International Journal of Nature and Life Sciences

IJNLS

https://dergipark.org.tr/tr/pub/ijnls

e-ISSN: 2602-2397 https://doi.org/10.47947/ijnls.1366849

*Article*

# The Impact of Various Nitrogen Treatments on Fennel Quality Attributes

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**Abstract:** The present study was conducted to determine the effects of various nitrogen doses on the quality characteristics and macro-micro nutrient elements of fennel (*Foeniculum vulgare* Mill. var. *dulce*) in Kahramanmaras conditions. The trial was conducted in 2020. Two different sweet fennel populations, Konya and Tokat 1, and six different N doses (0, 30, 60, 90, 120, 150 kg ha$^{-1}$) were used in the study. Apart from fixed oil content and fixed oil yield, substantial variations between the two fennel populations were found in other traits. Nitrogen dosages significantly affected every trait except the fixed oil ratio. In terms of protein content, essential oil content, and essential oil output, Tokat 1 population exhibited higher values. Oleic acid was abundant in both groups, however Tokat 1 had lower palmitic acid ratios and greater oleic acid ratios than Konya population. Also, Tokat 1 population had higher trans-anethole ratios (90.20%), and Konya population was richer in terms of other essential oil components (α-pinene, Limonene, β-phellandrene, β-ocimene, and Fenchone); Tokat 1 population contained all other nutrient elements (N, Ca, Mn, Ze, Fe, Mg, P, and K) at higher ratios except Cu. Increasing nitrogen doses caused significant increases in fixed oil and essential oil components. Fixed oil components were higher at 150 kg ha$^{-1}$ N dose. The highest trans-anethole content (88.44%) was detected at a 90 kg ha$^{-1}$ N dose.

**Keywords:** Fennel, *Foeniculum vulgare* var. *dulce*, Nitrogen fertilizer, Quality characteristics.

**Citation:** Gedik, O., & Kuş, İ. (2023). The impact of various nitrogen treatments on fennel quality attributes. International Journal of Nature and Life Sciences, 7 (2), 100-111.

Received: September 28, 2023
Accepted: October 27, 2023
Online Published: October 30, 2023



## 1. Introduction

Fennel (*Foeniculum vulgare*) is an important spice, medicine, and essential oil plant from the Apiaceae family. The Mediterranean and West Asian regions are where fennel originated, and it expanded to many other parts of the world in various methods. The majority of the world's cultivation takes place in Europe, as well as in Pakistan, India, Egypt, Türkiye, China, Argentina, and Indonesia. Egypt, India, and Türkiye supply the majority of the USA's fennel needs. Fennel has two main cultivars as bitter fennel (*Foeniculum vulgare* var. *vulgare*) and sweet fennel (*Foeniculum vulgare* var. *dulce*) (Baydar, 2016). One species is naturally distributed in the flora of Türkiye (Baydar, 2020). Fennel is among the medicinal plants exported by Türkiye (Bayram et al., 2010), and is used because of the essential oil in its ripe fruits in culture forms (Dirican and Telci, 2016). Essential oil is obtained at a ratio of 2-4% from sweet fennel fruits with the steam distillation method. Especially the amounts of trans-anethole (30-60%) and d-fencon (10-20%) determine the quality of fennel essential oil. The amount of trans-anethole in Turkish fennel essential oils is quite high (Baydar, 2020). In addition to being utilised in the food industry to flavour items and increase their shelf life, fennel fruits are used in the kitchen to add flavour to soups, sauces, pickles, pastries, bread, and cakes. According to Baydar (2020), fennel fruits contain stimulant, sedative, antibacterial, laxative, diuretic, and carminative properties. The plant's roots serve as a diuretic and its leaves are used in traditional folk medicine to treat wounds (Calıskan et al., 2010). Fertilization has a significant impact on the quality and output of aromatic and medicinal plants as well as other traditional goods (Tunctürk, 2008). Numerous organic substances, including protein, DNA, chlorophyll, and nucleic and amino acids, are formed by nitrogen, which is essential for many critical processes and is present in plant dry matter at a ratio of 2-4%. Nitrogen is the most significant nutritional shortfall in plant productivity, and excluding legumes, it is a crucial input in agricultural output. Although there is a high-level (78%) N in the atmosphere (N2), which plants cannot use directly, the amount of N plants may benefit from in the soil is very low (<0.02%). Although soil organic matter contains approximately 5% N, 1-4% of this amount is mineralized each year (Aras and Uygun, 2017). According to Chatzopoulou et al. (2006), as long as the N level in the soil is not below a minimum of 0.1%, additional N is not required to produce an acceptable amount of essential oil at adequate quality in fennel. In the study conducted by Tuncturk et al. (2009), although increasing nitrogen doses increased the nitrogen, phosphorus, potassium, and copper content in grains, it also decreased calcium, iron, and manganese content. In the study of Chatzopoulou et al. (2006) conducted in Greece, the essential oil yield and components varied according to the variety, they were not affected by increasing nitrogen doses. High-dose nitrogen fertilizer, according to Yildirim and Kan (2006), marginally boosted the essential oil ratios. One of the cultural practices is nitrogen fertilisation, which promotes generative and vegetative growth. Depending on the types of plants and the local ecology, different amounts, types, and timings of nitrogen delivery are used. Determining the proper nitrogen dosages for various kinds and geographical circumstances would therefore help to achieve good yield and quality. The goal of the current study was to ascertain how varying nitrogen levels affected the nutritional values and qualitative traits of two distinct fennel populations under Kahramanmaraş, Türkiye.

## 2. Materials and Methods

Two distinct populations of sweet fennel (Konya and Tokat 1) that were planted on November 21 and collected on July 15 were the focus of this study. The seed samples were taken from an experiment that had been running for several years.

### *2.1. The trial site and conditions*

The average precipitation amount is 650.80 mm for many years in the area. The total precipitation amount in the vegetation period of 2019-20, in which the study was conducted, was 652.30 mm, which was similar to the long-term average value. Although the average temperature value was 13.25 °C in the vegetation period of 2019-20, the average temperature for many years was 12.60 °C (Table 1). The average temperature value of the year in which the study was conducted was higher than the average temperature value for many years (Table 1).

**Table 1.** Kahramanmaras provincial center climate data for 2020 (Anonymous, 2020a).

| Climatic Factory | Year | Months | | | | | | | | Avarage |
|---|---|---|---|---|---|---|---|---|---|---|
| | | November | December | January | February | March | April | May | June | |
| Precipitation (mm) | 2019-2020 | 39.10 | 198.50 | 88.00 | 72.70 | 173.40 | 61.80 | 18.50 | 0.30 | 652.30 |
| | Long years (1980-2020) | 87.50 | 116.60 | 125.40 | 108.30 | 93.40 | 69.80 | 41.20 | 8.40 | 650.80 |
| Average Temperature (°C) | 2019-2020 | 13.50 | 8.40 | 6.30 | 6.10 | 12.50 | 15.90 | 15.90 | 24.50 | 13.25 |
| | Long years (1980-2020) | 11.50 | 6.80 | 4.90 | 6.40 | 10.60 | 15.50 | 20.30 | 25.30 | 12.60 |
| Relative humidity (%) | 2019-2020 | 56.20 | 81.90 | 69.30 | 68.30 | 67.30 | 58.20 | 47.20 | 46.90 | 61.91 |
| | Long years (1980-2020) | 66.68 | 79.85 | 69.99 | 65.62 | 60.00 | 57.59 | 54.95 | 49.67 | 63.04 |

Although the average relative humidity was 63.04%, according to the long-term average, the average relative humidity in 2019–20 was 61.91%, which was lower than the long-term average relative humidity number. At the University-Industry-Public Cooperation Development Implementation and Research Centre (USKIM), soil samples collected from the trial site were examined.

**Table 2.** Some chemical and physical properties of the study area soils (Anonymous, 2020b)

| Year | Texture class | Organic matter (%) | $CaCO_3$ (%) | EC (dS $m^{-1}$) | pH | $P_2O_5$ (mg $kg^{-1}$) | $K_2O$ (mg $kg^{-1}$) |
|---|---|---|---|---|---|---|---|
| 2019 | Clay (69.96) | 1.58 | 6.09 | 0.05 | 7.71 | 2.84 | 55.51 |

Table 2 lists a few physical and chemical characteristics of the soil samples. In the soil analysis, the total lime content was calculated using a Scheibler calcimeter device in accordance with Kacar (1994), the soil pH was established in accordance with Thomas (1996), and the organic matter was established using Nelson and Sommers' (1996) wet burning technique. Using the ammonium acetate technique developed by Helmke and Sparks in 1996, Ca, Mg, and K were quantified. The soil texture study was performed utilizing the bouyoucus hydrometer technique, which was created by Olsen et al. (1954), according to the method Olsen et al. (1954) described for the usable phosphorus (Gee and Bauder 1986). The electrical conductivity values were determined and the total salt amount of the soils was calculated with the formula specified by Tüzüner (1990). The trial area soil is clayey (69.96), unsalted (0.05 dS $m^{-1}$), low calcareous (6.09%) and has a low organic matter level (1.58%). The potassium (K2O) ratio of the soil is adequate (555.10 kg $ha^{-1}$), and the phosphorus (P2O5) ratio (28.40 kg $ha^{-1}$) is quite low (Table 2).

### *2.2. The trial material*

The population of Tokat 1, which was obtained from the Central Black Sea Transition Zone Agricultural Research Institute, and Konya population, which was obtained from the producers in Konya, were used in the study; and 60 kg $ha^{-1}$

$P_2O_5$ was applied to the trial area with sowing. Nitrogen was applied to all plots by hand-scattering at 6 different doses (0, 30, 60, 90, 120, and 150 kg $ha^{-1}$), half during planting, and the other half during bolting.

*2.3. Design and cultural practices*

At a sowing depth of 2-3 cm, in 5 rows with 40 cm between rows, the rows were opened with the aid of a marker. After emergence, the plants were spaced 20 cm apart above the row. In accordance with the split-plot trial design, the study was set up in three replications. Fennel populations and nitrogen dosages were distributed across subplots and main plots, respectively, in the current study. The parcel measured 3 m in length, 2 m in breadth, with a distance of 0.5 m between each parcel and 2.5 m between each block. Weed management was carried out manually, and watering was carried out using the drip irrigation technique. On July 15, 2020, harvesting was done manually after subtracting 0.5 m from the parcel heads to account for the "edge effect".

*2.4. Data collection*

The measurements of the quality characteristics of fennel are given below. The essential oil and fixed oil components were examined in Batı Akdeniz Agricultural Research Institute (BATEM) Laboratory, and the analyses of other characteristics were made in USKIM Laboratory.

*2.5. Protein content (%)*

The protein ratio was calculated by multiplying the N ratios of seeds by the coefficient of 6.25 using the Micro Kjeldahl technique (Bremner and Mulvaney, 1982).

*2.6. Essential oil content (%)*

After grinding 25 g of seeds cleaned and blended, the hydrodistillation process was performed in Neo-Clevenger device for 3 hours, and then the essential oil (%) was volumetrically determined (Kılıc, 2008). The essential oil composition of samples was analysed by gas chromatography (Agilent 5975C) coupled to flame ionization detector and mass spectrometry (Agilent 5975C) using capillary column (HP Innowax Capillary; 60.0 m × 0.25 mm × 0.25 µm) (Toker et al. 2017, Uysal and Çınar, 2020).

*2.7. Essential oil yield (L $ha^{-1}$)*

The essential oil ratio obtained in the study was multiplied by the seed yield in hectare and was calculated by dividing by one hundred and expressed as L $ha^{-1}$.

*2.8. Fixed oil content (%)*

After the seed samples were ground, 5-g samples were prepared from each sample, and the fixed oil (%) was determined by extraction with petroleum ether for 6 hours in the Soxhlet apparatus (Celik ve Ayran, 2020). The fatty acid composition of the samples was analyzed by gas chromatography (Agilent 5975C) coupled to flame ionization detector and mass spectrometry (Agilent 5975C) (GC-MS-FID) (Aydogdu and Gölükcü, 2017).

*2.9. Fixed oil yield (kg $ha^{-1}$)*

The fixed oil ratio obtained in the study was multiplied by the seed yield in hectare and was calculated by dividing by one hundred and expressed as kg $ha^{-1}$.

*2.10. Nutrient elements analysis (mg $kg^{-1}$)*

Plant nutritional elements were determined by outsourcing services to the Sütçü İmam University USKIM laboratory. 5 grams of ground sample was delivered to the laboratory and nutritional element values were determined with the ICP-OES (Optima 2100 DV: Perkin Elmer Inc.) device (Hossner, 1996).

*2.11. Statistical analyses*

The results obtained from the observations of the above-mentioned quality-related properties were analyzed using the JMP. (2010) package program according to the split-parcel trial design. Differences found to be significant were subjected to the LSD multiple comparison test ($P<0.05$ or $P<0.01$ according to the limit of probability found significant).

**3. Results and Discussion**

The effects of different nitrogen doses on quality traits and plant nutrient elements in two different sweet fennel populations were investigated in the present study.

*3.1. Protein content (%)*

The protein ratio was significantly affected by the fennel populations, nitrogen applications, and population x nitrogen dosage interaction (Table 3). In comparison to Konya population, Tokat 1 population exhibited a greater protein ratio. Protein ratio rose after nitrogen application. The 60 kg ha-1 dosage had the greatest protein ratio (13.55%). When adjusting for the lowest population, Tokat 1 population (14.22%) acquired the greatest value at 60 kg ha-1, while Konya population's application of 30 kg ha-1 produced the lowest result (Fig. 1a). Ehsanipour et al. (2012) identified the protein ratio in the range of 16.44%-19.03% in terms of doses, the highest protein ratio (19.03%) was detected in 120 kg $ha^{-1}$ application, and the lowest value was obtained in 0 kg $ha^{-1}$ (Control), and 40 kg $ha^{-1}$ in the same group, and the highest value (20.44%) was determined in the population x dose interaction in Yazd population at a dose of 160 kg $ha^{-1}$. The greatest protein ratio was measured as 13.68% by Ayub et al. (2015) using a 90:45 N/P application. Protein ratios were comparable, but it was discovered that at various dosages, they achieved their greatest value. The application, the environment, and the materials may all be to blame for this.

**Table 3**. The effect of different nitrogen doses on protein ratio, fixed oil ratio, fixed oil yield, essential oil ratio and essential oil yield in fennel populations.

| | | PO (%) | FOR (%) | FOY (kg ha$^{-1}$) | EOR (%) | EOY ( L ha$^{-1}$) |
|---|---|---|---|---|---|---|
| **Populations (P)** | Konya | 13.09 b | 15.75 | 404.82 | 1.68 b | 43.19 b |
| | Tokat 1 | 13.77 a | 16.49 | 372.91 | 2.04 a | 46.55 a |
| **LSD (P)** | | 0.04** | 1.08 | 27.53 | 0.11** | 3.63* |
| | $N_0$ | 13.49 ba | 16.30 | 337.90 b | 1.72 c | 35.45 c |
| | $N_{30}$ | 13.38 c | 16.29 | 409.15 a | 1.96 ba | 48.77 ab |
| **Doses (D)** | $N_{60}$ | 13.55 a | 16.46 | 417.80 a | 1.72 c | 43.25 b |
| **(kg ha$^{-1}$)** | $N_{90}$ | 13.47 b | 15.47 | 393.00 ab | 2.02 a | 51.95 a |
| | $N_{120}$ | 13.50 ba | 15.81 | 388.20 ab | 1.96 ba | 47.78 ab |
| | $N_{150}$ | 13.22 d | 16.38 | 387.15 ab | 1.77 bc | 42.02 bc |
| **LSD (D)** | | 0.079** | 1.879 | 47.69* | 0.204** | 6.29** |
| | $P_1$ X $N_0$ | 13.06 ef | 16.13 | 387.40 bcd | 1.64 | 39.27 cd |
| | $P_1$ X $N_{30}$ | 12.84 h | 16.42 | 442.50 ab | 1.71 | 46.28 bc |
| | $P_1$ X $N_{60}$ | 12.87 gh | 15.61 | 405.26 bc | 1.49 | 38.57 cd |
| | $P_1$ X $N_{90}$ | 13.12 de | 15.03 | 323.50 ef | 1.77 | 38.13 cd |
| | $P_1$ X $N_{120}$ | 13.19 d | 15.73 | 430.03 abc | 1.72 | 47.69 b |
| **Populations x Doses** | $P_1$ X $N_{150}$ | 13.48 c | 15.59 | 440.23 ab | 1.73 | 49.21 b |
| **(P x D)** | $P_2$ X $N_0$ | 13.92 b | 16.47 | 288.40 f | 1.80 | 31.62 d |
| | $P_2$ X $N_{30}$ | 13.92 b | 16.16 | 375.80 cde | 2.22 | 51.26 b |
| | $P_2$ X $N_{60}$ | 14.22 a | 17.32 | 430.33 abc | 1.95 | 47.94 b |
| | $P_2$ X $N_{90}$ | 13.82 b | 15.92 | 462.50 a | 2.26 | 65.78 a |
| | $P_2$X $N_{120}$ | 13.82 b | 15.90 | 346.36 de | 2.21 | 47.87 b |
| | $P_2$ X $N_{150}$ | 12.96 fg | 17.18 | 334.06 def | 1.80 | 34.83 d |
| **Mean** | | 13.43 | 16.12 | 388.86 | 1.86 | 44.87 |
| **CV** | | 0.48 | 9.67 | 10.18 | 9.17 | 11.65 |
| **LSD (P X D)** | | 0.10** | 2.90 | 55.74** | 0.27 | 8.18** |

PR: Protein ratio, FOR: Fatty oil ratio, FOY: Fatty oil yield, EOR: Essential oil ratio, EOY: Essential oil yield

*3.2. Fixed oil ratio (%)*

The interaction of population, nitrogen dose, and population x nitrogen dose did not have significant effects on the fixed oil ratio. Fennel populations had fixed oil ratio values of 15.75%-16.49%. Increasing nitrogen doses did not cause significant differences when compared to the control. The effects of nitrogen doses on fixed oil ratios did not change according to populations, and population x nitrogen dose interaction was not significant. Ayub et al. (2015) reported the fixed oil ratio as 9.17%-12.50%, and that the control application had the highest value. In his study, Ayırtman (2015) reported that increasing N doses had no effects on fixed oil ratios.

*3.3. Fixed oil yield (kg ha$^{-1}$)*

In the current study, it was discovered that the population x dosage interaction and the effects of nitrogen doses on fixed oil output were substantial. The fixed oil yield in Konya was greater, at roughly 3%. Application of N improved the production of fixed oil, although all dosages save the control were statistically equal (Table 3). The impacts of N dosages differed depending on the populations; the Tokat 1 population received the maximum fixed oil production with a 90 kg ha$^{-1}$ N treatment, whereas the same population received the lowest with a control (0 kg ha$^{-1}$) application (Fig. 1b). According to Keskin and Baydar (2016), fennel had a fixed oil yield that ranged from 13.15-15.07%, with the people of Denizli recording the highest figure.

*3.4. Essential oil ratio (%)*

It was found that the effect of population and nitrogen doses on the essential oil ratio was significant at 1%; however, the effect of population x nitrogen dose interaction was not significant. The essential oil ratio of Tokat 1 population (2.04%) was higher than that of Konya population (1.68%). When the effects of nitrogen doses were considered, the highest essential oil ratio was obtained from the 90 kg ha$^{-1}$ N application, and the lowest ratio was obtained from the control and

60 kg ha$^{-1}$ N applications, which were statistically in the same group (Table 3). Ehsanipour et al. (2012) reported that the essential oil ratio in the range of 1.42-2.30% stating that the EU11486 population gave the highest value with 160 kg ha$^{-1}$ application. Ayup et al. (2011) determined the essential oil ratio in the range of 2.59-2.75% in the first year, and in the range of 2.60-2.65% in the second year. Tunctürk (2008) reported the essential oil ratio in the range of 2.01-2.12%, and that the effect of nitrogen doses on the essential oil ratio to be insignificant.

*3.5. Essential oil yield (L ha$^{-1}$)*

It was found in the present study that the population effect on essential oil yield was significant at 5% level, and the effects of nitrogen doses and population x dose interaction were at 1% level (Table 3). The essential oil yield of Tokat 1 population (46.55 L ha$^{-1}$) was higher than the essential oil yield value of Konya population (43.19 L ha$^{-1}$). This was because of the high essential oil content of Tokat 1 population. The highest essential oil yield was obtained in 60 kg ha$^{-1}$ N dose, and the lowest from 0 kg ha$^{-1}$ N (Control) application. The effects of nitrogen doses varied among the populations. The highest essential oil yield was obtained in Tokat 1 population with 90 kg ha$^{-1}$ nitrogen application, and the lowest was obtained in the same population with 150 kg ha$^{-1}$ nitrogen application (Fig. 1c). Ehsanipour et al. (2012) reported that the highest essential oil yield (18.10) was obtained at a dose of 160 kg ha$^{-1}$ nitrogen, the effect of nitrogen varied according to varieties, and 80 kg ha$^{-1}$ application was the highest in the EU11486 population. Tunctürk (2008) reported the essential oil yield to be 9.7-13.9 L ha-1, and reported that the statistically highest value was obtained in 40 and 60 kg ha$^{-1}$ N doses in the same group.

**Table 4.** Effect of different nitrogen doses on fixed oil components in fennel populations.

| | | Palmitic acid (%) | Palmitoleic acid (%) | Stearic acid (%) | Oleic acid (%) | Linoleic acid (%) | Linolenic acid (%) |
|---|---|---|---|---|---|---|---|
| **Populations** | Konya | 4.38 a | 0.305 | 1.21 b | 82.69 b | 11.11 a | 0.25 a |
| | Tokat 1 | 4.33 b | 0.301 | 1.32 a | 83.39 a | 10.39 b | 0.24 b |
| **LSD (P)** | | 0.012** | 0.007 | 0.012** | 0.014** | 0.009** | 0.009** |
| **Doses (kg ha$^{-1}$)** | $N_0$ | 4.32 c | 0.28 b | 1.24 c | 83.40 b | 10.48 d | 0.24 b |
| | $N_3$ | 4.30 c | 0.31 a | 1.24 c | 83.55 a | 10.32 f | 0.24 b |
| | $N_6$ | 4.38 b | 0.30 a | 1.26 b | 83.01 c | 10.76 c | 0.24 b |
| | $N_9$ | 4.40 b | 0.30 a | 1.29 a | 82.61 d | 11.13 b | 0.24 b |
| | $N_{12}$ | 4.25 d | 0.31 a | 1.26 b | 83.40 b | 10.43 e | 0.30 a |
| | $N_{15}$ | 4.48 a | 0.30 a | 1.30 a | 82.26 e | 11.39 a | 0.23 b |
| **LSD (D)** | | 0.021** | 0.013** | 0.020** | 0.024** | 0.015** | 0.015** |
| **Populations x Doses (P x D)** | $P_1$ X $N_0$ | 4.27 e | 0.27 c | 1.19 ef | 83.39 d | 10.56 d | 0.24 def |
| | $P_1$ X $N_3$ | 4.20 f | 0.31 ab | 1.17 f | 83.90 a | 10.12 l | 0.26 bc |
| | $P_1$ X $N_6$ | 4.51 b | 0.31 ab | 1.21 e | 82.37 g | 11.32 c | 0.24 ef |
| | $P_1$ X $N_9$ | 4.44 c | 0.31 ab | 1.25 d | 81.96 h | 11.81 b | 0.22 g |
| | $P_1$ X $N_{12}$ | 4.25 e | 0.33 a | 1.19 ef | 83.51 c | 10.36 ı | 0.33 a |
| | $P_1$ X $N_{15}$ | 4.63 a | 0.29 bc | 1.25 d | 81.03 ı | 12.52 a | 0.23 efg |
| | $P_2$ X $N_0$ | 4.36 d | 0.29 bc | 1.29 c | 83.42 d | 10.40 h | 0.24 ef |
| | $P_2$ X $N_3$ | 4.41 c | 0.31 ab | 1.31 bc | 83.21 f | 10.52 e | 0.23 fg |
| | $P_2$ X $N_6$ | 4.25 e | 0.29 bc | 1.32 abc | 83.65 b | 10.20 k | 0.25 cdg |
| | $P_2$ X $N_9$ | 4.35 d | 0.29 bc | 1.32 ab | 83.26 e | 10.46 g | 0.26 cd |
| | $P_2$ X $N_{12}$ | 4.26 e | 0.30 b | 1.34 a | 83.30 e | 10.50 f | 0.28 b |
| | $P_2$ X $N_{15}$ | 4.34 d | 0.31 ab | 1.34 a | 83.50 c | 10.26 j | 0.23 fg |
| **Mean** | | 4.36 | 0.30 | 1.26 | 83.04 | 10.75 | 0.25 |
| **CV** | | 0.41 | 3.71 | 1.35 | 0.02 | 0.12 | 5.22 |
| **LSD (P X D)** | | 0.03** | 0.019** | 0.026** | 0.039** | 0.026** | 0.019** |

*3.8. Fixed oil components (%)*

It was found that the effects of population, nitrogen doses, and population x nitrogen dose interaction on fixed oil components were significant (Table 4). The main fatty acid is oleic acid in terms of fixed oil components in fennel. Palmitic acid, linoleic acid, and linolenic acid were higher in Konya population than in Tokat 1 population, but stearic and oleic acid values were higher in Tokat 1 population. When the nitrogen dose effects were evaluated, palmitic acid, palmitoleic acid, stearic acid, and linoleic acid had the highest value at a dose of 150 kg ha$^{-1}$ N, oleic acid had the highest value at 30 kg ha$^{-1}$ N, and linoleic acid had the highest value at 120 kg ha$^{-1}$ N (Table 4). When the population x dose interaction was evaluated in terms of fixed oil components, the highest value was obtained in Konya population for components other than stearic acid. The highest value was obtained for palmitic acid and linoleic acid at a dose of 150 kg ha$^{-1}$, at a dose of 120 kg ha$^{-1}$ for palmitoleic and linolenic acid, and 30 kg ha$^{-1}$ N for oleic acid. The highest value for stearic acid was obtained at 120 kg da$^{-1}$ and 15 kg da$^{-1}$ N doses in the statistically same group in Tokat 1 population (Table 4, Fig. 1a-ı). Celik and Ayran (2020) reported the main fixed oil component as 84.356% oleic acid, linoleic acid 10.014%, palmitic acid 5.048%, palmitoleic acid 0.28%, and linolenic 0.29% in fennel, which is consistent with the data of this study.

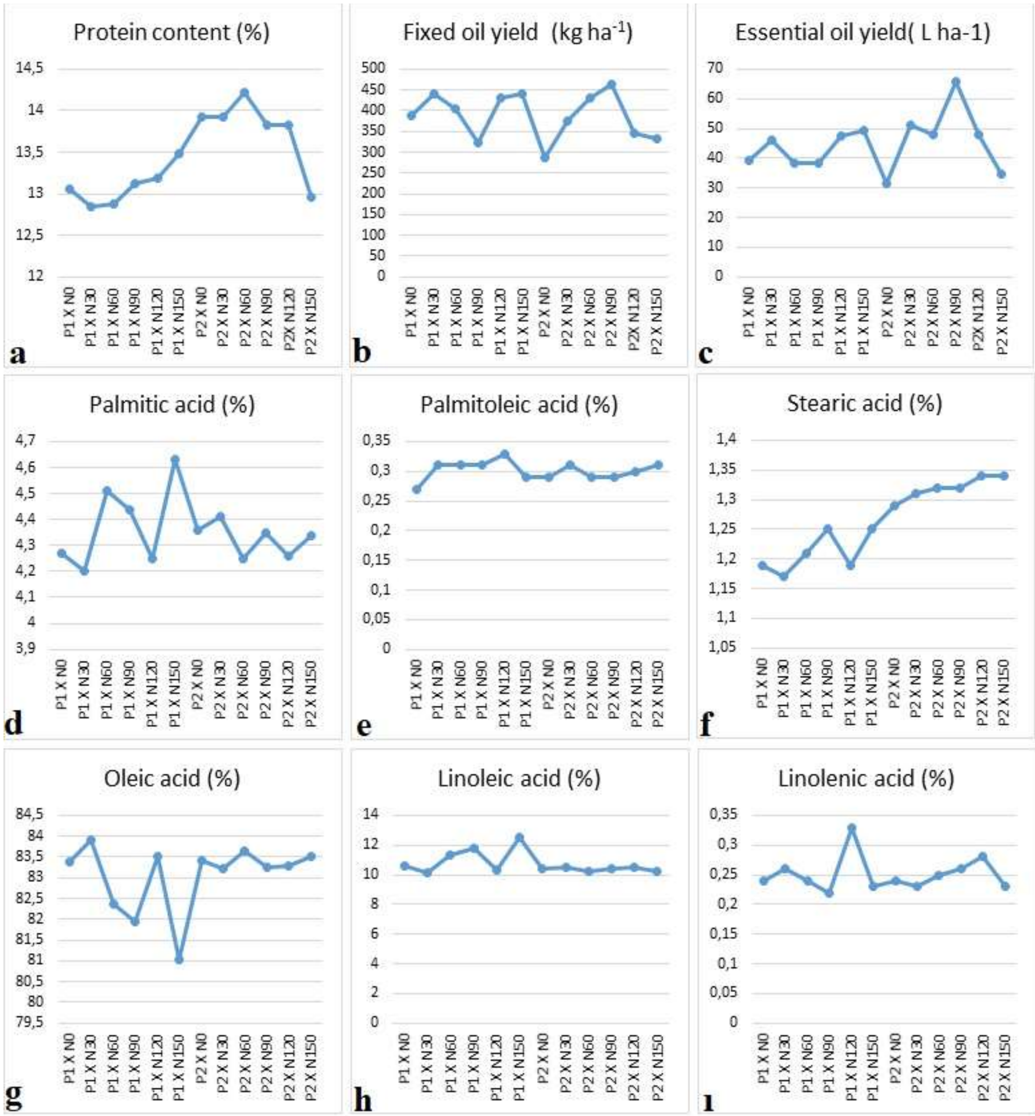


**Figure 1.** Statistically significant genotype x dose interaction values in terms of protein content, fixed oil yield, essential oil yield and fixed oil components of fennel populations grown at different nitrogen doses (a-ı).

*3.9. Essential oil components (%)*

Konya population had higher values than Tokat 1 population in all determined components except for trans-anethole in terms of essential oil components. Tokat 1 population had approximately 6% higher trans-anethole ratio. Sabinene and β-myrcene components could not be detected in Tokat 1 population (Table 5). The significant effects of the nitrogen doses were detected on fenchone and trans-anethole, the highest fenchone content was obtained in 150 kg da$^{-1}$ N dose, and the highest trans-anethole content was obtained in 90 kg ha$^{-1}$ N dose.

**Table 5.** Effect of different nitrogen doses on essential oil components in fennel populations.

| | | α-pinene (%) | Sabinene (%) | β-myrcene (%) | Limonene (%) | β -phellandrene (%) | β-ocimene (%) | Fenchone (%) | Trans-anethole (%) |
|---|---|---|---|---|---|---|---|---|---|
| **Populations** | Konya | 1.43 a | 0.31 | 0.34 | 10.49 a | 0.64 a | 0.75 a | 2.00 a | 84.23 b |
| | Tokat 1 | 0.67 b | - | - | 6.85 b | 0.33 b | 0.68 b | 0.89 b | 90.20 a |
| **LSD (P)** | | 0.014** | 0.007** | 0.010** | 0.018** | 0.011** | 0.013** | 0.009** | 0.455** |
| | $N_0$ | 1.20 a | 0.17 a | 0.19 a | 8.48 d | 0.52 a | 0.74 a | 1.56 c | 86.80 dc |
| | $N_{30}$ | 1.02 b | 0.15 dc | 0.15 dc | 9.36 a | 0.44 c | 0.66 d | 1.24 e | 86.66 d |
| **Doses** | $N_{60}$ | 0.93 d | 0.14 d | 0.14 d | 8.70 c | 0.45 cb | 0.69 c | 1.30 d | 88.08 ba |
| **(kg ha$^{-1}$)** | $N_{90}$ | 0.97 c | 0.15 dc | 0.16 bc | 8.29 e | 0.53 a | 0.73 ba | 1.18 f | 88.44 a |
| | $N_{120}$ | 0.99 c | 0.17 ba | 0.17 bc | 7.89 f | 0.51 a | 0.75 a | 1.61 b | 87.50 bc |
| | $N_{150}$ | 1.17 a | 0.16 bc | 0.18 ba | 9.30 b | 0.47 b | 0.71 bc | 1.79 a | 85.84 e |
| **LSD (D)** | | 0.024** | 0.013** | 0.018** | 0.031** | 0.019** | 0.023** | 0.017** | 0.789** |
| | $P_1$ X $N_0$ | 1.73 a | 0.35 a | 0.39 a | 11.35 a | 0.72 a | 0.85 a | 1.91 c | 82.69 f |
| | $P_1$ X $N_{30}$ | 1.32 c | 0.30 bc | 0.31 d | 11.21 b | 0.57 d | 0.67 def | 1.83 d | 83.75 ef |
| | $P_1$ X $N_{60}$ | 1.09 e | 0.28 c | 0.28 e | 9.98 d | 0.55 d | 0.69 cd | 1.63 f | 85.49 d |
| | $P_1$ X $N_{90}$ | 1.29 d | 0.30 bc | 0.33 cd | 10.02 d | 0.69 b | 0.73 b | 1.76 e | 86.23 d |
| | $P_1$ X $N_{120}$ | 1.44 b | 0.34 a | 0.34 bc | 9.64 e | 0.72 a | 0.85 a | 2.37 b | 84.23 e |
| **Populations** | $P_1$ X $N_{150}$ | 1.70 a | 0.32 b | 0.37 ab | 10.78 c | 0.60 c | 0.71 bc | 2.52 a | 83.01 f |
| **x Doses** | $P_2$ X $N_0$ | 0.67 h | 0.00 | 0.00 | 5.62 k | 0.31 f | 0.63 g | 1.21 g | 90.91 a |
| **(P x D)** | $P_2$ X $N_{30}$ | 0.72 g | 0.00 | 0.00 | 7.51 g | 0.31 f | 0.66 efg | 0.64 k | 89.57 bc |
| | $P_2$ X $N_{60}$ | 0.76 f | 0.00 | 0.00 | 7.43 h | 0.36 e | 0.69 cde | 0.97 ı | 90.63 ab |
| | $P_2$ X $N_{90}$ | 0.66 h | 0.00 | 0.00 | 6.55 ı | 0.38 e | 0.73 b | 0.60 l | 90.65 ab |
| | $P_2$ X $N_{120}$ | 0.55 ı | 0.00 | 0.00 | 6.15 j | 0.31 f | 0.65 fg | 0.86 j | 90.77 a |
| | $P_2$ X $N_{150}$ | 0.65 h | 0.00 | 0.00 | 7.82 f | 0.33 f | 0.71 bc | 1.06 h | 88.68 c |
| **Mean** | | 1.05 | 0.15 | 0.17 | 8.67 | 0.49 | 0.71 | 1.44 | 87.22 |
| **CV** | | 1.94 | 6.97 | 9.08 | 0.29 | 3.24 | 2.73 | 0.98 | 0.75 |
| **LSD (P X D)** | | 0.034** | 0.019** | 0.023** | 0.056** | 0.026** | 0.032** | 0.028** | 1.150** |

Increased nitrogen dose above 90 kg ha$^{-1}$ decreased trans-anethole content. According to Chatzopoulou et al. (2006), Desmarest (1978) reported that high nitrogen fertilization reduced the anethole content. Chatzopoulou et al. (2006) reported that α-pinene was 0.44%, sabinene 0.20% myrcene 0.22%, limonene 6.80%, phellandrene 0.10%, ocimene 0.50 % fenchone 2.10% anethole 82.30% in the Turkish population used in their study in the Chalkidiki region; and the anethole ratio was reported to be lower than that found in this study, and the ratios of the other components were determined to be consistent with the data of this study. According to Delfieh et al. (2016), when the essential oil components of fennel using nitrogen fertilizer was considered, α-pinene $N_1$ dose was 5.55%, $N_2$ dose was 4.83%, sabinene $N_1$ dose was 1.45%, $N_2$ dose was 1.78%, limonene $N_1$ dose was 4.75, $N_2$ dose was 5.05, fenchone $N_1$ dose was 3.00, $N_2$ dose was 2.88, anethole $N_1$ dose was 27.10, and 28.28 in $N_2$ dose. Anethole, which is the main component in fennel, was determined to be much lower than the value found in this study. According to Ozguven et al. (2008), cultivation techniques and agricultural inputs, mainly irrigation, fertilization, harvest time, drying, and processing, greatly affect the secondary metabolite contents and compositions in medicinal plants. Celik and Ayran (2020) reported the trans-anethole ratio in fennel as 86.898%.

The response of the populations to nitrogen doses was different, and the components other than fenchone and trans-anethole had the highest control doses. In Konya population, 150 kg ha$^{-1}$ N dose of α-pinene and 120 kg ha$^{-1}$ N dose of sabinene, β-phellandrene, and β-ocimene components were in the same statistical group as the control group (0 kg ha$^{-1}$ N). Fenchone was obtained at the highest dose of 150 kg ha$^{-1}$ N in Konya population, and the lowest at 90 kg ha$^{-1}$ N in Tokat 1 population (Fig. 2 a-h). Trans-anethole, which is the most important compound in fennel essential oil, was observed to be at the highest dose of 120 kg ha$^{-1}$ N in the same group with the control dose of Tokat 1 population; and the lowest dose was found in the control and 150 kg ha$^{-1}$ N dose in Konya population, which was in the same group.

*3.10. Plant nutrient elements (mg kg$^{-1}$)*

In the present study, it was found that the effects of population, nitrogen doses, and population x dose interaction on nutrient content were significant at 1% level (Table 6). In terms of all investigated elements except for Cu, Tokat 1 population had higher values than Konya population. The effects of nitrogen doses on the investigated elements were found to be different, and the other elements were significantly different from the control except for Mg and Cu. The highest N content was obtained in 60 kg ha$^{-1}$ N, the highest Ca and Fe content in 30 kg ha$^{-1}$ N, the highest Mn content in 120 kg ha$^{-1}$ N, the highest Zn, P, and K content in N application in 150 kg ha$^{-1}$ N.


**Figure 2.** Statistically significant genotype x dose interaction values in terms of essential oil components of fennel populations grown at different nitrogen doses (a-h).

**Table 6.** Effect of different nitrogen doses on plant nutrients in fennel populations.

| | | N (%) | Ca (mg kg$^{-1}$) | Mn (mg kg$^{-1}$) | Zn (mg kg$^{-1}$) | Fe (mg kg$^{-1}$) | Mg (mg kg$^{-1}$) | P (mg kg$^{-1}$) | K (mg kg$^{-1}$) | Cu (mg kg$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|
| **Populations** | Konya | 2.09 b | 13770.00 b | 50.16 b | 48.49b | 314.11b | 4398.58b | 3350.66b | 21986.67b | 21.57a |
| | Tokat 1 | 2.20 a | 15955.83 a | 62.13 a | 52.74a | 372.73a | 4818.66a | 3495.58a | 23430.00a | 20.75b |
| **LSD (P)** | | 0.006** | 84.19** | 0.31** | 0.28** | 1.88** | 19.97** | 9.71** | 54.24** | 0.09** |
| **Doses (kg ha$^{-1}$)** | $N_0$ | 2.15 ba | 14837.50 d | 53.64e | 50.51c | 310.50d | 4749.50a | 3334.25c | 22400.00d | 24.19a |
| | $N_{30}$ | 2.14 c | 16082.50 a | 56.07c | 46.63e | 366.60a | 4591.25c | 3098.50f | 22355.00d | 21.29c |
| | $N_{60}$ | 2.16 a | 13452.50 f | 57.41b | 48.75d | 365.72a | 4493.25d | 3134.25e | 22000.00e | 21.12d |
| | $N_{90}$ | 2.15 b | 14270.00 e | 54.11e | 45.52f | 348.42b | 4490.50d | 3262.25d | 22957.50b | 19.26f |
| | $N_{120}$ | 2.16 ba | 15170.00 c | 60.53a | 55.37b | 334.87c | 4619.50c | 3644.75b | 22572.50c | 19.61e |
| | $N_{150}$ | 2.11d | 15365.00 b | 55.12d | 56.91a | 334.42c | 4707.75b | 4064.75a | 23965.00a | 21.49b |
| **LSD (D)** | | 0.013** | 145.82** | 0.53** | 0.49** | 3.25** | 34.60** | 16.82** | 93.95** | 0.16** |
| **Populations x Doses (P x D)** | $P_1$ X $N_0$ | 2.09 ef | 14535.00 e | 58.32 c | 49.34 e | 336.70 ef | 4431.50 f | 3257.00 g | 21655.00 g | 28.09 a |
| | $P_1$ X $N_{30}$ | 2.05 h | 13470.00 h | 46.04 f | 44.04 e | 294.95 g | 4365.50 g | 3239.50 g | 21050.00 h | 21.38 cd |
| | $P_1$ X $N_{60}$ | 2.06 gh | 12845.00 ı | 55.40 d | 44.62 h | 345.95 d | 4374.00 fg | 2947.50 ı | 22030.00 e | 21.60 c |
| | $P_1$ X $N_{90}$ | 2.09 de | 12965.00 ı | 42.05 h | 44.84 h | 282.75 h | 4230.00 h | 3045.00 h | 21825.00 f | 19.28 h |
| | $P_1$ X $N_{120}$ | 2.11 d | 13770.00 g | 55.08 d | 47.03 f | 338.40 e | 4360.00 g | 3421.00 e | 21145.00 h | 19.31 h |
| | $P_1$ X $N_{150}$ | 2.15 c | 15035.00 d | 44.10 g | 61.07 b | 285.95 h | 4630.50 e | 4194.00 a | 24215.00 a | 19.74 g |
| | $P_2$ X $N_0$ | 2.22 b | 15140.00 d | 48.97 e | 51.68 d | 284.30 h | 5067.50 a | 3411.50 e | 23145.00 d | 20.29 f |
| | $P_2$ X $N_{30}$ | 2.22 b | 18695.00 a | 66.11 a | 49.22 e | 438.25 a | 4817.00 c | 2957.50 ı | 23660.00 c | 21.19 d |
| | $P_2$ X $N_{60}$ | 2.27 a | 14060.00 f | 59.43 b | 52.89 c | 385.50 c | 4612.50 e | 3321.00 f | 21970.00 e | 20.64 e |
| | $P_2$ X $N_{90}$ | 2.21 b | 15575.00 c | 66.18 a | 46.20 g | 414.10 b | 4751.00 d | 3479.50 d | 24090.00 b | 19.24 h |
| | $P_2$ X $N_{120}$ | 2.21 b | 16570.00 b | 65.98 a | 63.71 a | 331.35 f | 4879.00 b | 3868.50 c | 24000.00 b | 19.92 g |
| | $P_2$ X $N_{150}$ | 2.07 fg | 15695.00 c | 66.15 a | 52.75 c | 382.90 c | 4785.00 cd | 3935.50 b | 23715.00 c | 23.24 b |
| **Mean** | | 2.15 | 14862.92 | 56.15 | 50.61 | 343.42 | 4608.62 | 3423.12 | 22708.33 | 21.16 |
| **CV** | | 0.45 | 0.81 | 0.79 | 0.81 | 0.78 | 0.62 | 0.40 | 0.34 | 0.65 |
| **LSD (P X D)** | | 0.016** | 163.72** | 0.805** | 0.549** | 5.468** | 60.500** | 21.873** | 107.21** | 0.308** |

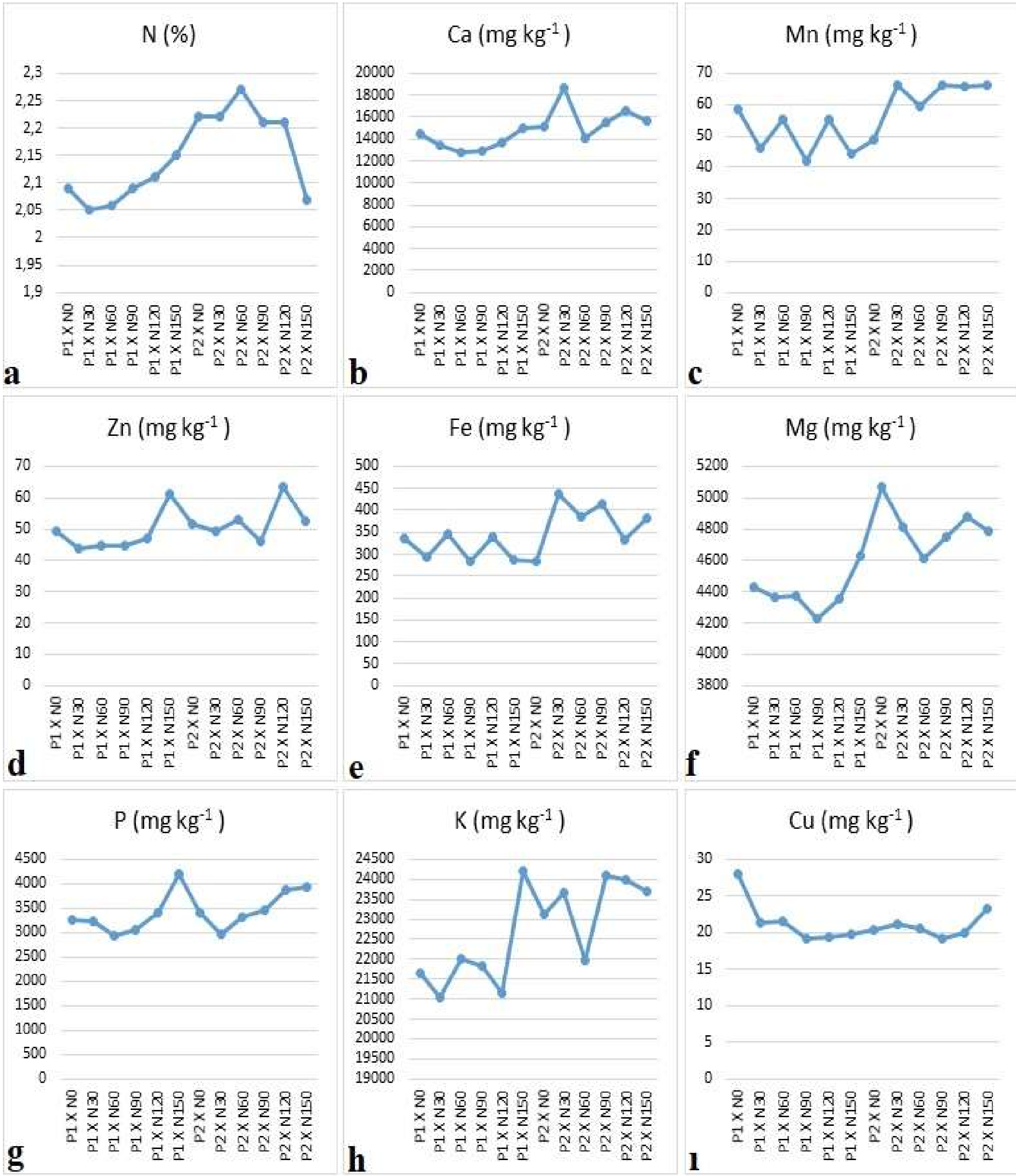


**Figure 3.** Statistically significant genotype x dose interaction values in terms of plant nutritiens elements of fennel populations grown at different nitrogen doses (a-ı).

The effect of nitrogen doses varied among fennel populations. The highest N content was obtained in 60 kg ha$^{-1}$ in Tokat 1 population, the highest Zn content in 120 kg ha$^{-1}$ in Tokat 1 population, the highest Ca, Mn, and Fe content in 30 kg ha$^{-1}$ nitrogen application in the same population, and the highest P and K content was obtained in 150 kg ha$^{-1}$ nitrogen application in Konya population (Fig. 3a-ı). According to Tuncturk et al. (2009), who examined the effects of N and P doses on nutrient elements in fennel, the dose had a different effect, and different doses were formed for different nutrient elements.

## 4. Conclusion

The goal of the current study was to evaluate the effects of various nitrogen dosages (0, 30, 60, 90, 120, and 150 kg ha$^{-1}$) on quality and plant nutrients in two distinct fennel populations (Konya and Tokat 1) under the ecological conditions of the Kahramanmaras region during the winter growing season of 2019–2020. It was discovered that, with the exception of the constant oil ratio, all the tested features were significantly impacted by the nitrogen dosages given. Higher levels of protein, essential oils, and essential oil output were found in the Tokat 1 population. The Konya population was found to have greater levels of other components, excluding stearic acid and oleic acid from fixed oil components, and other components, excluding trans-anethole from essential oil components. All of the investigated plant nutrient elements except for Cu had higher values in Tokat 1 population than in Konya population. When the effects of N doses on the quality characteristics of fennel were evaluated, it was found that the protein ratio was the highest at a dose of 60 kg ha$^{-1}$ N, the essential oil ratio at 90 kg ha$^{-1}$ N, the essential oil yield was at 30 and 90 kg ha$^{-1}$ N, and the fixed oil yield at the doses outside the control, and was affected significantly by increasing nitrogen doses. Nitrogen doses caused increased fixed oil components and significantly increased trans-anethole, which is one of the main essential oil components. Except for Cu and Mg, other nutritional components significantly increased in response to nitrogen treatment. The fixed oil ratio was the only feature on which nitrogen treatment had a negative impact, the researchers concluded. One may argue that selecting the nitrogen dosages based on the cultivars and ecological conditions relevant to the cultivation would be a wiser decision.

**Acknowledgments**
Some of the data used in this research were taken from Ilknur Kuş's master's thesis.

**Conflict of interest**
On behalf of all authors, the corresponding author states that there is no conflict of interest

**Financial Disclosure**
Author declare no financial support.

**Statement contribution of the authors**
This study's experimentation, analysis and writing, etc. all steps were made by the authors.

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