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Influence of Seed Development and Seed Position on Oil, Fatty Acids and Total Tocopherol Contents in Sunflower (*Helianthus annuus* L.)

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Abstract: Sunflower (*Helianthus annuus* L.) is one of the most important oil crops in the world due to its excellent oil quality. This research was conducted to evaluate changes in the contents of oil, fatty acids and total tocopherol of sunflower seeds obtained from different maturity stages and positions on the head. The heads were harvested sequentially 10, 15, 20, 25, 30, 35, 40, and 45 days after flowering (DAF) in 2002 and 2003. The oil content of sunflower seeds increased significantly with seed development, reaching a maximum value of 45.8% at 35 DAF in 2002 and 47.9% at 30 DAF in 2003, after which it started to decline gradually up to 45 DAF. With regard to fatty acid composition, the general trend for linoleic acid was the opposite of that for oleic acid. Oleic acid decreased significantly, while linoleic acid increased significantly during the seed maturity process in both years. Palmitic and stearic acids showed different accumulation patterns depending on the year. In changes in total tocopherol a gradual decrease was detected from 10 to 35 DAF, after which a gradual increase was determined. The position of the seeds on the head had little effect on the oil content, but had a strong effect on the fatty acid contents. Linoleic acid decreased and oleic acid increased linearly from the side to the center seeds. The highest total tocopherol content was found in the side seeds of the head.

Key Words: *Helianthus annuus* L., seed development and position, oil, fatty acids, tocopherol

Ayçiçeğinde (*Helianthus annuus* L.) Tohum Gelişiminin ve Tohum Pozisyonunun Yağ, Yağ Asitleri ve Total Tokoferol İçerikleri Üzerine Etkisi

Özet: Ayçiçeği (*Helianthus annuus* L.) mükemmel yağ kalitesi nedeniyle dünyanın en önemli yağ bitkilerinden birisidir. Bu araştırma farklı olgunlaşma safhalarında ve farklı tabla pozisyonlarında bulunan ayçiçeği tohumlarının yağ, yağ asitleri ve total tokoferol içeriklerindeki değişimleri saptamak amacıyla yürütülmüştür. 2002 ve 2003 yıllarında çiçeklenmeden sonraki 10, 15, 20, 25, 30, 35, 40 ve 45. günlerde tablalar hasat edilmiştir. Ayçiçeği tohumlarındaki en yüksek yağ içeriği değerine 2002 yılında çiçeklenmeden 35 gün sonra (%45.8) ve 2003 yılında çiçeklenmeden 30 gün sonra (%47.9) ulaşılmış, daha sonra 45. güne kadar yağ içeriği sürekli olarak azalmaya başlamıştır. Yağ asitleri dikkate alındığında, linoleik asit için genel eğilim oleik asidinin tersine olmuştur. Her iki deneme yılında da tohum olgunlaşma sürecinde oleik asit önemli şekilde azalırken, linoleik asit önemli şekilde artmıştır. Palmitik ve strearik asit yıllara bağlı olarak farklı birikim eğilimleri göstermiştir. Total tokoferol değişiminde çiçeklenmeden sonraki 10. günden 35. güne kadar düzenli bir azalış, daha sonra ise düzenli bir artış olduğu saptanmıştır. Tabla üzerinde tohum pozisyonunun yağ içeriği üzerine etkisinin az, ancak yağ asitleri içerikleri üzerine etkisinin güçlü olduğu belirlenmiştir. Tabla kenarından merkeze doğru gidildikçe tohumlarda düzenli olarak linoleik asit azalırken, oleik asit artmıştır. En yüksek total tokoferol içeriği tablanın kenar tohumlarında bulunmuştur.

Anahtar Sözcükler: *Helianthus annuus* L., tohum gelişimi ve pozisyonu, yağ, yağ asitleri, tokoferol

Introduction

Sunflower is one of the most important oil crops in the world due to the favorable fatty acid composition of the oil with regard to human consumption. Sunflower oil contains 4 commercially important fatty acids: palmitic (16:0), stearic (18:0), oleic (18:1), and linoleic (18:2). Traditional sunflower oil rich in linoleic acid is primarily used in the edible oil industry. Recently, significant progress has been made in fatty acid alteration of sunflower oil. The high oleic type of sunflower, which contains >85% oleic acid, is considered to be highly valuable not only for the food industry but also for various technical uses, e.g., as a basic material for the

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oleochemical industry (Dehmer and Friedt, 1998). The modification of the fatty acid composition by classical or advanced methods seems to be improving, but there are still many barriers to be overcome to achieve further improvements. For the efficient improvement of oil quality, the accumulation pattern in developing seeds and its relation to fatty acid composition must be investigated.

In general there are 2 substantial changes during development: one is the change in seed volume and the other is biochemical and physiological changes. The former involves division, enlargement and differentiation of seed cells and the latter involves changes in seed components such as storage lipids, fatty acids and other seed storage metabolic substances (Chung et al., 1995).

The oil content and fatty acid composition of the oilseeds are modified by the duration of the seed development (Norton and Harris, 1975; Ichihara and Noda, 1980; Dornbos and McDonald, 1986; Chung et al., 1995; Ishikawa et al., 2001; Rahmatalla et al., 2001; Bhardwaj and Hamama, 2003); in this sense, the genetic analysis of oil and fatty acid composition needs to take into account the duration of development (Ishikawa et al., 2001).

There is an opinion that lipid oxidation remains a major problem in the food industry, and natural antioxidants currently attract the attention of scientists because of the shift of interest from synthetic to natural inhibitors of oil oxidation (Haumann, 1990). Tocopherols, which are the most powerful natural fat-soluble antioxidants (Vitamin E), exist in 4 forms of homologues as minor oil ingredients: α-,β-, γ- and δ– tocopherols (Slover, 1970). The sunflower tocopherol complex is known to contain predominantly the α-form, which has the highest vitamin content and the lowest antioxidant properties, while most oil crops possess high percentages of other forms, especially γ-tocepherol (Demurin et al., 1996). Tocopherol composition in sunflower seeds shows genetic and phenotipic variability (Demurin, 1986; Demurin et al., 1996), and is affected by the refining process; for example, the content of α-, β-, γ- and δ– tocopherols decreases particularly after the deodorization stage (Alpaslan et al., 2001).

The chemical composition of the seed oil depends on the genetic and environmental conditions as well as the stage of maturity of the seed. Information on the changes in oil, fatty acids and total tocopherol in sunflower seeds at different stages of seed development and in different parts of the head is still insufficient or limited. The objectives of this research were to (i) determine the influence of seed development and (ii) determine the influence of seed position along the head on the synthesis of oil, fatty acids and total tocopherol in sunflower seed.

Materials and Methods

Field experiments

Seeds of the hybrid sunflower cultivar 'AS-503' were planted at the Kuleönü farm of Süleyman Demirel University in Isparta province in Turkey (latitude 37° 45' N, longitude 30° 33'E, altitude 997 m) on May 10, 2002, and on May 9, 2003. The soil at Kuleönü was a clay-loam texture with pH of 7.8. The topsoil is very fertile and does not limit the growth of irrigated sunflower. Air temperature, humidity and precipitation data of the site are presented in Figure 1. The experimental design was a randomized complete block design with 3 replications. The plots were furrow-irrigated for uniform emergence as necessary during the growing season. Seeding rate was

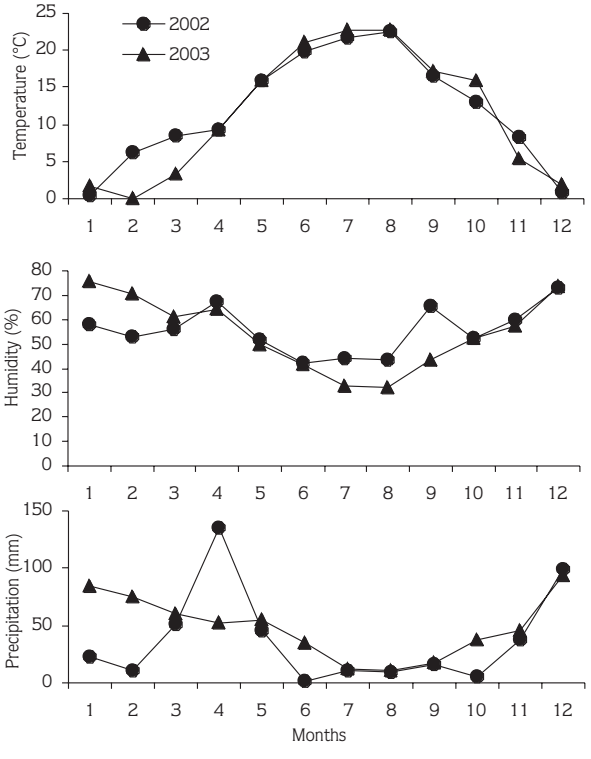

Figure 1. Average monthly air temperature, moisture and precipitation.

0.7 m between rows and 0.25 m within rows. This provided a population density of about 5.7 plants m^{-2}. Before sowing the sunflower, 200 kg ha^{-1} of 18:46:0 fertilizer was applied and then the crop was fertigated at a rate of 64 kg N ha^{-1}. The plots received common cultural practices for the area where the experiments were conducted. Individual heads in the rows were tagged when 50% flowering occurred. The heads were harvested sequentially 10, 15, 20, 25, 30, 35, 40, and 45 days after flowering (DAF) in both years. Twelve heads were harvested for each harvest date. Fresh seeds were dried at 50 °C for 2 days and weighed to determine the average seed yield per head (g), average dry weight per seed (mg) and husk ratio (%). The dry seeds were left in bags at –10 °C until determination of oil, fatty acids, and tocopherol contents.

At the maturity stage, 3 positions were sampled in the heads – side, middle and center. A random sample of seeds (from the filled achenes) was taken from each position to determine oil, fatty acids and total tocopherol contents. The measurements were analyzed as randomized complete blocks using plants as blocks and position within the head as treatment.

Oil extraction

The seeds were oven-dried at 40 °C for 4 h, using a ventilated oven, up to a moisture content of about 5%, and were then ground with a Waring blender. Four grams of dried sunflower seeds were extracted with petroleum ether for 6 h in a Soxhlet system (Büchi Universal Extraction System B-811, Germany) according to the AOCS method (AOCS, 1993). The oil extract was evaporated by distillation at reduced pressure in a rotary evaporator at 40 °C until the solvent was totally removed.

Analysis of fatty acids

The oil was extracted 3 times from 2 g of air-dried seed sample by homogenization with hexane/isopropanol, 3:2, v/v. The oil sample (50-100 mg) was converted to its fatty acid methyl esters (FAME) as described by Marquard (1987). The methyl esters of the fatty acids (0.5 µl) were analyzed in a Hewlett-Packard 6890 series gas chromatograph (Perkin Elmer Auto System XL, USA) equipped with a flame ionizing detector (FID) and a fused silica capillary column (MN FFAP (50 m x 0.32 mm i.d.; film thickness = 0.25 µm). This was operated under the following conditions: oven temperature program, 120 °C for 1 min raised to 240 °C at a rate of 6 °C min^{-1} and then kept at 240 °C for 15 min); injector and detector temperatures, 250 and 260 °C, respectively; carrier gas, helium at a flow rate of 40 ml min^{-1}; split ratio, 1/20 ml min^{-1}. Peak identification was performed by comparing the relative retention times with those of a commercial standard mixture of FAME. The contents of palmitic (C16:0), stearic (C18:0), oleic (C18:1), and linoleic (C18:2) acids were determined using a computing integrator. The effects of the independent variables on oil content and palmitic, stearic, oleic, and linoleic acid concentrations of the oil were analyzed on a percentage basis.

Analysis of total tocopherol

Total tocepherol analysis was performed as described by Linow and Pohl (1970). A series of concentrations (0, 25, 50, 100, 150, 200 and 250 µg in 0.2 ml ethyl acetate) of DL-α-tocopherol were prepared for a standard curve. Before spectrophotometric measurements, 1 ml of α-α—diphenyl-β-picrylhydranyl (DPPH) solution (20 mg DPPH in 50 ml ethyl acetate) was put into each of the tubes containing 200 µl DL-α-tocopherol standards and each of the tubes containing 200 mg of freshly-pressed oil. The values were monitored with a spectrophotometer (Perkin Elmer UV/VIS Lamda 20) at an excitation wavelength of 522 nm. The amount of total tocopherol was determined as mg kg^{-1} in oil extracted from the seeds obtained from the 2003 experiment.

Statistical analysis

Data were statistically analyzed using ANOVA in the MSTAT-C package computer program (version 2.1, Michigan State University, 1991). When significant treatment differences occurred, means were separated using Duncan's multiple range test at the 1% level. Correlation coefficients were also calculated as the average of the 2002 and 2003 experimental years.

Results and Discussion

Analysis of variance for seed yield per head, dry weight per seed and husk ratio in the seed maturity stages is shown in Table 1. Significant differences were determined for all these agronomic characters ($P \leq 0.01$). Analysis of variance for the oil content, fatty acid composition and total tocopherol content in the seed maturity stages and seed positions is shown in Table 2.

Table 1. Analysis of variance for the seed yield per head, dry weight per seed and husk ratio.

Source	df	Seed yield per head MS		Dry weight per seed MS		Husk ratio MS	
		2002	2003	2002	2003	2002	2003
Stage	7	235.6**	618.7**	164.5**	428.3**	379.8**	1130.7**
Block	2	4.25	0.14	7.8*	4.5	1.6	2.5
Error	14	0.8	2.1	1.6	1.5	2.1	2.5

*, ** Significant at $P \leq 0.05$ and $P \leq 0.01$, respectively, MS = Mean Square

Table 2. Analysis of variance for the oil content, fatty acid composition and total tocopherol content in stages (top) and positions (bottom).

Source	df	Oil MS		Palmitic MS		Stearic MS		Oleic MS		Linoleic MS		Tocopherol MS
		2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	
Stage	7	79.8**	70.0**	2.3**	17.7**	0.7**	8.9**	116.8**	167.8**	164.5**	351.1**	16057.1**
Block	2	2.5**	0.1	0.0	0.0	0.0	0.7	0.1	0.0	0.1	0.7	1237.5*
Error	14	0.1	0.5	0.0	1.0	0.0	0.2	0.0	0.4	0.1	0.8	330.7
Position	2	1.2	1.5	0.4*	19.3*	0.2*	1.4*	3.0**	4.7*	1.1*	54.2*	30642.8**
Block	2	3.0	1.1	0.0	0.4	0.0	0.0	0.4	0.6	0.5*	0.1	1244.9
Error	4	0.0	2.8	0.0	3.0	0.0	0.2	0.1	1.1	0.0	4.3	1039.5

*, ** Significant at $P \leq 0.05$ and $P \leq 0.01$, respectively, MS = Mean Square

Significant differences were found in all the fatty acids and tocopherol content. Oil content was significantly influenced by the maturity stages in both years ($P \leq 0.01$), but was not significantly influenced by the seed positions.

Table 3 shows the changes in seed yield per head, dry weight per seed and husk ratio during the maturity stages in 2002 and 2003. In 2002, seed yield and seed weight increased remarkably at 25 DAF and maximized at 30 DAF, at 66.1 g $head^{-1}$ and 56.4 g, respectively. In 2003, seed yield and seed weight increased gradually up to the last harvest date at 60.8 g $head^{-1}$and 52.0 mg, respectively (Table 3). The gradual increases in the seed yield may be due to the relatively higher rainfall in the 2003 maturity periods in comparison with those in 2002 (Figure 1).

Seed yields per head up to the last maturity stage in 2003 were lower than those in 2002 (Table 3). Flowering period was from the last week of July to the first half of August in both years. In the 2003 flowering season there were higher air temperatures and relative humidity than in the 2002 flowering season (Figure 1). The lower seed yields in 2003 may be due to the higher temperatures and the lower relative humidity, which cause poor pollination. Miralles et al. (1997) also reported that seasons with high temperatures and low relative humidity produce many empty and sterile achenes and so low sunflower head fertility.

The husk ratio, which is of prime importance for profitable oil production, decreased gradually from 52.4% to 24.0% in 2002 and from 72.8% to 24.8% in 2003 during maturity or development (Table 3). The heavier seeds from the late stages of development gave the lowest husk ratio. There was a negative relationship between seed weight and husk ratio.

Changes in oil content, fatty acid composition and total tocopherol content in the developing seeds are given in Table 4. The oil percentage of whole sunflower seed depends on both the percentage of husk and the percentage of oil in the kernel (Weiss, 1983). In changes in oil contents in 2002, a sudden increase was initiated at 15 DAF and continued until 35 DAF. Significant increases

Table 3. Changes in seed yield per head, seed weight and husk ratio in developing sunflower seeds.

Days after flowering	Seed yield per head (g)		Dry weight per seed (mg)		Husk ratio (%)	
	2002	2003	2002	2003	2002	2003
10	40.4 f[1]	22.0 e	36.1 e	22.8 e	52.4 a	72.8 a
15	43.9 e	22.3 e	39.9 d	25.2 d	48.8 b	66.7 b
20	46.3 e	36.4 d	45.1 c	33.4 c	41.5 c	44.3 c
25	49.4 d	39.2 d	46.8 c	43.2 b	32.3 d	33.8 d
30	66.1 a	48.3 c	56.4 a	49.0 a	31.2 d	26.9 e
35	60.7 b	48.6 c	55.2 a	49.6 a	25.5 c	26.2 e
40	56.8 c	55.4 b	53.4 b	50.8 a	24.3 c	25.8 e
45	48.1 d	60.8 a	51.8 b	52.0 a	24.0 c	24.8 e

[1] Values within a column followed by the same letter or letters are not significantly different at the 1% level (Duncan's multiple range test)

Table 4. Changes in oil content, fatty acid composition and total tocopherol in developing sunflower seeds.

Days after flowering	Oil content (%)		Fatty acid composition (%)								Tocopherol (mg kg^{-1} in oil)
			Palmitic (C16:0)		Stearic (C18:0)		Oleic (C18:1)		Linoleic (C18:2)		
	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	
10	30.5 e[1]	31.5 e	8.7 a	16.6 a	6.4 a	8.8 a	38.3 a	40.9 a	46.0 h	33.7 f	652.4 a
15	38.7 d	40.0 d	8.6 a	12.4 b	5.3 c	7.3 b	36.0 b	37.8 b	49.2 g	42.5 e	517.5 b
20	43.3 c	41.5 d	7.7 b	9.5 c	5.3 c	7.3 b	31.3 c	36.0 c	55.3 f	47.2 d	506.4 b
25	44.8 b	45.6 b	6.8 c	10.0 bc	5.6 b	5.1 c	28.6 d	28.7 d	58.6 e	56.2 c	482.6 bc
30	45.4 ab	47.9 a	7.6 b	9.5 c	4.8 f	5.1 c	24.5 e	26.0 e	62.7 d	58.4 c	474.4 bc
35	45.8 a	43.3 c	6.6 d	10.0 bc	5.1 d	5.0 c	24.4 e	26.5 e	63.6 c	58.5 c	398.7 d
40	44.7 b	41.3 d	6.7 c	9.5 c	5.1 d	4.9 c	23.1 f	22.8 f	64.5 b	62.6 b	453.4 c
45	42.6 c	41.3 d	6.7 c	11.4 bc	5.3 c	3.5 d	21.4 g	20.2 g	65.6 a	64.9 a	473.6 bc

[1]Values within a column followed by the same letter or letters are not significantly different at the 1% level (Duncan's multiple range test)

in oil content from 30.5% to 45.8% were observed in these periods of seed development. The oil content did not increase significantly from 30 to 35 DAF, after which it started to decline gradually from 45.8% to 42.6%. The accumulation pattern of the oil was similar in 2003, and the highest oil content was determined at 30 DAF with a value of 47.9%. Although the oil contents were higher from 10 to 30 DAF in 2003, 2002 was a better year than 2003 in terms of the oil content of the final seeds (Table 4). Sunflower oil content is generally influenced by temperature during seed development (Goyne et al., 1979; Miralles et al., 1997). Temperature changes and increases during the sub-period seed maturation in 2003 may have negatively affected the oil synthesis.

According to the results from both experimental years, the accumulation amount of crude oil in the developing sunflower seeds started at the beginning of seed development and increased rapidly after 15 DAF, finally reaching the highest levels at 30 and 35 DAF (Table 4). Jasso de Rodriguez et al. (2002) previously reported that the oil content of sunflower seed analyzed at grain filling and harvest indicated a slight decrease from grain filling to harvest. In safflower, oil content increased significantly with seed development, reaching a

maximum value at 30 DAF, after which it decreased gradually (Rahmatalla et al., 1998). On the other hand, in a study by Bhardwaj and Hamama (2003), the oil content of rapeseed increased gradually from the first to the last seed development stages.

Changes in fatty acids are of special importance to the quality of the oil. In the present study, fatty acid accumulation patterns resulting from seed development duration were observed. The results showed that the composition of fatty acids changed significantly during seed development. Palmitic acid, stearic acid, oleic acid and linoleic acid comprised over 99% of total lipids on the average, and of these oleic and linoleic acids comprised over 85% of total fatty acids (Table 4).

Changes in the contents of unsaturated fatty acids (oleic and linoleic) were clearer than those in the saturated fatty acids (palmitic and stearic) during seed development. The accumulation patterns of palmitic and stearic acids were quite similar, with slight fluctuations as the seeds developed. In the first year, palmitic and stearic acid contents decreased significantly with seed development, reaching minimum values of 6.6% at 35 DAF and 4.8% at 30 DAF, respectively. In the second year, while palmitic acid fluctuated up to late maturity stages, stearic acid showed a regular decrease from 8.8% to 3.5% (Table 4). Harris et al. (1978) reported that palmitic acid decreased from 19.6% to 6.2% and that stearic acid increased from 1.8% to 5.4% during seed development in sunflower.

A rapid decrease in the synthesis of oleic acid and a rapid increase in the synthesis of linoleic acid were observed during the development of sunflower seeds, with no abrupt fluctuation. When the seeds developed from 10 to 45 DAF, oleic acid content decreased from 38.3% to 21.4% in 2002 and from 40.9% to 20.2% in 2003, linoleic acid increased from 46.0% to 65.6% in 2002 and 33.7% to 64.9% in 2003. Thereafter, oleic acid content significantly declined, while linoleic acid content significantly increased during seed development (Table 4).

Oleic and linoleic acid percentages of sunflower oil vary greatly, depending mainly upon the temperature during seed development. Seed maturation during periods of high temperature results in oil with high and low concentrations of oleic and linoleic acids, respectively (Seiler, 1983; Lajara et al., 1990). Temperatures during seed maturation in 2003 were generally higher than those in 2002 (Figure 1). The higher temperatures in 2003 thus resulted in higher oleic acid and lower linoleic acid levels in comparison with 2002 (Table 4). The results indicated that, in contrast, the percent composition of the other fatty acids showed a gradual decrease, suggesting the major storage form of fatty acids in sunflower oil would be linoleic acid. These findings were also in accordance with those of Weiss (1983), who reported a decrease in the content of oleic acid and an increase in the content of linoleic acid in the developing sunflower seed.

In changes in total tocopherol in the sunflower developing seeds, a gradual decrease was detected from 10 to 35 DAF, and final total tocopherol content was 473.6 mg kg^{-1} in pure oil after a gradual increase from 40 to 45 DAF. Total tocopherol content in oil did not change significantly from 15 to 20, 25 to 30 or 40 to 45 DAF (Table 4).

Table 5 shows the changes in oil, fatty acids and total tocopherol contents in the seeds found on the different head parts. Seed position along the head had little effect on oil content, but had a strong effect on fatty acids. The

Table 5. Changes in oil content, fatty acid composition and total tocopherol content in seeds from different positions on the head.

Seed positions	Oil content (%)		Fatty acid composition (%)								Tocopherol (mg kg^{-1} in oil)
			Palmitic (C16:0)		Stearic (C18:0)		Oleic (C18:1)		Linoleic (C18:2)		
	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	
Side	45.3	44.4	7.9 a	15.8 b[1]	4.7 a	5.7 b	19.3 b	24.0 b	67.3 a	54.5 a	592.0 a
Middle	45.6	45.6	7.4 b	20.5 a	4.5 b	6.0 b	21.0 a	25.8 a	66.9 a	47.7 b	409.7 b
Center	44.4	44.5	7.2 b	19.8 a	4.2 c	7.0 a	21.2 a	26.4 a	66.1 b	46.6 b	408.6 b

[1]Values within a column followed by the same letter or letters are not significantly different at the 1% level (Duncan's multiple range test)

seeds from the center part of the head had the lowest oil content. The seeds from the middle part of the head produced the highest oil contents, 45.6%, in both trial years (Table 5). These data were in accordance with those of Karadogan et al. (1998).

In the first experimental year, the levels of palmitic, stearic and linoleic acids decreased, and the level of oleic acid increased linearly from the side to the center seeds. In the second experimental year, the levels of palmitic, stearic and oleic acids increased and the level of linoleic acid decreased from the side to center seeds (Table 5). In both experimental years it was thus found that oleic acid increased and linoleic acid decreased from the side to the center parts of the head. Our data appear to be in contrast to those of Zimmerman and Fick (1973), who observed that the level of linoleic acid increased and the level of oleic acid decreased from the perimeter toward the center of the head. This contrasting result may be due to genotypic and environmental differences. The total tocopherol content decreased gradually from the side to the center part of the head. The seeds from the side part of the head, which were heavier than the seeds from the middle and center parts, gave the highest total tocopherol content, 592.0 mg kg^{-1} (Table 5). In conclusion, oil quality attributes changed with the seed position on the head.

Dry weight per seed was significantly affected by the position of seeds on the head, and this decreased from the side to the center (54.1, 45.4 and 38.3 mg in 2002 and 55.2, 45.8 and 39.6 mg in 2003, from the side to the center parts, respectively). This was probably due to the earlier maturation and production of more filled seeds in the peripheral zones of the head.

Bird damage is an important problem in sunflower culture (Weiss, 1983). The maturation of the seeds takes place from the perimeter to the center of the sunflower head. In general, birds damage the perimeter seeds of the head. In the case of heavy bird damage, the seeds harvested from the sunflower plants are generally produced from the middle or center parts of the heads. Therefore, it is possible to say, based on our results, that seeds from plants damaged by birds would be poor in terms of oil, linoleic acid and total tocopherol contents. For this reason, new hybrids with resistance or tolerance to birds should be developed to enhance the high quality sunflower seed production.

Correlation coefficients between oil, fatty acids and total tocopherol components are given in Table 6. Oil content was negatively correlated with oleic acid ($r = -0.69$) and positively correlated with linoleic acid ($r = 0.72$), and both were significant at $P < 0.01$. Seed maturation periods give opposite results for oleic and linoleic acids. As oleic acid decreased, linoleic acid increased as evidenced by a high negative correlation coefficient ($r = -0.96$, $P < 0.01$). According to our results, tocopherol content was positively correlated with oleic acid ($r = 0.79$), and negatively correlated with linoleic acid ($r = -0.82$), both being significant at $P < 0.01$. The high negative correlation between tocopherol content and linoleic acid content shows why sunflower oils should be protected prior to human consumption. In addition, a strong negative correlation between oil content and tocopherol content ($r = -0.91$, $P < 0.01$) was determined (Table 6). Demurin (1986) reported a similar result in that the average total tocopherol content of

Table 6. Correlation coefficients on an overall basis among oil, fatty acids and total tocopherol components.

Components	2	3	4	5	6
1. Oil content	-0.54**	-0.52**	-0.69**	0.72**	-0.91**
2. Palmitic acid content		0.52**	0.49**	-0.69**	0.80**
3. Stearic acid content			0.79**	-0.85**	0.80**
4. Oleic acid content				-0.96**	0.79**
5. Linoleic acid content					-0.82**
6. Tocopherol content					

** Significant at $P \leq 0.01$

sunflower oil, about 800 mg kg^{-1}, was negatively correlated with seed oil content. Advanced plant breeding approaches for strong antioxidant activity in sunflower should thus combine high oil content and high tocopherol content. Demurin et al. (1996) also reported that it is possible to combine high yield potential with high antioxidant and vitamin parameters in new varieties of oilseed plants by breeding.

Conclusions

There are many important changes in the seed and oil characteristics of sunflower during seed maturity or development. Our results could be improved by experiments including more genotypes, years and locations. However, the information obtained from this study could be helpful in agronomic, genetic and biotechnological research related to determining the ideal harvest time, applying some specific chemical agents and modifying fatty acid composition.

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