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Original article

Influence of different sowing times on yield and biochemical characteristics of different opium poppy (*Papaver somniferum* L.) genotypes

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ABSTRACT

Background: Opium poppy (*Papaver somniferum* L.) is an important industrial plant that could be cultivated in Turkey during autumn and spring seasons. However, the impact of different seasons on yield and biochemical attributes of different genotypes in Turkey is rarely tested. This study determined the effect of different sowing times (autumn and spring) on alkaloid, oil content, yield and related traits, and phenological properties of different opium poppy genotypes.

Methods: The experiment was conducted at two different locations (Topcu and Yerkoy) during autumn and spring seasons of 2020 and 2021. A total 18 different poppy genotypes available for cultivation were included in the study. Data on yield related traits and biochemical attributes were recorded at harvest.

Results: Alkaloid and oil contents were higher in spring sowings than autumn sowings. However, autumn sowings recorded higher yield and yield-related traits compared to spring sowings. During autumn sowings, morphine ratio varied from 0.33 % to 1.40 %, morphine yield ranged between 4.28 and 21.97 kg ha^{-1}, capsule yield differed between 1156.1 and 2393.3 kg ha^{-1}, and seed yield ranged from 1162.0 to 2420.0 kg ha^{-1}. Similarly, during spring sowings, morphine ratio differed from 0.40 % and 1.50 %, morphine yields ranged between 3.13 and 17.44 kg ha^{-1}, capsule yield varied between 721.7 and 1757.8 kg ha^{-1}, and seed yield ranged from 656.0 to 1676.4 kg ha^{-1}. The genotypes 'Celikoglu', 'Tinaztepe', 'Seyitgazi', 'Ofis 95' and 'Afyon 95' are recommended for autumn sowing, whereas genotypes 'Huseyinbey', 'Ofis 96', 'Celikoglu', 'Seyitgazi' and 'Ofis NM' are recommended for spring sowing due to their higher yield and yield characteristics. The genotypes 'Ofis 1' and 'Ofis 2' can be used in both autumn and spring sowings for morphine production. The genotypes 'Ofis 8' and 'TMO 1' during autumn sowings, and 'Ofis 96' and 'TMO 1' are recommended for spring sowings to obtain higher oil contents.

Conclusion: The results have grouped and identified the available genotypes according to their specific traits. Therefore, the selection of the genotype must be done for the required purpose based on the results of the current study.

1. Introduction

Medicinal plants have been used for the prevention and treatment of human and animal diseases since ancient times. Opium poppy (*Papaver somniferum* L.) is an annual medicinal plant with diploid chromosome number of 2n = 22. It is the member of *Papaver* genus from *Papaveraceae* family of *Ranunculales* order. There are 43 genera and ~500 species in the Papaveraceae family (Yazici, 2020). There are 7 genera and 36 species, 22 subspecies and varieties, making a total of 58 papaver taxa in Turkey, of which 15 taxa are endemic (Guner et al., 2012).

Poppy has several industrial uses. The products obtained from this plant are used in different fields such as food, cosmetics, chemistry, and ornamental plants, especially in the pharmaceutical industry. Legal poppy cultivation, production and trade are carried out in the world according to the 1961 TEK (Single Convention on Narcotic Drugs) contract. Poppy is grown in Turkey, India, Australia, Spain, France, and Hungary as the main legal producer countries for medical purposes in the world (TMO 2014). The Czech

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Republic, China, Austria, Poland, Slovakia, Germany and England are the other poppy producing countries in the world. The annual average legal poppy cultivation area was 80 thousand ha for morphine, thebaine and codeine, and the average morphine equivalent raw material production in the world was 483 tons between 2017 and 2021 (INCB, 2021).

Opium poppy that can be cultivated in autumn and spring seasons in Turkey. A total seventy-thousand-hectare limit has been allocated to Turkey by the United Nations for legal poppy production in the country. The poppy was cultivated on an area of 46.877 ha with an annual production of 22.220 tons of seeds and 23 thousand tons of capsule Turkey (TUİK, 2022).

Opium poppy has two important products, one of which is capsules containing alkaloids, while the other is seeds and oil. Researchers have identified 80 different alkaloids of medical importance from opium poppy capsules (Marciano et al., 2018; Mishra et al., 2013). Morphine, codeine, thebaine, noscapine, oripavine, and papaverine are among the most important alkaloids found in opium poppy capsules. Stranska et al. (2012) reported morphine content between 0.45 and 1.64 %, whereas Arslan et al. (2000) reported between 0.25 and 0.89 %. Similarly, Ayhan and Yıldırım (2021) reported morphine content in the range of 1.07–1.17 % in autumn sowing, and 1.29–1.46 % in spring sowing. There are no alkaloids in poppy seeds. Ripe poppy seeds are known to have 45–55 % oil and 20–30 % proteins. The oil extracted from poppy seeds is rich in unsaturated fatty acids such as linoleic acid and oleic acid. It consists of 52–71 % linoleic acid (Omega 6), 13–24 % oleic acid (Omega 9), 12–18 % palmitic acid, 2–4 % stearic acid, and 0.1–0.4 % linolenic acid (Ozcan and Atalay, 2006).

Genotype and environmental factors, especially precipitation and temperature are the most important variables affecting growth, development, and yield of a plant (Yu et al., 2014). In poppy, yield, quality characteristics, and vegetation period are affected by cultural practices, cultivar characteristics, climatic factors, genotype and sowing times **(Yazici, 2018). The autumn sowing of opium poppy in Turkey is done from 20 September to the end of October, whereas spring crop is grown between 1 March and 15 April, depending on the weather and soil conditions.

Poppy crop is mostly sown during autumn in Turkey. Climate change-induced production losses in poppy range between 12 and 65 % with an average of 33 %. Production losses are due to adverse climatic conditions such as cold stress, drought stress, lack of precipitation, and extreme temperatures (Yazici, 2020). In spring sowings, yield losses are caused by inappropriate genotypes. Therefore, it is important to determine the appropriate genotype and sowing times for obtaining better yield and quality. Hence, this study determined the impact of sowing time on yield and quality attributes of available opium poppy genotypes in Turkey. The major aim of the study was to determine the alkaloid, oil, yield, and yield components of poppy genotypes registered in Turkey sown at different locations and sowing times. It was hypothesized that the genotypes will significantly differ for the studied traits. Furthermore, it was expected that different genotypes will prove better for different traits. The results of the study would allow to select the optimum sowing time and genotype according to the desired objective of production.

2. Materials and methods

2.1. Experimental site

This study was carried out in the experimental fields of Yozgat Bozok University, Topcu and Yerkoy Agricultural Application and Research Center. The trial was set up in two different locations (Topcu and Yerkoy) under autumn and spring sowings times. The autumn sowings was done on 10 and 16 October 2020, whereas spring sowing was done on 08 and 14 April 2021 at Topcu and Yerkoy locations, respectively. Yozgat province is located between 34° 05′ – 36° 10′ east meridians and 38° 40′ – 40° 18′ north parallels. The province has semi-arid climate and humid climate. Springs are hot and dry, while autumns are cold and rainy. The Topcu location is at an altitude of 1300 m above sea level, and the Yerkoy location is at an altitude of 768 m above sea level (TOM, 2022).

2.2. Experimental details

The experiment included 18 different opium poppy genotypes (i.e., 'Afyon 95', 'Anayurt', 'Bolvadin 95', 'Celikoglu', 'Hüseyinbey', 'Ofis 1', 'Ofis 2', 'Ofis 4', 'Ofis 8', 'Ofis 95', 'Ofis 96', 'Ofis NM', 'Seyitgazi', 'Tınaztepe', 'TMO 1', 'TMO 2', 'TMO 3', and 'Zaferyolu') cultivated during autumn and spring seasons in Turkey. The genotypes were obtained from the genetic stocks of Ankara University Faculty of Agriculture, Afyon Alkaloids Factory, Eskişehir and Tokat Research Institutes. The genotypes with superior yield and alkaloid properties recently registered in Turkey were used (Yazici and Yilmaz, 2021). Pure seeds of the studied genotypes were used in the study with 95 % germination obtained by selfing in previous years. The experimental soil was clayey with 1.1 and 1.3 % organic matter 5 and 10 kg ha^{-1} phosphorus (P_2O_5), and 55 and 62 kg ha^{-1} potassium (K_2O) at Topcu and Yerkoy locations, respectively. The average temperature was 10.77 and 10.06 °C and 14.42 and 13.85 °C, and total precipitation was 264.4 and 331.6, and 314.8 and 325.9 in Topcu and Yerkoy locations during 2020 and 2021 years, respectively (Fig. 1).

2.3. Experimental setup

The trial was established according to randomized blocks trial design with 3 replications. The genotypes were sown in two rows of 3 m in length with 45 cm row spacing and 10 cm plant spacing.

2.4. Agronomic practices

Based on the soil analysis of experimental soil, 60 kg/ha N and 60 kg/ha P_2O_5 and top fertilizer 60 kg/ha N fertilizer was applied during sowing. In both seasons, top fertilizer was applied during plant bolting (Yazici, 2018). Agronomic practices such as weed control, irrigation, and thinning were done as needed. Irrigation was applied by drip irrigation method. Capsules were manually harvested at ripening during July for autumn sowings and during September for spring sowings.

2.5. Data collection

Adequate number of samples were extracted from capsule shells of each genotype, ground to powder and their alkaloid (morphine, thebaine, noscapine, codeine, oripavine, and papaverine) ratios were determined using HPLC (Kucuk,1996). Oil ratios were determined as a percentage value from the seeds of each genotype after grinding 2 g sample, boiling in 80 ml ether for 60 min in a Soxtec 2055 oil analyzer at 135 °C.

2.6. Statistical analysis

The collected data were analyzed by one-way analysis of variance (ANOVA) to test the difference among genotypes included in the study. The data were checked for normality and homogeneity of variance before ANOVA. The data had normal distribution; therefore, analyses were performed with the original data. The least significant difference post hoc test at 95 % probability was used to infer the differences among means where ANOVA indicated

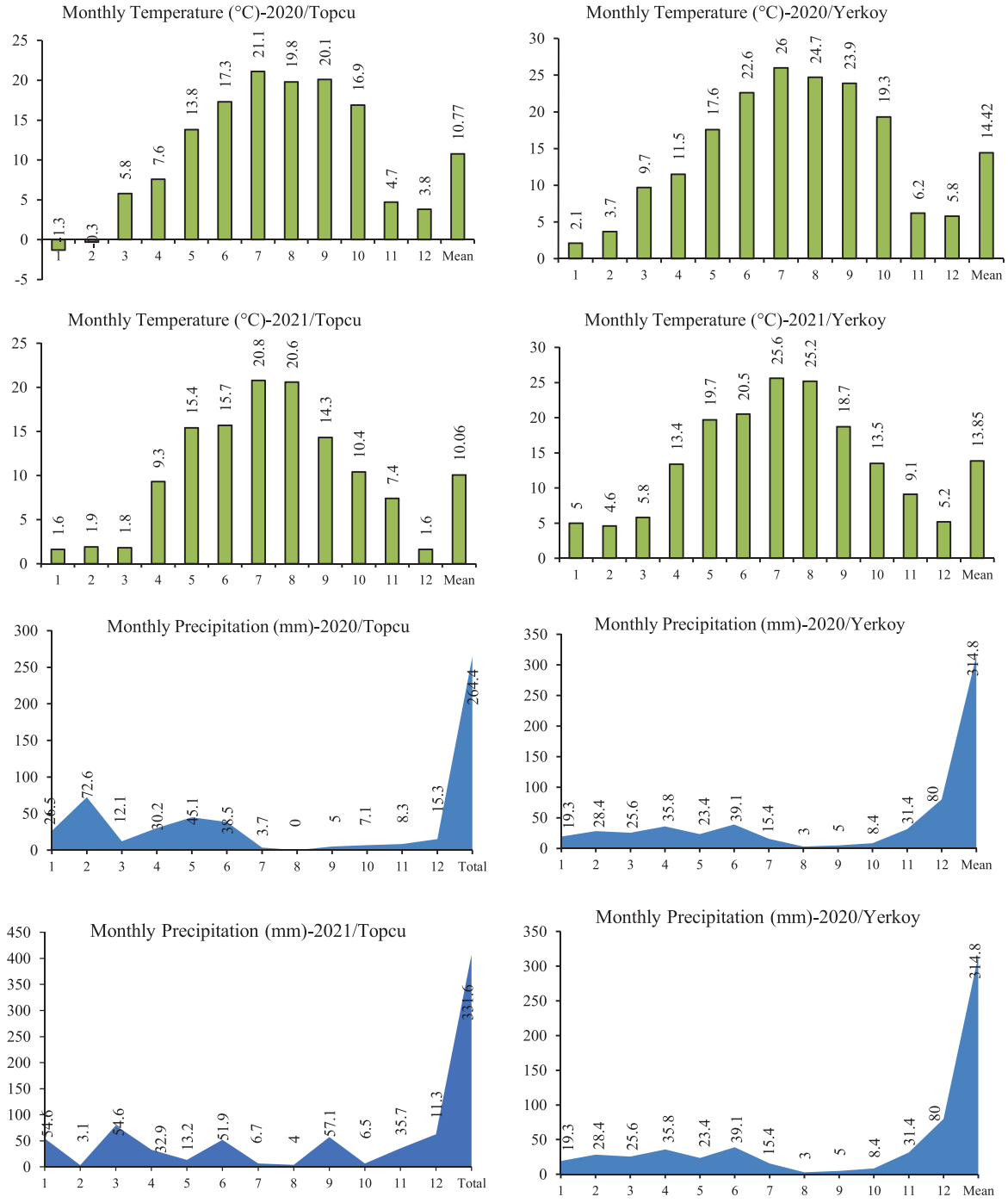

Fig. 1. Temperature and precipitation data of different experimental sites during both seasons.

significant differences. Principal component analysis was used to group the genotypes for easier interpretation. The data for locations and sowing times were analyzed separately. All statistical computations were done on SPSS statistical software version 21.0.

3. Results and discussion

The average emergence, bolting, budding, and flowering time of poppy genotypes grown during autumn and spring at two locations are given in Table 1.

Average emergence time was 14–18 and 13–16 days for autumn and spring sowing, respectively. The average bolting time was 198.7 and 72.1 days, budding time was 210.3 and 79.2 days, the flowering time was 215.52 and 84.37 days for autumn and spring sowings, respectively (Table 3). Average values and statistical significance regarding plant height (cm), and the number of capsule stigmas are presented in Table 2.

3.1. Plant height (cm)

Plant height values ranged from 76.2 to 109.8 cm and the average value was 93.4 cm for autumn sowings at two locations. During spring sowing, plant height values ranged between 74.2 and 108.5 cm with an average value of 89.5 cm (Table 2). Plant height

Table 1
Average values for different phenological phases of opium poppy genotypes grown during autumn and spring seasons at two different locations.

Physiological phases	Autumn sowing		Spring sowing	
	Topcu	Yerkoy	Topcu	Yerkoy
Emergence time (days)	15–18	14–16	13–15	14–16
Bolting time (days)	203.46	194.05	73.50	70.72
Budding time (days)	215.30	205.38	79.63	78.84
Flowering time (days)	220.00	211.05	85.20	83.55

Table 2
Significance levels and mean values for plant height and the number of capsule stigmas of different opium poppy genotypes included in the study.

Varieties	Plant height (cm)				Number of capsule stigmas (piece)			
	Autumn sowing		Spring sowing		Autumn sowing		Spring sowing	
	Topcu	Yerkoy	Topcu	Yerkoy	Topcu	Yerkoy	Topcu	Yerkoy
Afyon 95	94.33	105.89	90.56	101.34	10.86	11.22	9.78	10.15
Anayurt	88.91	90.30	84.78	87.41	11.54	11.27	11.89	10.54
Bolvadin 95	76.18	99.61	74.23	97.04	11.62	11.89	10.70	11.16
Celikoglu	83.62	109.78	82.22	108.57	11.78	10.89	12.00	10.47
Hüseyinbey	96.87	96.44	92.24	84.21	11.57	10.89	11.34	10.62
Ofis 1	91.60	95.22	93.74	84.21	12.17	12.56	11.09	12.15
Ofis 2	93.29	91.67	91.11	90.20	10.78	12.44	10.11	12.05
Ofis 4	98.57	97.56	93.67	95.52	10.73	11.44	11.33	11.22
Ofis 8	86.29	92.44	89.11	82.86	12.03	11.00	12.22	10.52
Ofis 95	88.83	92.67	86.78	86.24	9.67	11.33	8.56	11.22
Ofis 96	92.27	92.22	91.97	88.57	12.02	11.11	12.26	10.67
Ofis NM	91.83	92.67	87.00	90.22	11.31	11.39	11.17	10.81
Seyitgazi	80.41	94.18	80.00	93.33	10.41	11.33	10.38	10.97
Tınaztepe	93.41	103.89	89.78	103.59	11.66	11.22	12.31	11.14
TMO 1	94.05	95.33	93.56	99.29	12.34	11.66	11.78	11.15
TMO 2	93.25	87.78	85.44	75.25	12.66	11.78	13.08	10.71
TMO 3	94.75	96.67	91.78	82.77	11.99	11.36	11.82	11.16
Zaferyolu	94.41	95.67	91.45	82.67	12.34	10.74	11.22	10.91
Mean	90.72	96.11	88.30	90.74	11.53	11.42	11.28	10.98
Locations	93.42		89.52		11.48		11.13	
MS	101.02	204.18	86.14	227.68	1.80	0.77	3.38	0.781
F Ratio	3.58**	11.04**	11.41**	8.05**	2.47*	3.25**	8.98**	1.64
CV (%)	5.84	4.61	3.09	5.85	7.40	4.28	5.47	6.27
LSD $_{(0.05)}$	8.79	7.12	4.54	8.81	1.40	0.79	1.01	0.27

*, ** = Significant at P < 0.05 and P < 0.01 probability levels, respectively.

significantly differed among poppy genotypes included in the study. Similarly, plant height also differed among autumn and spring sowings. Plant height was higher during autumn sowing compared to spring, and at Yerkoy location compared to the Topcu location. The genotypes 'Ofis 4' and 'Çelikoğlu' had the highest plant height, while the lowest plant height was recorded for 'Bolvadin 95' and 'TMO 2' genotypes during autumn sowings at Topcu and Yerkoy locations, respectively. For spring sowings, the highest plant height was recorded for 'Ofis 1' and 'Çelikoğlu' genotypes, while the lowest value was noted for 'Bolvadin 95' genotype. The average two sowing times indicated the highest plant height for 'Afyon 95' genotype, while the lowest value was recorded for 'Bolvadin 95' and 'TMO 2' genotypes. The plant height values of opium poppy reported in the literature are 98.0–118.1 cm for autumn sowings and 63.3–99.7 cm for spring sowing (Kara, 2017). Similarly, the other range of the opium popy genotypes in literature is 106.11–119.34 cm (Rahimi, 2013), 87–105 cm (Solanki, 2014), and 95–100 cm (Alaca, 2015). The plant height values recorded in the current study are different than earlier studies. This difference can be linked to genetic effects, the location of the experiments, and climate differences among earlier studies.

3.2. Capsule stigmas number (piece)

The number of capsule stigmas ranged from 9.7 to 12.6, with an average of 11.5, during autumn sowing, and varied between 8.6 and 13.1 with average value of 11.13 during spring sowings (Table 2). The average value of autumn and spring sowing was 10.2 and 12.1, with an average of 11.3 pieces. The genotypes 'TMO 2' and 'Ofis 1' recorded the highest number of capsule stigmas, while the lowest were noted for 'Ofis 95' and 'Zaferyolu' genotypes during autumn sowing. The highest number of capsule stigmas was noted for the genotypes 'TMO 2' and 'Ofis 1', while the lowest were recorded for 'Ofis 95' and 'Afyon 95' genotypes during spring sowing. The earlier studies reported that the average number of capsule stigmas in opium poppy genotypes were 10–12 pieces (Ipek, 2011), 12.0–13.2 (Karabuk, 2012), and 11.2–12.5 pieces (Rahimi, 2013). The values of the number of capsule stigmas recorded in this study are similar to earlier reports. The number of capsules stigmas directly affects yield of opium poppy. The number of capsule stigmas depends on the genetic structure and influenced by genotype × environment interaction.

3.3. Capsule length (mm)

Capsule length was significantly different among opium poppy genotypes included in the study (Table 3). The capsule length of autumn sowing ranged between 32.7 and 41.4 mm with mean value of 36.12 mm. Similarly, capsule length during spring sowing ranged from 29.9 to 40.5 mm with an average 34.75 mm. The capsule length recorded for autumn sowings was higher than spring sowing (Table 3). The average value of autumn and spring sowing was 32.2 and 40.0 mm, with mean value of 35.44 mm. There was no difference among locations during autumn sowings. The vegetation period of autumn sowing is longer than spring sowing and plants require more water and plant nutrients which significantly

Table 3
Significance levels and mean values for capsule length and width of different opium poppy genotypes included in the study.

Varieties	Capsule length (mm)				Capsule width (mm)			
	Autumn sowing		Spring sowing		Autumn sowing		Spring sowing	
	Topcu	Yerkoy	Topcu	Yerkoy	Topcu	Yerkoy	Topcu	Yerkoy
Afyon 95	38.39	35.89	37.08	34.96	36.30	39.56	34.51	38.53
Anayurt	35.52	36.91	35.30	35.80	41.59	41.67	41.56	40.48
Bolvadin 95	34.95	35.33	33.58	34.37	38.61	39.22	37.00	38.49
Celikoglu	37.55	37.00	36.45	36.04	43.03	43.76	40.47	38.27
Hüseyinbey	35.60	33.33	34.00	34.65	40.80	42.44	40.00	40.67
Ofis 1	36.71	35.17	35.89	34.25	37.54	37.78	35.78	36.58
Ofis 2	36.35	36.11	35.57	34.91	34.61	39.00	29.67	36.85
Ofis 4	34.46	38.56	32.89	37.88	38.85	41.67	38.53	40.10
Ofis 8	34.02	35.44	32.44	34.32	40.55	39.78	39.11	37.90
Ofis 95	37.20	40.00	37.11	39.53	35.30	34.69	30.44	35.50
Ofis 96	35.95	35.11	33.00	30.73	40.16	41.56	40.44	37.72
Ofis NM	34.22	34.24	33.10	33.08	41.26	42.35	42.00	38.42
Seyitgazi	35.69	32.67	30.63	29.89	37.00	40.67	37.28	38.39
Tınaztepe	41.12	41.44	40.46	37.29	43.67	40.67	41.87	37.78
TMO 1	36.05	36.06	34.44	35.08	38.62	39.19	38.45	35.47
TMO 2	32.84	35.00	30.78	33.46	40.67	40.44	39.22	36.76
TMO 3	36.34	37.40	35.56	36.28	41.40	42.15	40.67	40.39
Zaferyolu	35.77	36.09	35.27	35.13	40.27	40.72	39.00	38.76
Mean	36.04	36.21	34.64	34.87	39.46	40.41	38.11	38.17
Locations	36.12		34.75		39.93		38.14	
MS	10.15	17.83	14.44	15.734	19.41	11.46	51.25	7.423
F Ratio	3.84**	14.13**	13.41**	7.84**	6.86**	9.23**	27.41**	1.92*
CV (5)	4.51	3.15	2.97	4.04	4.26	2.80	3.53	5.14
LSD $_{(0.05)}$	2.68	1.84	1.70	2.33	2.78	1.82	2.25	3.24

*, ** = Significant at P < 0.05 and P < 0.01 probability levels, respectively.

increase capsule length. The highest capsule length was observed for 'Tınaztepe' and 'Ofis 95' genotypes, while 'Seyitgazi' and 'Zaferyolu' genotypes resulted in the lowest capsule length during autumn and spring sowings. Capsule length reported reported in earlier studies is 30.3 and 40.0 mm (Yadav et al., 2008) and 33.8–39.1 mm (Boydak and Kavurmacı, 2015). Our results showed similarities with the earlier reports.

3.4. Capsule width (mm)

The capsule width ranged between 34.6 and 43.7 mm with a mean value of 39.9 mm during autumn sowings at two locations. During spring sowings, capsule width ranged between 29.7 and 42.0 mm with the average value of 38.1 mm (Table 3). The average capsule width during autumn and spring sowings was 33.6 and 42.5 mm, with an average of 39.0 mm. The genotypes 'Tınaztepe' and 'Çelikoğlu' had the highest, while 'Ofis 2' and 'Ofis 95' recorded the lowest capsule width during autumn sowing at both locations. During spring sowing, the highest value was noted for 'Ofis NM' and 'Hüseyinbey' genotypes, while the lowest was recorded for 'Ofis 2' and 'TMO 1' genotypes. Autumn sowings had higher capsule width than spring sowings at both locations. Capsule width increased in autumn plantings due to longer vegetation period. There was no difference between locations in spring sowings. The earlier studies reported capsule width as 32–43 mm (Solanki, 2014), 43–44 mm (Boydak and Kavurmacı, 2015), 34–39 mm (Inan and Kaynak, 2016), and 36–46 mm (Haritwal, 2017).

3.5. Capsule yield (kg ha^{-1})

The capsule yield significantly differed among opium poppy genotypes. The capsule yield in poppy varieties ranged between 1156.1 and 2393.3 kg ha^{-1} and the average yield was 1553.7 kg ha^{-1} during autumn sowings. During spring sowings, capsule yield varied between 768.1 and 1596.7 kg ha^{-1} and with mean value of 1047.6 kg ha^{-1} (Table 4). The average yield during autumn and spring sowings was 1048.6 and 1743. kg ha^{-1}, respectively. The genotypes 'Çelikoğlu' and 'Seyitgazi' resulted in the highest capsule yield during autumn and spring sowings of Topcu and Yerkoy locations, while the lowest was noted for 'Ofis 95' and 'Ofis 8' genotypes during autumn sowings at Topcu and Yerkoy locations. The locations differed for capsule yield during autumn sowings. The capsule yield was 1364.9 kg ha^{-1} in Topcu location, while it was 1742.5 kg ha^{-1} in Yerkoy location. The average temperature was higher in the Yerköy compared to the Topcu which had a positive effect on capsule yield. Significant differences were recorded for capsule yield during autumn sowing. It is thought that the high yield of capsules in autumn sowings is the result of long vegetation period, better development of root system, more uptake of plant nutrients and water. In earlier studies Osalou (2015) reported capsule yield in the range of 620.0–1140.0 kg ha^{-1}, while Kara (2017), reported that yield differed between 416.7 and 1375.6 kg ha^{-1} during autumn sowing, and 204.3–830.7 kg ha^{-1} during spring sowing. In the same way **Koşar (2017) reported capsule yield range of 1200.0–1370.0 kg ha^{-1}, whereas Özgen (2019) noted 660.0–1060.0 kg ha^{-1} capsule yield for opium poppy. The results of the current study are in accordance with the capsule yield reported in earlier studies.

3.6. Seed yield (kg ha^{-1})

The seed yield ranged from 1162.0 to 2420.0 kg ha^{-1} with the mean value of 1651.6 kg ha^{-1} for autumn sowing. For spring sowing, the seed yield differed between 720.2 and 1413.7 kg ha^{-1} with a mean value of 1076.9 kg ha^{-1} (Table 4). The highest seed yield during autumun sowing was recorded for 'Çelikoğlu' and 'Afyon 95' genotypes, while the lowest was noted for 'Ofis 95' and 'Ofis NM' genotypes. Similarly, genotypes 'Hüseyinbey' and 'Ofis 96' produced the highest seed yield, whereas 'Ofis 8' and 'Ofis NM' resulted in the lowest yield during spring sowing.

Seed yield of autumn sowing was higher than spring sowing. The increase in length and width of capsule during autumn sowing increased seed yield. The earlier studies on seed yield have reported the seed yield of opium poppy genotypes in the range of 303–486 kg ha^{-1} (Inan, 2013), 720.0–1170.0 kg ha^{-1} (Koc et al., 2014), 720.0–1250.0 kg ha^{-1} (Alaca, 2015), 577.0–1046.0 kg

Table 4
Significance levels and mean values for capsule and seed yield of different opium poppy genotypes included in the study.

Varieties	Capsule yield (kg ha^{-1})				Seed yield (kg ha^{-1})			
	Autumn sowing		Spring sowing		Autumn sowing		Spring sowing	
	Topcu	Yerkoy	Topcu	Yerkoy	Topcu	Yerkoy	Topcu	Yerkoy
Afyon 95	1353.6	2099.1	947.5	1348.1	1349.5	2420.0	921.3	1382.5
Anayurt	1157.6	1435.4	793.5	936.6	1162.5	1466.7	795.4	1198.7
Bolvadin 95	1320.8	1723.2	968.0	1225.1	1319.7	1951.9	952.5	1248.5
Celikoglu	1800.8	2334.8	1374.4	1464.0	1899.9	2060.6	1318.4	1337.9
Hüseyinbey	1625.7	1740.7	1136.0	1181.6	1850.9	1842.1	1358.5	1089.8
Ofis 1	1442.8	1648.5	1035.7	1001.1	1668.9	2120.9	1220.7	1233.2
Ofis 2	1366.5	1863.2	942.9	1165.9	1203.1	1888.8	812.8	1303.3
Ofis 4	1349.4	2080.0	890.3	1400.2	1316.1	2094.7	847.9	1371.9
Ofis 8	1233.6	1222.5	846.9	891.6	1212.8	1464.4	720.2	986.7
Ofis 95	1156.1	1430.0	768.1	893.1	1162.0	1640.0	772.6	970.3
Ofis 96	1405.8	1795.5	1035.2	1074.2	1636.1	2209.3	1118.1	1413.7
Ofis NM	1353.0	1446.7	944.6	970.5	1498.9	1436.7	1099.2	895.2
Seyitgazi	1260.1	2393.3	1064.1	1596.7	1432.5	2270.0	981.1	1395.8
Tınaztepe	1465.5	2052.2	1010.8	1419.1	1489.1	1906.7	1009.1	1232.2
TMO 1	1202.5	1630.0	815.2	1033.7	1352.0	1756.7	868.6	1106.3
TMO 2	1386.3	1436.1	900.2	926.6	1451.0	1771.2	951.3	1223.8
TMO 3	1402.3	1506.7	982.4	961.9	1412.2	1653.3	932.0	1011.2
Zaferyolu	1285.2	1526.7	960.5	808.9	1251.6	1836.7	747.9	939.5
Mean	1364.9	1742.5	967.6	1127.7	1426.0	1877.3	968.2	1185.6
Locations	1553.7		1047.6		1651.6		1076.9	
MS	754.73	3349.16	590.23	1630.46	1443.18	2424.97	1078.12	870.78
F Ratio	10.79**	13.95**	7.11**	9.82**	23.45**	36.27**	11.37**	3.53**
CV (%)	6.12	8.89	9.41	11.42	5.49	4.35	10.05	13.22
LSD $_{(0.05)}$	138.4	256.5	151.1	213.5	130.0	135.4	161.1	260.1

*, ** = Significant at P < 0.05 and P < 0.01 probability levels, respectively.

ha^{-1} (Boydak and Kavurmacı, 2015), 170.0 kg ha^{-1} (Koşar et al. 2017), 720.0–1090.0 kg ha^{-1} (Ozgen et al., 2017), and 1126.0–1167.0 kg ha^{-1} for autumn sowing, and 151.0–157.7 kg ha^{-1} in spring sowing (Ayhan and Yıldırım, 2021).

The main reasons for the differences between the findings of the current study and the other studies are thought to stem from genotype × environment interactions. However, there were also differences in precipitation and temperatures, soil properties, and the materials used in the experiment.

3.7. Morphine ratio

The morphine ratio was significantly affected by opium poppy genotypes included in the study. The morphine ratio in opium poppy genotypes varied between 0.33 % and 1.40 % and Topcu and Yerkoy the autumn sowings. In spring sowing, the ratio was between 0.40 % and 1.50 % (Table 5). Kara (2017) reported the morphine ratio of 0.47–1.00 % for autumn sowing and 0.45–0.97 % for spring sowing in opium poppy varieties. The highest morphine

Table 5
Significance levels and mean values for morphine and codeine ratios of different opium poppy genotypes included in the study.

Varieties	Morphine ratio (%)				Morphine yield (kg ha^{-1})			
	Autumn sowing		Spring sowing		Autumn sowing		Spring sowing	
	Topcu	Yerkoy	Topcu	Yerkoy	Topcu	Yerkoy	Topcu	Yerkoy
Afyon 95	0.52	0.54	0.48	0.67	7.06	11.13	4.59	8.97
Anayurt	0.43	0.44	0.48	0.61	5.00	6.28	3.84	5.70
Bolvadin 95	0.55	0.59	0.61	0.77	7.20	10.21	5.88	9.37
Celikoglu	0.49	0.44	0.50	0.59	8.76	10.33	6.92	8.70
Hüseyinbey	0.50	0.40	0.49	0.55	8.12	6.96	5.54	6.50
Ofis 1	1.40	1.21	1.44	1.47	20.14	20.02	14.90	14.71
Ofis 2	1.31	1.18	1.31	1.50	17.96	21.98	12.44	17.45
Ofis 4	0.47	0.44	0.49	0.66	6.37	9.18	4.39	9.15
Ofis 8	0.44	0.41	0.44	0.58	5.50	5.02	3.77	5.09
Ofis 95	0.36	0.36	0.40	0.59	4.28	5.14	3.13	5.27
Ofis 96	0.43	0.45	0.46	0.61	6.05	8.01	4.77	6.54
Ofis NM	0.72	0.72	0.75	0.90	9.76	10.38	7.12	8.77
Seyitgazi	0.61	0.65	0.69	0.84	7.62	15.49	7.31	13.41
Tınaztepe	0.52	0.48	0.51	0.64	7.58	9.89	5.19	9.09
TMO 1	0.56	0.61	0.66	0.78	6.82	9.97	5.39	8.10
TMO 2	0.47	0.33	0.43	0.49	6.43	4.68	3.85	4.46
TMO 3	0.50	0.43	0.44	0.63	6.94	6.53	4.35	6.03
Zaferyolu	0.50	0.49	0.50	0.68	6.40	7.53	4.84	5.53
Mean	0.60	0.57	0.62	0.75	8.22	9.92	6.01	8.49
Locations	0.585		0.685		9.08		7.25	
MS	0.246	0.188	0.257	0.243	51.95	70.22	27.93	37.73
F Ratio	25.43**	66.35**	70.72**	61.28**	24.84**	40.25**	35.39**	27.99**
CV (%)	16.38	9.36	9.74	8.35	17.51	13.30	14.64	13.66
LSD $_{(0.05)}$	0.16	0.09	0.08	0.10	2.39	2.17	1.46	1.90

*, ** = Significant at P < 0.05 and P < 0.01 probability levels, respectively.

ratio was recorded for 'Ofis 1' and 'Ofis 2' genotypes, while the lowest was noted for 'Ofis 95' and 'TMO 2' genotypes during autumn and spring sowing. The morphine ratio was higher in spring sowing compared to autumn sowing. **Dubedout (1993) stated that there is no relationship between morphine content and agro-morphological characteristics. Danos (1968) reported that morphine content increased in hot and dry weather and decreased in rainy weather after flowering and seed setting. It is thought that hot and dry air increases the morphine content due to the late harvest in spring sowing.

3.8. Morphine yield

Opium poppy varieties genotypes produced morphine yield in the range of 4.28 to 21.97 kg ha^{-1} during autumn sowing (Table 5). For spring sowings, morphine yield ranged from 3.13 to 17.44 kg ha^{-1}. The average value of locations and sowings times was 4.45 and 17.45 kg ha^{-1}. In autumn and spring sowing, the highest morphine yield was recorded for 'Ofis 2' and 'Ofis 1' genotypes, while the lowest was noted for 'Ofis 95' and 'TMO 2' genotypes. When all location and sowing times are evaluated together, the highest morphine yield was determined for 'Ofis 2' and 'Ofis 1' genotypes, and the lowest for 'Ofis 95' and 'Ofis 8' genotypes. The average morphine yield of autumn plantings was higher than spring sowing. However, average value of Yerköy location during spring sowing was higher than autumn sowing of Topcu location. Özgen (2019) reported the morphine yield between 6.63 15.46 kg ha^{-1}, whereas Inan and Kaynak (2016) reported the ratio between 2.1 and 3.6 kg ha^{-1}.

3.9. Thebaine ratio

The thebaine ratio in poppy genotypes ranged between 0.00 % and 0.45 % during autumn sowing. In spring sowing, the thebaine ratio varied between 0.00 % and 0.47 % (Table 6). The average value of autumn and spring sowing in poppy genotypes was between 0.00 % and 0.45 %. While the highest thebaine ratio was determined for 'Ofis 1' and 'Hüseyinbey' genotypes during autumn sowings, the lowest was yielded by 'Ofis 95' and 'Ofis 4' genotypes. In spring sowings, the highest thebaine ratio was noted for 'Ofis 1' and 'Tınaztepe' genotypes, while the lowest was found in 'Ofis 4' and 'TMO 2' genotypes.

3.10. Papaverine ratio

The papaverine ratio in poppy genotypes varied between 0.01 % and 0.07 % with an average of 0.03 % in autumn and spring sowings (Table 6). The genotypes 'Hüseyinbey' and 'Ofis 8' had the highest, while the lowest papaverine ratio was noted in 'Tınaztepe' genotype during autumn sowing. During spring sowings, the highest papaverine ratio was determined for 'Hüseyinbey' and 'Seyitgazi' genotypes, whereas the lowest was noted in 'Ofis 2' and 'Ofis NM' genotypes. As the average of the two sowing times, the highest papaverine ratio was determined in 'Seyitgazi' and 'Hüseyinbey' genotypes, while the lowest was recorded for 'Ofis 1' and 'Ofis' 2 genotypes.

3.11. Noskapine ratio

The noscapine ratio varied between 0.01 % and 0.36 % with an average of 0.08 % in autumn sowing, while it was between 0.02 % and 0.41 % with an average of 0.08 % in spring sowing (Table 7). The average value of autumn and spring sowings was 0.02 % and 0.36 %, with an average of 0.08 % (Table 7). The highest noscapine ratio was noted for 'Ofis 2' and 'Ofis 1' genotypes, while the lowest was recorded for 'TMO 3', 'Ofis 95' and 'Ofis 96' genotypes during autumn and spring sowing.

3.12. Oil ratio

The proportion of thebaine in genotypes ranged between 40.43 % and 46.32 in autumn sowings, while 43.24 % and 47.77 % for spring sowing. The average value of autumn and spring sowing was 41.16 % and 47.77 % (Table 7). While the highest oil ratio was

Table 6
Significance levels and mean values for thebaine and papaverine ratios of different opium poppy genotypes included in the study.

Varieties	Thebaine ratio (%)				Papaverine ratio (%)			
	Autumn sowing		Spring sowing		Autumn sowing		Spring sowing	
	Topcu	Yerkoy	Topcu	Yerkoy	Topcu	Yerkoy	Topcu	Yerkoy
Afyon 95	0.01	0.03	0.00	0.03	0.04	0.03	0.03	0.04
Anayurt	0.13	0.11	0.13	0.21	0.03	0.03	0.03	0.03
Bolvadin 95	0.08	0.05	0.06	0.06	0.02	0.02	0.02	0.03
Celikoglu	0.17	0.12	0.12	0.17	0.01	0.02	0.01	0.03
Hüseyinbey	0.00	0.08	0.00	0.09	0.03	0.07	0.02	0.10
Ofis 1	0.40	0.45	0.47	0.47	0.00	0.01	0.01	0.01
Ofis 2	0.05	0.05	0.05	0.06	0.01	0.01	0.01	0.01
Ofis 4	0.00	0.00	0.00	0.00	0.04	0.02	0.03	0.03
Ofis 8	0.02	0.01	0.02	0.01	0.06	0.05	0.04	0.05
Ofis 95	0.03	0.02	0.02	0.03	0.04	0.03	0.03	0.03
Ofis 96	0.03	0.02	0.02	0.02	0.06	0.03	0.03	0.04
Ofis NM	0.16	0.17	0.13	0.20	0.01	0.05	0.01	0.04
Seyitgazi	0.23	0.18	0.21	0.25	0.06	0.07	0.07	0.07
Tınaztepe	0.15	0.18	0.23	0.26	0.02	0.01	0.02	0.02
TMO 1	0.04	0.05	0.05	0.06	0.04	0.03	0.03	0.03
TMO 2	0.02	0.01	0.02	0.01	0.05	0.02	0.06	0.03
TMO 3	0.05	0.02	0.02	0.02	0.05	0.02	0.02	0.03
Zaferyolu	0.16	0.12	0.13	0.22	0.04	0.04	0.03	0.04
Mean	0.10	0.09	0.09	0.12	0.03	0.03	0.03	0.04
Locations	0.10		0.11		0.03		0.04	
MS	0.032	0.035	0.0418	0.047	0.0009	0.001	0.0009	0.001
F Ratio	19.93**	44.79**	79.62**	34.57**	3.92**	1.57	13.73**	1.33
CV (%)	41.66	30.43	23.65	30.75	44.11	86.66	30.51	88.82
LSD $_{(0.05)}$	0.06	0.05	0.03	0.06	0.02	0.04	0.01	0.05

*, ** = Significant at P < 0.05 and P < 0.01 probability levels, respectively.

Table 7
Significance levels and mean values for noscapine and oil ratios of different opium poppy genotypes included in the study.

Varieties	Noscapine ratio (%)				Oil ratio (%)			
	Autumn sowing		Spring sowing		Autumn sowing		Spring sowing	
	Topcu	Yerkoy	Topcu	Yerkoy	Topcu	Yerkoy	Topcu	Yerkoy
Afyon 95	0.04	0.04	0.03	0.04	43.98	42.51	44.35	44.68
Anayurt	0.05	0.05	0.05	0.05	44.57	44.93	47.11	44.86
Bolvadin 95	0.08	0.08	0.08	0.08	43.18	41.40	43.24	41.85
Celikoglu	0.03	0.04	0.02	0.04	44.93	40.43	45.84	42.54
Hüseyinbey	0.05	0.04	0.05	0.04	43.93	44.61	47.77	46.02
Ofis 1	0.33	0.34	0.39	0.37	43.20	41.19	44.94	43.74
Ofis 2	0.27	0.36	0.30	0.41	43.85	43.88	46.13	45.92
Ofis 4	0.04	0.04	0.05	0.04	43.27	45.78	44.68	45.96
Ofis 8	0.06	0.05	0.07	0.04	44.90	46.32	45.41	47.31
Ofis 95	0.04	0.02	0.02	0.02	42.95	42.64	43.77	44.87
Ofis 96	0.03	0.02	0.04	0.03	44.22	45.39	46.69	46.99
Ofis NM	0.05	0.06	0.03	0.06	42.74	43.37	44.87	44.89
Seyitgazi	0.09	0.07	0.10	0.07	42.28	42.78	43.95	44.82
Tınaztepe	0.03	0.05	0.02	0.05	42.47	42.22	44.06	43.54
TMO 1	0.06	0.05	0.07	0.06	45.64	42.16	47.28	43.85
TMO 2	0.04	0.03	0.03	0.03	43.54	43.34	44.92	41.16
TMO 3	0.02	0.01	0.02	0.02	44.27	42.19	45.41	44.08
Zaferyolu	0.05	0.04	0.05	0.04	44.23	42.56	45.77	44.53
Mean	0.08	0.08	0.08	0.08	43.79	43.21	45.34	43.98
Locations	0.08		0.08		43.50		44.66	
MS	0.020	0.030	0.0307	0.037	2.485	8.125	4.961	36.558
F Ratio	12.44**	67.03**	103.69**	99.45**	1.15	12.35**	32.92**	1.34
CV (%)	53.33	27.27	22.05	23.65	3.34	1.87	0.85	11.89
LSD $_{(0.05)}$	0.07	0.03	0.02	0.03	2.41	1.34	0.62	8.66

*, ** = Significant at P < 0.05 and P < 0.01 probability levels, respectively.

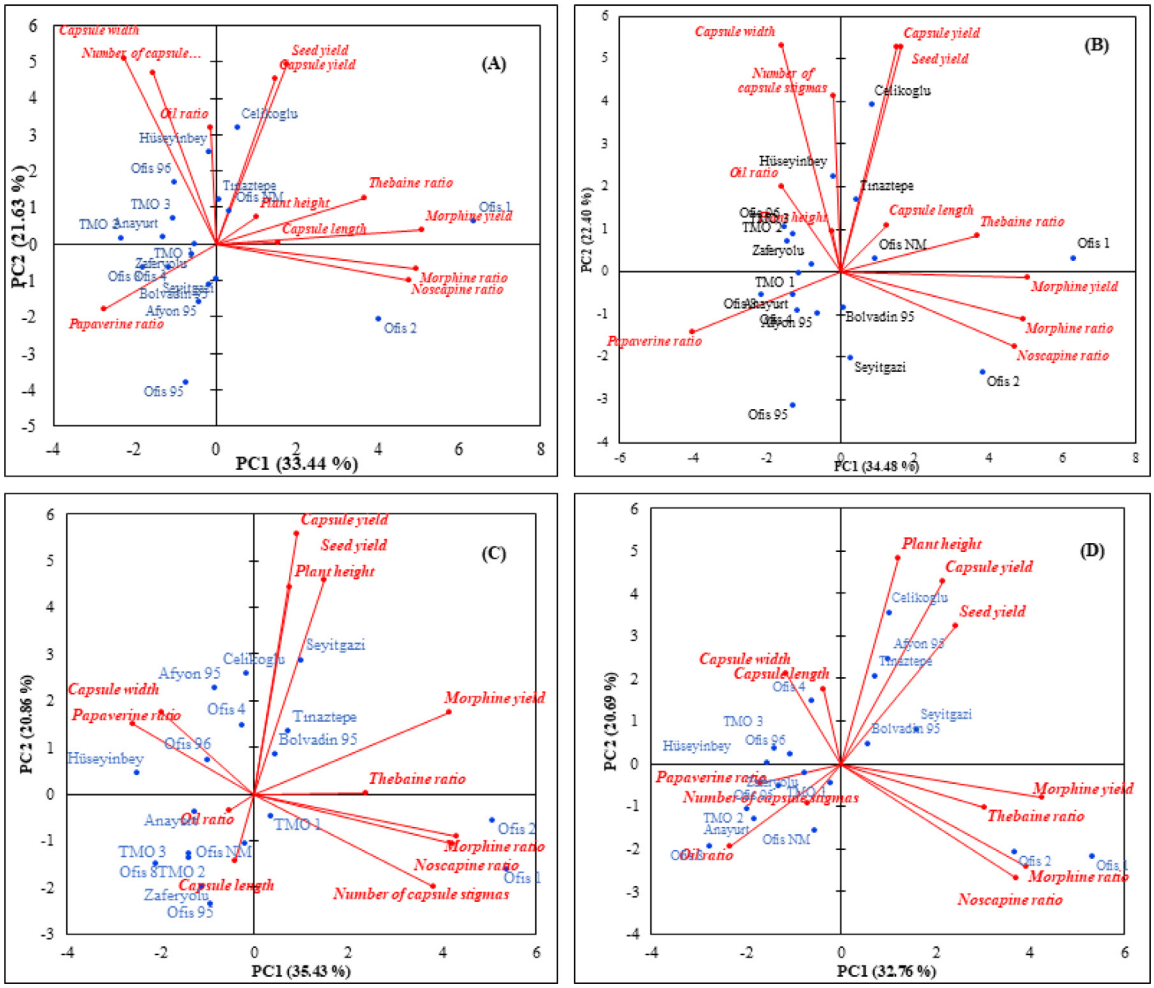

Fig. 2. Principal component analysis indicating the grouping of different opium poppy genotypes grown at Topçu (A = spring, B = autumn) and Yerkoy (A = spring, B = autumn) locations.

determined for 'Ofis 8' and 'TMO 1' genotypes in autumn sowing, the lowest was recorded for 'Çelikoğlu' and 'Seyitgazi' genotypes. During spring sowings, the highest oil raito was determined for 'Ofis 96' and 'TMO 1' genotypes, while the lowest was recorded for 'Bolvadin 95' and 'TMO 2' genotypes.

3.13. Multivariate analysis

The principal component analysis grouped the genotypes included in the current study according to different yield and biochemical attributes. The 'Çelikoğlu' was the highest seed yield producing genotype at Topçu location during both sowing times. Similarly, 'Seyitgazi' genotype during spring and 'Çelikoğlu' genotype during autumn proved the highest yield producing genotypes at Yerkoy location (Fig. 2A-2D). The genotypes 'Ofis 1' and 'Ofis 2' emerged as the highest morphine yield and morphine producing genotypes.

4. Conclusions

Plant height, capsule length, capsule width, capsule yield, seed yield and morphine yield values were found higher in autumn planting compared to spring plantings. However, alkaloid and oil ratios were higher in spring planting. Yerköy location recorded higher morphine yield for spring sowing than autumn sowing at Topcu location. Spring sowing can be considered for industrial purposes, i.e., alkaloid and oil production, and can be an alternative to farmers for the negative effects of cold damage and insufficient precipitation in autumn planting.

According to findings of the study, it can be suggested that genotypes 'Çelikoğlu', 'Tınaztepe', 'Seyitgazi', 'Ofis 95' and 'Afyon 95' for autumn sowing, and 'Huseyinbey', 'Ofis 96', 'Çelikoğlu', 'Seyitgazi' and 'Ofis NM' in spring sowing must be sown for higher yield and yield characteristics. The genotyopes 'Ofis 1' and 'Ofis 2' can be planted in both autumn and spring sowings for morphine purpose production. The varieties 'Ofis 8' and 'TMO 1' in autumn, and 'Ofis 96' and 'TMO 1' in spring are recommended for oil contents. It is necessary to develop varieties with superior alkaloid and yield characteristics suitable for autumn and spring sowings by carrying out breeding studies in poppy.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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