | 9.617 | 13.583 | 11.693 | 87.975 | 2.507 | 1318.927 | 1.502 | 20.030 |
| | 30 | 54.110 | 7.835 | 13.165 | 14.497 | 85.273 | 2.313 | 1441.470 | 1.505 | 21.563 |
| | 0 | 55.557 | 9.000 | 11.250 | 10.107 | 81.225 | 2.570 | 2198.758 | 1.345 | 27.133 |
| 100 | 15 | 54.445 | 9.220 | 12.693 | 10.635 | 85.733 | 2.427 | 2249.181 | 1.572 | 35.070 |
| | 30 | 54.223 | 9.750 | 11.500 | 11.500 | 73.343 | 2.380 | 2210.786 | 1.287 | 23.638 |
| $LSD_{0.05}$ | | n.s | n.s | n.s | 0.993 | n.s | n.s | n.s | 0.074 | 6.327 |
| $LSD_{0.01}$ | | n.s | n.s | n.s | n.s | n.s | n.s | n.s | 0.101 | n.s |
| **Means of both Locations** | | | | | | | | | | |
| | 0 | 45.473 | 8.416 | 10.913 | 10.573 | 81.297 | 2.404 | 1115.895 | 1.470 | 16.797 |
| 50 | 15 | 47.403 | 8.767 | 12.250 | 10.736 | 74.026 | 2.378 | 989.978 | 1.515 | 14.846 |
| | 30 | 49.847 | 8.418 | 12.072 | 11.582 | 75.622 | 2.293 | 1049.661 | 1.736 | 17.398 |
| | 0 | 46.653 | 8.278 | 11.243 | 9.040 | 70.058 | 2.412 | 1627.194 | 1.714 | 24.507 |
| 100 | 15 | 47.153 | 8.804 | 11.986 | 8.845 | 81.919 | 2.267 | 1729.268 | 1.768 | 28.018 |
| | 30 | 48.084 | 8.708 | 11.201 | 10.228 | 69.600 | 2.393 | 1850.913 | 1.535 | 24.163 |
| $LSD_{0.05}$ | | n.s | n.s | n.s | n.s | 4.989 | n.s | n.s | 0.067 | 3.496 |
| $LSD_{0.01}$ | | n.s | n.s | n.s | n.s | 6.665 | n.s | n.s | 0.090 | n.s |

n.s: not significant

**7- Interaction of sowing dates, plant densities, and nitrogen fertilizer:** The interaction effect between sowing dates, plant density, and nitrogen fertilizer on the growth and yield characteristics of anise was examined at two different locations. The results are shown in Table 9. At the first location, the following characteristics: no. of umbels $plant^{-1}$, no. of seeds $umbel^{-1}$, seed yield, essential oil percent, and essential oil yield, showed a highly significant response ($p \leq 0.01$) to these factors. The maximum value for the no. of umbels $plant^{-1}$ was 10.333, which was observed when sowing was done on the 20th Oct., with 50 plants $m^{-2}$ and 15 kg N $ha^{-1}$. In contrast, the minimum value of the no. of umbels $plant^{-1}$ of 5.777 umbels, occurred when sowing on the 20th Nov., with 100 plants $m^{-2}$ and 15 N kg $ha^{-1}$. Similarly, the maximum number of seeds $umbel^{-1}$, 92.017 seeds, was recorded when sowing was conducted on the 20th Oct., with 100 plants $m^{-2}$ and 15 N $kg^{-1}$. Conversely, the minimum number of seeds $umbel^{-1}$, which was 50.647 seeds, was obtained by the interaction of 20th Nov., with 100 plants $m^{-2}$ and 30 kg N $ha^{-1}$. The maximum seed yield and essential oil yield were 2067.796 and 29.760 kg $ha^{-1}$, respectively, and these values were observed when sowing was done on the 20th Oct., with 100 seeds $m^{-2}$ and 30kg N $ha^{-1}$. On the other hand, the minimum seeds yield of 427.192 kg $ha^{-1}$ and essential oil yield of 5.366 kg $ha^{-1}$ were obtained when sowing on the 20th Nov., with 50 plants $m^{-2}$ and control treatment. Regarding the essential oil percentage, the maximum value of 2.601% was observed with the interaction of the sowing date of 20th Nov., 100 seeds $m^{-2}$, and 15kg N $ha^{-1}$. In contrast, the minimum essential oil percentage (0.946%) was recorded with the interaction of the sowing date of 20th Oct., 50 seeds $m^{-2}$, and 15kg N $ha^{-1}$. At the second location, a highly significant effect ($p \leq 0.01$) was observed for the following characters: no. of umbels $plant^{-1}$, seed yield, and essential oil content. However, for essential oil yield, this effect was only significant ($p \leq 0.05$), and non-significant effects were recorded for the other characters. The maximum values recorded for the no. of umbels $plant^{-1}$ and seed yield were 15.667 umbels and 3449.974 kg $ha^{-1}$, respectively. These values were obtained through the interaction of the 20th Oct., with 100 plants m², and 30 kg N ha$^{-1}$. On the other hand, the lowest number of umbel plant$^{-1}$ and seed yield were 7.333 umbels and 971.597 kg ha$^{-1}$, respectively, resulting from the interaction of the 20th of November, with 100 plants m$^{-2}$, and 30 kg N ha$^{-1}$. Regarding the essential oil %, the highest value recorded was 1.680%, which was obtained through the interaction of the 20th Nov., 100 seeds m$^{-2}$, and 30kg N ha$^{-1}$. Conversely, the minimum essential oil % of 0.893% was obtained through the interaction of the 20th October, 100 plants m$^{-2}$, and 30 kg N ha$^{-1}$. The highest value for essential oil yield was 39.930 kg ha$^{-1}$, which was recorded through the interaction of 20th Oct., with 100 seeds m$^{-2}$ and 15 kg N ha$^{-1}$.

**Table 9. The means of some growth and yield characters of anise are affected by the interaction effect of sowing date, plant density, and nitrogen fertilizer**

| Sowing Dates | Plant density (m$^2$) | Nitrogen Fertilizer (Kg ha$^{-1}$) | Plant height (cm) | No. of branches plant$^{-1}$ | Root depth (cm) | No. of umbels plant$^{-1}$ | No. of seeds umbel$^{-1}$ | 1000 seeds wt. (g) | Seeds yield (kg ha$^{-1}$) | Essential oil (%) | Essential oil yield (kg ha$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **Qlyasan Location** | | | | | | |
| 20th Oct. | | 0 | 32.500 | 7.220 | 10.000 | 10.000 | 79.690 | 2.253 | 898.580 | 1.972 | 17.712 |
| | 50 | 15 | 36.390 | 6.947 | 11.500 | 10.333 | 65.177 | 2.180 | 731.117 | 0.946 | 6.907 |
| | | 30 | 38.000 | 8.447 | 11.223 | 8.000 | 62.157 | 2.240 | 563.214 | 1.620 | 9.086 |
| | | 0 | 34.223 | 7.223 | 11.167 | 8.723 | 64.293 | 2.160 | 1213.012 | 2.012 | 24.410 |
| | 100 | 15 | 35.777 | 7.887 | 10.557 | 8.333 | 92.017 | 2.160 | 1653.552 | 1.325 | 21.952 |
| | | 30 | 34.890 | 8.000 | 11.333 | 10.223 | 81.067 | 2.493 | 2067.796 | 1.437 | 29.760 |
| 20th Nov. | | 0 | 43.557 | 7.667 | 10.500 | 6.003 | 60.203 | 2.377 | 427.192 | 1.263 | 5.366 |
| | 50 | 15 | 46.000 | 8.887 | 10.333 | 9.223 | 54.977 | 2.320 | 590.942 | 2.110 | 12.417 |
| | | 30 | 53.167 | 9.557 | 10.733 | 9.333 | 69.783 | 2.307 | 752.490 | 2.314 | 17.381 |
| | | 0 | 41.277 | 7.887 | 11.307 | 7.223 | 53.490 | 2.347 | 898.247 | 2.152 | 19.352 |
| | 100 | 15 | 43.943 | 8.890 | 12.000 | 5.777 | 64.193 | 2.053 | 765.158 | 2.601 | 19.979 |
| | | 30 | 49.000 | 7.333 | 10.470 | 7.687 | 50.647 | 2.320 | 914.285 | 2.131 | 19.613 |
| | LSD $_{0.05}$ | | n.s | n.s | n.s | 1.293 | 5.291 | n.s | 242.495 | 0.166 | 4.841 |
| | LSD $_{0.01}$ | | n.s | n.s | n.s | 1.757 | 7.191 | n.s | 329.593 | 0.225 | 6.580 |
| | | | | | **Kanipanka Location** | | | | | | |
| 20th Oct. | | 0 | 41.333 | 9.333 | 11.500 | 15.340 | 95.960 | 2.787 | 2056.385 | 1.579 | 32.466 |
| | 50 | 15 | 44.220 | 10.000 | 13.447 | 12.997 | 88.527 | 2.853 | 1649.095 | 1.592 | 26.111 |
| | | 30 | 45.610 | 6.557 | 13.443 | 14.993 | 88.080 | 2.413 | 1591.475 | 1.400 | 22.284 |
| | | 0 | 49.113 | 9.557 | 11.167 | 12.657 | 86.983 | 2.700 | 2970.758 | 1.020 | 30.344 |
| | 100 | 15 | 44.443 | 9.110 | 13.553 | 12.047 | 86.833 | 2.560 | 2676.558 | 1.492 | 39.930 |
| | | 30 | 45.500 | 10.500 | 10.777 | 15.667 | 88.777 | 2.480 | 3449.974 | 0.893 | 30.937 |
| 20th Nov. | | 0 | 64.500 | 9.443 | 11.653 | 10.947 | 89.333 | 2.200 | 1081.424 | 1.066 | 11.645 |
| | 50 | 15 | 63.000 | 9.233 | 13.720 | 10.390 | 87.423 | 2.160 | 988.759 | 1.412 | 13.949 |
| | | 30 | 62.610 | 9.113 | 12.887 | 14.000 | 82.467 | 2.213 | 1291.466 | 1.610 | 20.842 |
| | | 0 | 62.000 | 8.443 | 11.333 | 7.557 | 75.467 | 2.440 | 1426.759 | 1.670 | 23.922 |
| | 100 | 15 | 64.447 | 9.330 | 11.833 | 9.223 | 84.633 | 2.293 | 1821.805 | 1.653 | 30.211 |
| | | 30 | 62.947 | 9.000 | 12.223 | 7.333 | 57.910 | 2.280 | 971.597 | 1.680 | 16.340 |
| | LSD $_{0.05}$ | | n.s | n.s | n.s | 1.405 | n.s | n.s | 534.164 | 0.105 | 8.948 |
| | LSD $_{0.01}$ | | n.s | n.s | n.s | 1.909 | n.s | n.s | 726.022 | 0.143 | n.s |
| | | | | | **Means of both Locations** | | | | | | |
| 20th Oct. | | 0 | 36.917 | 8.277 | 10.750 | 12.670 | 87.825 | 2.520 | 1477.482 | 1.776 | 25.089 |
| | 50 | 15 | 40.305 | 8.473 | 12.473 | 11.665 | 76.852 | 2.517 | 1190.106 | 1.269 | 16.509 |
| | | 30 | 41.805 | 7.502 | 12.333 | 11.497 | 75.118 | 2.327 | 1077.344 | 1.510 | 15.685 |
| | | 0 | 41.668 | 8.390 | 11.167 | 10.690 | 75.638 | 2.430 | 2091.885 | 1.516 | 27.377 |
| | 100 | 15 | 40.110 | 8.498 | 12.055 | 10.190 | 89.425 | 2.360 | 2165.055 | 1.408 | 30.941 |
| | | 30 | 40.195 | 9.250 | 11.055 | 12.945 | 84.922 | 2.487 | 2758.885 | 1.165 | 30.349 |
| 20th Nov. | | 0 | 54.028 | 8.555 | 11.077 | 8.475 | 74.768 | 2.288 | 754.308 | 1.165 | 8.505 |
| | 50 | 15 | 54.500 | 9.060 | 12.027 | 9.807 | 71.200 | 2.240 | 789.850 | 1.761 | 13.183 |
| | | 30 | 57.888 | 9.335 | 11.810 | 11.667 | 76.125 | 2.260 | 1021.978 | 1.962 | 19.112 |
| | | 0 | 51.638 | 8.165 | 11.320 | 7.390 | 64.478 | 2.393 | 1162.503 | 1.911 | 21.637 |
| | 100 | 15 | 54.195 | 9.110 | 11.917 | 7.500 | 74.413 | 2.173 | 1293.482 | 2.127 | 25.095 |
| | | 30 | 55.973 | 8.167 | 11.347 | 7.510 | 54.278 | 2.300 | 942.941 | 1.906 | 17.976 |
| | LSD $_{0.05}$ | | n.s | n.s | n.s | 0.928 | 7.055 | n.s | 285.040 | 0.095 | 4.943 |
| | LSD $_{0.01}$ | | n.s | n.s | n.s | 1.239 | 9.425 | n.s | 380.778 | 0.127 | 6.604 |

In contrast, the interaction of the 20th Nov., with 50 plants m$^{-2}$ and control treatment produced the minimum essential oil yield of 11.645 kg h$^{-1}$. Regarding the means of both locations, the interaction effect among these factors was highly significant ($p \leq 0.01$) for the following characters: no. of umbels plant$^{-1}$, no. of seeds umbel$^{-1}$, seed yield, essential oil percent, and essential oil yield. However, the interaction effect was not significant for the other characters. The maximum values for the no. of umbels per plant$^{-1}$ and seed yield were 12.945 umbels and 2758.885 kg ha$^{-1}$, respectively, recorded with the interaction of the 20$^{th}$ Oct. with 100 seeds m$^{-2}$ and 30kg N ha$^{-1}$. On the other hand, the lowest number of umbels plant$^{-1}$ was 7.390 umbels recorded with the interaction of the 20$^{th}$ November 100 plants m$^{-2,}$ and the control treatment. The minimum seed yield of 754.308 kg ha$^{-1}$ was recorded with the interaction of the 20$^{th}$ Nov., 50 plants m$^{-2,}$ and control treatment. As for the no. of seeds umbel$^{-1}$ and essential oil yield, the highest values were 89.425 seeds and 30.941 kg ha$^{-1}$, respectively, recorded with the interaction of the 20$^{th}$ Oct., 100 plants m$^{-2}$ and 15 kg N ha$^{-1}$. The lowest no. of seeds umbel$^{-1}$, 54.278 seeds, was obtained with the interaction of 20$^{th}$ Nov., 50 plants m$^{-2,}$ and control. Similarly, the minimum essential oil yield of 8.505 kg ha$^{-1}$ was produced with the interaction of the 20$^{th}$ Nov., 50 plants m$^{-2,}$ and control. Concerning the maximum essential oil %, it was 2.127% shown with the interaction of the 20$^{th}$ Nov., with 100 seeds m$^{-2}$ and 15kg N ha$^{-1}$. However, the lowest essential oil % was 1.165 % with both the interaction of the 20$^{th}$ Oct., 100 plants m$^{-2}$ and 30 kg N ha$^{-1}$, and 20$^{th}$ Nov., 50 plants m$^{-2}$ and control treatment, respectively

n.s: not significant

**8- Effect of locations on studied traits**

The effects of different locations on the studied characters are illustrated in Table 10. All the studied characters exhibited a highly significant response to these effects, except for the no. of branches plant$^{-1}$, root depth, and 1000 seeds weight, which showed only a significant response. The Kanipanka location outperformed the Qlyasan location for all characters, except for the essential oil percentage, where the Qlyasan location demonstrated a superior oil percentage. The Kanipanka location surpassed the Qlyasan location by 25.58%, 14.26%, 12.52%, 41.93%, 26.92%, 7.94%, 91.50%, and 46.60% for the characters plant height, no. of branches plant$^{-1}$, root depth, no. of umbels plant$^{-1}$, no. of seeds per umbel, 1000 seeds weight, seeds yield, and essential oil yield, respectively. However, the Qlyasan location had a higher essential oil percentage, prevailing over the Kanipanka location by 28.27% These findings suggest that the location of cultivation significantly influences the studied characteristics of the anise plants. The Kanipanka location exhibited better performance in terms of growth parameters, seed yield, and essential oil yield. This could be attributed to favorable environmental conditions, particularly the moderate temperature. The provided meteorological data in Table 1 further support this observation. Anise plant growth is hindered when the soil temperature drops to 6°C (35). To achieve a profitable yield and obtain high-quality essential oil from Anise, it is advantageous to have a warm, sunny, and dry autumn season (15), Table 1. McCord (16) mentioned that the life zone for anise cultivation is 8-23 °C with 1000-1200 mm annual precipitation, producing excellent crops, and soil pH ranged from 6.3 to 7.3.

**Table 10. Effect of Locations on the studied characters**

| Locations | Plant height (cm) | No. of branches plant$^{-1}$ | Root depth (cm) | No. of umbels plant$^{-1}$ | No. of seeds umbel$^{-1}$ | 1000 seed wt. (g) | Seeds yield (kg ha$^{-1}$) | Essential oil (%) | Essential oil yield (kg ha$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| Qlyasan | 40.727 | 7.995 | 10.927 | 8.405 | 66.474 | 2.268 | 956.299 | 1.824 | 16.995 |
| Kanipanka | 54.144 | 9.135 | 12.295 | 11.929 | 84.366 | 2.448 | 1831.338 | 1.422 | 24.915 |
| LSD $_{0.05}$ | 1.591 | 0.705 | 0.936 | 0.776 | 3.767 | 0.137 | 204.470 | 0.086 | 4.202 |
| LSD $_{0.01}$ | 2.638 | n.s | n.s | 1.287 | 6.247 | n.s | 339.066 | 0.142 | 6.969 |

**n.s: not significant**

## Conclusion

The findings of this study demonstrate that sowing date, plant density, and nitrogen fertilization exert significant influences on the growth, yield, and essential oil production of anise. Early sowing on 20$^{th}$ October generally enhanced seed yield, umbel number, and essential oil yield, while later sowing on 20$^{th}$ November favored plant height and essential oil percentage. Higher plant density (100 plants m$^{-2}$) improved seed yield and oil yield but reduced umbels number and seeds per umbel compared to lower density (50 plants m$^{-2}$). Application of 30 kg N ha$^{-1}$ promoted plant height, umbel number, and seed yield, whereas 15 kg N ha$^{-1}$ increased root depth and essential oil percentage in some cases. Significant interactions among sowing date, plant density, and nitrogen levels indicate that optimum performance is achieved under early sowing, higher plant density, and moderate nitrogen application, reflecting the need to balance vegetative growth with reproductive output. These results provide a basis for optimizing agronomic practices to maximize both yield and essential oil quality in anise cultivation under similar environmental conditions.

## CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

## DECLARATION OF FUND

The authors declare that they have not received a fund.

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