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Effect of sowing time on grain yield, oil content, and fatty acids in rapeseed (*Brassica napus* subsp. oleifera)

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Abstract: Sowing time is an important factor affecting crop yield and quality, especially in arid and semi-arid regions. The aim of this research was to investigate the effects of sowing time on the growth, yield, and quality of rapeseed genotypes and to determine genotype × sowing time interactions for grain yield and its related traits. The study was carried out using 8 winter rapeseed genotypes (H604049, H604038, H604041, Viking, Elan, Titan, Lorenz, and Trabant) and 4 sowing times (10 October, 20 October, 30 October and 10 November) during the 2005-2006 and 2006-2007 growing seasons. An NIRS system was used to determine oil, protein, glucosinolate and sinapic acid esters. Fatty acid analyses were done by the capillary gas chromatography method. Significant differences were found between sowing times for most of the traits measured. The lowest average seed yield (1027.40 kg ha^{-1}) was obtained from the latest sowing time, whereas the highest average seed yield (2437.50 kg ha^{-1}) was obtained from the earliest sowing time. The genotype H604038 produced the highest seed yield (1988.4 kg ha^{-1}), and it was followed by Trabant (1980.8 kg ha^{-1}) and Titan (1963.8 kg ha^{-1}). The highest oil content, at 42.0%, was obtained from genotype Lorenz at the first sowing time and from genotype Trabant at the second sowing time. No interaction was found between genotype and sowing time for oil content, but significant interactions were found for seed yield and glucosinolates. Seed yield significantly decreased as sowing time was delayed. The effects of sowing time on fatty acid composition were also significant. As a result, it was found that sowing time is an important factor for seed yield and quality in rapeseed.

Key words: *Brassica*, fatty acids, planting time, quality, varieties, yield

Kolzada (*Brassica napus* subsp. oleifera) ekim zamanının tohum verimi, yağ içeriği ve yağ asitlerine etkisi

Özet: Özellikle kurak ve yarı - kurak bölgelerde ekim zamanı, ürün verimi ve kalitesini etkileyen önemli bir faktördür. Bu araştırmanın amacı ekim zamanının kolza genotiplerinin gelişimi, verim ve kalitesi üzerine etkisinin araştırılması yanında verim ve verim ile ilgili karakterler arasındaki interaksiyonları belirlemektir. Deneme 2005-2006 ve 2006-2007 yıllarında 8 kışlık kolza genotipi (H604049, H604038, H604041, Viking, Elan, Titan, Lorenz ve Trabant) ve 4 ekim

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zamanı (10, 20, 30 Ekim ve 10 Kasım) kullanılarak yürütülmüştür. Yağ, protein, glukozinolat ve sinapik asit esterlerinin belirlenmesinde NIRS sistemi kullanılmıştır. Yağ asidi analizleri kapilar gaz kromotografi yöntemi ile yapılmıştır. Ölçülen karakterlerin çoğunda ekim zamanları arasındaki fark istatistiki olarak önemli bulunmuştur. En düşük ortalama tohum verimi (1027.40 kg ha^{-1}) en geç ekim tarihinden elde edilirken en yüksek ortalama verim (2437.50 kg ha^{-1}) ise ilk ekim tarihinden elde edilmiştir. H604038 genotipi en yüksek tohum verimi verirken (1988.4 kg ha^{-1}), bunu Trabant (1980.8 kg ha^{-1}) ve Titan (1963.8 kg ha^{-1}) izlemiştir. En yüksek yağ içeriği %42 ile Lorenz genotipinin ilk ekim tarihinden ve Trabant genotipinin ise ikinci ekim tarihinden elde edilmiştir. Yağ içeriği bakımından genotip ve ekim zamanı arasındaki interaksiyon önemsiz bulunurken tohum verimi ve glukozinolat açısından önemli bulunmuştur. Tohum verimi, geciken ekim zamanı ile önemli düzeyde azalmıştır. Ayrıca ekim zamanın yağ asitleri üzerine etkisi de önemli bulunmuştur. Sonuç olarak kolzada ekim zamanının, tohum verimi ve kalitesi açısından önemli bir faktör olduğu bulunmuştur.

Anahtar sözcükler: *Brassica*, çeşit, ekim zamanı, kalite, verim, yağ asitleri

Introduction

Many studies have shown that all quantitatively inherited traits can significantly vary depending upon environmental conditions as well as cultivation practices such as sowing time (Çalışkan et al. 1999; Özel and Özgüven 2002; Salmasi et al. 2006). As sowing time is one of the most important factors affecting crop yield and other agronomic traits, the optimisation of sowing time for winter rapeseed is essential. Sowing either too early or too late has been reported to be unfavourable (Hocking and Stapper 2001; Robertson et al. 2004; Uzun et al. 2009). In late autumn sowing, seed germination is very slow and this leads to limited seedling development (Kondra et al. 1983; Christensen and Drabble 1984). Consequently, if seedling growth does not reach optimum rosette stage before winter, the plants are not able to survive during frozen weather conditions (Auld et al. 1984). In many studies, the effects of sowing time on agronomical traits were investigated and the results varied (Taylor and Smith 1992; Hocking 1993; Hocking et al. 1997; Ozer 2003). Most previous studies have revealed that late sowing in many crops results in lower yields (Scott et al. 1973; Kondra et al. 1983; Hocking and Stapper 2001; Oz 2002; Ozer 2003; Robertson et al. 2004; Uzun et al. 2009). The detrimental effects of insects and diseases on canola yields, as well as the effect of delayed sowing on production cost, have been reported (Yousaf et al. 2002). Late sowings not only reduce seed yield, but also decrease oil levels in winter rapeseed (Pritchard et al. 2000; Ozer 2003). As a result, there have been some studies on the effect of sowing time on the agronomic traits of various crops; however, studies on the effect of sowing time on the fatty acid composition of rapeseed oil using a wide range of genotypes are limited in number. Therefore, the objective of this research conducted over 2 years was to determine the effects of 4 sowing times on some agronomic and quality traits including fatty acid composition in rapeseed genotypes.

Materials and methods

Eight German winter rapeseed genotypes were used in the field experiments. The trials were conducted during 2 consecutive growing seasons (2005-2006 and 2006-2007) at the Experimental Station of Çanakkale Onsekiz Mart University in Çanakkale, Turkey. The geographic coordinates of the station are 40°08′N and 28°20′E at 2 m above sea level. Climate data for the experimental area are given in Table 1.

The soil of the experimental field was clay-loam with a pH of 7.7, calcareous containing 15.3%, ($CaCO_3$), 22.3 meq 100 g^{-1} cation exchange capacity, and 177 dS m^{-1} EC (Ozcan et al. 2004). The organic matter content in Ap horizons (0-30 cm) was 2.29%, which decreased to 0.81% depending on profile depth (49-79 cm).

Planting dates were 10 October, 20 October, 30 October, and 10 November for both growing seasons. A randomised complete block split-plot design was used with 3 replications. Sowing times were done in the main plots according to genotype subplots. Each plot (1.20 m × 5 m) consisted of 4 rows. The experimental field was fertilised at planting with 50 kg ha^{-1} of N. The remaining N was applied at a rate of

Table 1. Climatic data for the experimental area in 2 growing seasons (Çanakkale Turkish State Meteorological Service, 2008).

Month	2005-2006					2006-2007					Long-term		
	Rainfall (mm)	Temperature (°C)			Relative humidity (%)	Rainfall (mm)	Temperature (°C)			Relative humidity (%)	Rainfall (mm)	Temp. (°C)	Relative humidity (%)
		Min.	Max.	Mean			Min.	Max.	Mean				
Oct	46.8	4.2	26.2	14.9	78.3	38.0	6.4	25.5	16.2	88.7	47.0	15.8	77.8
Nov	218.8	0.8	18.0	10.5	85.5	33.9	-2.2	19.3	10.4	86.5	86.5	11.8	81.5
Dec	71.3	-3.1	19.2	9.1	89.6	25.6	-4.3	15.6	7.5	85.0	108.9	8.3	83.4
Jan	53.2	-8.6	14.6	3.1	89.3	30.2	5.5	13.4	9.2	89.5	98.7	6.1	83.3
Feb	84.7	-6.5	15.9	5.6	88.6	48.4	2.2	9.3	8.1	89.8	71.1	6.6	81.0
Mar	124.0	-1.8	18.5	8.7	89.4	151.5	6.5	13.5	10.0	88.8	65.0	8.0	80.7
Apr	3.8	3.8	23.3	13.2	81.2	18.1	7.4	18.3	12.7	87.6	42.8	12.3	79.4
May	16.7	5.8	30.4	17.7	80.6	44.7	14.6	24.1	18.8	81.1	29.7	17.3	77.0
Jun	23.0	10.8	34.1	22.2	78.1	35.2	19.1	30.3	24.5	77.8	23.7	21.9	72.1

100 kg ha^{-1} between the rows in March. Nitrogen dose (Urea) was determined according to our previous study on rapeseed during 2004-2005 in the same experimental area (Egesel et al. 2008). Weed control was done manually and no chemicals were applied. The experiment was not irrigated during both growing seasons. The beginning of flowering was determined when at least 5% of plants per plot began to bloom and was expressed as a number of days (Gul 2002). For example, when the first flowering in the experiment occurred on 20 March, this was accepted as 20. When the next flowering occurred on 5 April, this value was calculated as 35 (20 + 16). This presentation was used in order to evaluate delays in inflorescence. In the experiment, the first flowering for both seasons occurred in March. The duration of flowering was determined to be the number of days between the beginning and end of flowering. Harvesting was performed manually and all plants in each plot were threshed together. Samples were taken randomly from each plot for quality analysis. Oil (O), protein (P), glucosinolates (GSL), and sinapic acid esters (S) were determined at the Institute for Plant Breeding and Plant Production of the Georg-August University, Germany, using monochromator Near Infrared Reflection Spectroscopy (NIRS, Inc., Silver Springs, MD, USA. Model 6500). The sample size scanned was about 3 g intact seeds. NIRS allows for a simultaneous analysis of different seed components in intact samples. The analyses were done according to the methods previously described by Reinhardt (1992), Tillman (1997), and zum Felde et al. (2006).

The fatty acids determined in the study were palmitic (C16:0), stearic (C18:0), oleic (C18:1), linoleic (C18:2), and eicosenoic (C20:1). The fatty acids were analysed by using gas chromatography according to Schierholt (2000) and Gul et al. (2008). The fine milled rapeseed meal (50 mg) was mixed with 1 mL of sodium methylate (0.5 mol Na L^{-1} methanol) in a plastic tube by vortexing briefly. The tubes were then kept at 20 °C for 20 min before vortexing again. After this step, 400 mL of isooctane was added and the tubes were shaken for a few seconds vigorously. In the next step, 200 mL of 5% $NaHSO_4$ was added. After vortexing, the tubes were centrifuged at 1000 rpm for 5 min. Supernatant (150 mL) was decanted into a vial and 3 mL of it was injected into GC by using an auto sampler unit. A gas-liquid chromatographer (Perkin-Elmer 8600, San Jose, California, USA) was used with a Permabond-FFAP, 25 m × 0.25 mm ID, split 1:100. Hydrogen was used as a carrier gas at a pressure of 120 kPa. Finally, a mixed oil of 2 rapeseed varieties (Wl-Ramsch /85 Ll-Standard) was used as a standard.

Analysis of variance (ANOVA) was performed using the general linear model of SAS statistical software (SAS Institute 1998). Differences in treatment means were compared by LSD test ($P < 0.05$). The statistical model used was as follows:

$$Y_{ijklm} = \mu + S_i + R_j(S_i) + G_k + SxG_{ik} + ST_l + SxST_{il} + GxST_{kl} + SxGxST_{ikl} + e_{ijklm}$$

where:

Y_{ijklm}: observation value

m: general population mean

S_i: effect of growing season i (i = 1, 2)

R_j: effect of replication j within growing season i (j = 1, 2, 3)

G_k: effect of genotype k (k = 1, 2, 3, ..., 8)

SxG_{ik}: interaction effect of genotype by growing season

ST_l: effect of sowing time (l = 1, 2, 3, 4)

$SxST_{il}$: interaction effect of sowing time by growing season

$GxST_{kl}$: interaction effect of genotype by sowing time

$SxGxST_{ikl}$: interaction effect of growing season by genotype by sowing time

e_{ijklm}: random error term

Results

Agronomic traits

The results of ANOVA for agronomic traits are presented in Table 2. The effects of all treatments, except for season × sowing time × genotype interaction, on the beginning of flowering and seed yield were significant. The effects of season, sowing time, and their interaction on the duration of flowering and plant height were also significant.

Seed yield in the first season was significantly higher than that of the second season. Similarly, there were significant differences among the genotypes grown at different sowing times and seasons for all agronomic traits, except plant height (Table 2). The highest mean seed yield was obtained from H604038 (1988.4 kg ha^{-1}) followed by Trabant (1980.8 kg ha^{-1}) and Titan (1963.8 kg ha^{-1}). Trabant and Elan were the earliest flowering genotypes. These 2 genotypes also had the longest duration of flowering at 27.4 and 28.5 days, respectively. Although differences between the genotypes in terms of flowering duration were statistically significant, differences of 1-2 days in flowering should not be considered on an agronomic basis.

The average response of the genotypes to sowing time indicated that the highest value for the beginning of flowering was obtained from the latest sowing time (Table 2). In general, the plants in early sowings flowered earlier than the plants from late sowings and the duration of flowering shortened with the later sowings. Seed yields fell significantly as sowing times were delayed. The lowest seed yield was obtained from the latest sowing time, whereas the highest seed yield was obtained from the first two sowing times. In addition, plant height decreased when sowing times were delayed.

The significant season × genotype and sowing time × genotype interactions, especially for the beginning of flowering and seed yield, revealed that the genotypes responded differently to different sowing times and seasons.

Quality traits

The results of ANOVA and means comparisons for a range of quality traits are presented in Table 3. There were significant differences between the seasons for all quality traits except for C16:0 in this study. The effect of genotype on most of the traits measured was also significant. Quality traits such as GSL, oil content, protein content, C18:1, C18:2 and C20:1 significantly varied according to genotype. The cultivars Elan, Lorenz, Trabant, H604038, H604041, and H604049 had higher GSL than Viking (11.34 µ mol g^{-1}) and Titan (11.36 µ mol g^{-1}). Titan, Lorenz, and Trabant had higher oil content. Also, H604041, H 604038, H604049, Viking, Elan, and Trabant gave higher protein content.

Sowing time significantly affected all quality traits, except for C20:1. In general, the mean values for all quality traits except C18:1 and C20:1 decreased as sowing times were delayed (Table 3). On the other hand, there were no significant differences between first and last sowing times in terms of oil content, GSL and sinapine concentrations. However, oleic acid

Table 2. Analysis of variance and mean values for some agronomic traits in 8 rapeseed genotypes grown at 4 different sowing times in 2 seasons.

Parameters	Mean Squares[1] and Mean Values			
	Beginning of flowering (day)	Duration of flowering (day)	Plant height (cm)	Seed yield (kg ha^{-1})
Season (S) (df = 1)	**465.6** **	**277.9** **	**5916.2** **	**44,421.4** **
S1	38.3 a[2]	26.3 b	109.1 b	197.5 a
S2	35.2 b	28.7 a	120.2 a	167.1 b
$LSD_{0.05}$	*0.5*	*0.7*	*4.2*	*11.2*
Sowing Time (ST) (df = 3)	**1123.8** **	**63.3** **	**2302.3** **	**211,963.9** **
ST1	31.9 d	27.9 b	121.4 a	2437.5 a
ST2	34.2 c	26.7 c	114.5 b	2298.8 a
ST3	38.2 b	28.9 a	117.6 ab	1526.6 b
ST4	42.9 a	26.4 c	105.2 c	1027.4 c
$LSD_{0.05}$	*0.7*	*0.9*	*5.7*	*14.9*
Genotype (G) (df = 7)	**20.1** **	**8.4***	**162.9**	**7679.0** **
H604049	37.7 a	26.5 c	116.3	1844.8 ab
H604038	37.3 ab	27.4 abc	113.8	1988.4 a
H604041	37.5 a	27.7 abc	112.6	1829.8 ab
Viking	36.6 b	27.4 abc	116.7	1720.2 b
Elan	35.5 c	28.5 a	111.4	1804.6 ab
Titan	36.9 ab	27.9 ab	117.1	1963.8 a
Lorenz	37.4 ab	27.1 bc	111.6	1448.2 c
Trabant	35.4 c	27.4 abc	117.8	1980.8 a
$LSD_{0.05}$	*0.9*	*1.3*	ns	*211.3*
S × G (df = 7)	**17.8** **	**4.2**	**121.9**	**9668.5** **
S × ST (df = 3)	**13.8** **	**293.1** **	**895.3** *	**39,367.7** **
ST × G (df = 21)	**5.6** **	**7.2**	**169.9**	**2320.5** *
S × ST × G (df = 21)	**4.1**	**7.6**	**93.4**	**1838.7**
Replication (df = 4)	**3.8**	**33.8**	**721.8**	**9382.8**
Error (df = 124)	**2.7**	**4.9**	**199.3**	**1367.3**

* $P < 0.05$ and ** $P < 0.01$.
[1]: Bold values across the main parameter in the Table indicate mean squares.
[2]: Mean values with the same letter in each column are not significantly different. ns: non-significant.

Table 3. Analysis of variance and mean values for some quality traits in 8 rapeseed genotypes grown at 4 different sowing times.

Factors	df	Mean Squares[1] and Mean Values									
		GSL µmol g^{-1}	Sinapine µmol g^{-1}	Oil %	Protein %	C16:0 %	C18:0 %	C18:1 %	C18:2 %	C18:3 %	C20:1 %
Season (S)	**1**	**175.49****	**0.01****	**122.86****	**14.17****	**0.40**	**24.60****	**557.19****	**36.93****	**19.30****	**1.47****
S1		11.66 b[2]	0.34 b	41.07 a	19.78 a	4.82	1.02 b	65.49 a	20.12 b	6.66 b	0.99 b
S2		13.57 a	0.35 a	39.47 b	19.24 b	4.91	1.74 a	62.08 b	20.99 a	7.29 a	1.20 a
$LSD_{0.05}$		*0.68*	*0.01*	*0.52*	*0.37*	ns	*0.11*	*0.47*	*0.44*	*0.14*	*0.03*
Sowing Time (ST)	**3**	**24.39****	**0.01****	**9.12****	**6.36****	**8.29****	**1.54****	**215.52****	**66.76****	**6.53****	**< 0.00**
ST1		13.09 a	0.35 ab	40.08 ab	19.54 a	5.45 a	1.58 a	61.02 d	22.12 a	7.40 a	1.05
ST2		13.02 a	0.36 a	40.76 a	19.60 a	4.84 b	1.48 a	63.35 c	20.64 b	7.18 b	1.11
ST3		11.57 b	0.35 ab	39.76 b	19.89 a	4.65 c	1.24 b	64.84 b	20.16 b	6.69 c	1.10
ST4		12.81 a	0.33 b	40.47 a	19.01 b	4.51 c	1.22 b	65.91 a	19.31 c	6.64 c	1.12
$LSD_{0.05}$		*0.97*	*0.02*	*0.68*	*0.51*	*0.17*	*0.15*	*0.66*	*0.62*	*0.20*	ns
Genotype (G)	**7**	**17.20****	**<0.00**	**15.69****	**4.10****	**0.17**	**0.19**	**12.10****	**13.61****	**0.26**	**0.01**
H604049		12.54 ab	0.34	40.10 bcd	19.40 abc	4.76	1.28	63.44 cde	21.10 ab	6.99	1.10
H604038		13.00 a	0.35	39.31 d	19.83 a	4.91	1.35	63.25 de	20.96 ab	7.07	1.10
H604041		12.95 a	0.36	39.18 d	20.05 a	4.86	1.39	63.34 cde	21.12 ab	6.85	1.12
Viking		11.34 b	0.34	39.91 cd	19.81 a	4.95	1.47	62.78 e	21.50 a	6.84	1.10
Elan		13.67 a	0.35	40.37 bc	19.65 ab	4.95	1.41	64.24 abc	20.02 cd	6.91	1.07
Titan		11.36 b	0.34	41.51 a	19.02 bc	4.87	1.53	64.80 a	19.27 d	7.09	1.09
Lorenz		13.23 a	0.35	40.88 ab	18.84 c	4.89	1.27	63.82 bcd	20.53 bc	7.10	1.07
Trabant		12.88 a	0.37	40.90 ab	19.47 abc	4.71	1.34	64.60 ab	19.97 cd	6.93	1.12
$LSD_{0.05}$		*1.37*	ns	*0.96*	*0.72*	ns	ns	*0.93*	*0.88*	ns	ns
S × G	**7**	**8.53**	**< 0.00**	**10.12****	**3.94****	**0.50****	**0.10**	**1.64**	**0.92**	**0.47**	**< 0.00**
S × ST	**3**	**48.27****	**0.01****	**160.05****	**5.93****	**0.22**	**1.89****	**5.78**	**5.73**	**9.10****	**0.01**
ST × G	**21**	**10.53****	**< 0.00**	**3.50**	**1.97**	**0.10**	**0.09**	**2.60**	**2.17**	**0.23**	**< 0.00**
S × ST × G	**21**	**5.66**	**< 0.00**	**3.43**	**1.27**	**0.11**	**0.09**	**2.65**	**2.50**	**0.29**	**< 0.00**
Replication	**4**	**15.13****	**0.01****	**16.27****	**4.15****	**0.36**	**0.12**	**7.23***	**5.17**	**0.65***	**< 0.00**
Error	**124**	**5.71**	**< 0.00**	**2.86**	**1.59**	**0.17**	**0.14**	**2.65**	**2.35**	**0.25**	**0.01**

*: $P < 0.05$ and **: $P < 0.01$.

[1]: Bold values across the main factors in the Table indicate mean squares.

[2]: Mean values with the same letter in each column are not significantly different. ns: non-significant.

(C18:1) concentrations were significantly affected by sowing times. These values ranged from 61.02% for the first sowing time to 65.92% for the last sowing time. Other fatty acids also decreased as sowing time was delayed.

Discussion

In most crops, yield and yield components show variation depending upon sowing time. For example, Gross (1963) reported that sowing time significantly affected growth and yield in rape and turnip rape and, furthermore, days to flowering and flowering duration, while seed yield reduced with delayed sowing time. The same trend was also determined by other researchers (Moore and Guy 1997; Hocking and Stapper 2001; Uzun et al. 2009), who noted that late sowing caused delayed flowering time, decreased flowering duration and reduced seed yield. Plant height was also negatively influenced by delayed sowings. In addition, the results of a study on two winter rapeseed cultivars with three sowing times revealed that late sowing similarly reduced plant height and thousand-kernel weight (Oz 2002). In our study, inflorescence started earlier in early sowing times compared to late sowings, whereas flowering duration shortened a little with late sowing. Robertson et al. (2004) and Uzun et al. (2009) also found similar results in rapeseed. Plant height decreased with delayed sowing. Our results were compatible with the studies given above. This result can be attributed to the shortened vegetative growth period and temperature increase during the flowering period. It can be expected that inflorescence time and flowering duration in plants will decrease at increased temperatures.

Average seed yield significantly varied depending on growing seasons (Table 2). In the first season, the seed yield was higher than that of the second season. This can be attributed to higher total rainfall in the first season (Table 1).

Crop yield parameters showed a complex inheritance and were significantly influenced by environmental conditions and cultivation practices. Table 2 indicates the mean values of seed yield (2299 and 2438 kg ha^{-1}), showing insignificant changes between the first and second sowing times (10 October and 20 October, respectively); however, delaying the sowing time resulted in significant reductions in seed yield (1527 and 1027 kg ha^{-1}). The main reasons for this yield reduction with late sowing could be (a) insufficient plant growth and consequently a lack of preparedness for early winter frosts (Table 1), (b) early flowering caused by high temperatures in late spring and (c) a period of drought starting after April.

As in all *Brassica* species, rapeseed has a certain amount of glucosinolate and sinapine in its vegetative and generative organs. Although these 2 components play an important role in a plant's defence mechanism against pests, glucosinolate and sinapine are unfavourable for animal feed and egg production, respectively (Harbone 1980; Kozlowska et al. 1990; Penaud 1999). The differences between sowing times in terms of glucosinolate and sinapine were found to be significant. It is likely that glucosinolate and sinapine are influenced by environmental conditions and cultivation practices. In a previous study, sinapine and glucosinolate values in rapeseed varied significantly after the application of nitrogen fertiliser and fungicide (Mert-Turk et al. 2008). With regard to oleic acid content, it was observed that the mean values increased as sowing time was delayed. In the first sowing time, the oleic acid content was 61.02%, whereas it increased to 65.91% in the last sowing time.

In general, genotype × environment interaction is not desirable for plant breeders. However, such interactions are important in breeding studies in order to develop a specific variety suitable for a given region (Becker 1993). Sowing time is one of the important cultivation practices in rapeseed production, as it is in all crops. In our study, sowing time × genotype interaction for the beginning of flowering, seed yield, and GSL was found to be significant. Similarly, in a previous study, the interaction between sowing time and genotype for seed yield and oil content in 2 rapeseed genotypes (Moore and Guy 1997) was also found to be significant. In another study, although the interactions between genotype and sowing time were found to be significant for oil rate and some other characteristics, the genotype × sowing time interaction was not significant for seed yield character (Ozer 2003). Studies on various quality traits showed that genotype × environment interactions are

significant in traits with low degrees of heritability (Marwede et al. 2004; Khan et al. 2008). It was found that genotype × environment interaction in rapeseed was significant for tocopherol content, which has a low degree of heritability (Marwede et al. 2004). Therefore, the results of our study are in agreement with most previous studies (Moore and Guy 1997; Hocking and Stapper 2001; Ozer 2003; Uzun et al. 2009). However, there are small differences that can be attributed to the differences in genotypes and number of replicates used in the studies reviewed. In order to obtain more appropriate and comprehensive results, different genotypes should be tested in different locations for several years to reduce the variation caused by environmental effects.

The relationships between the traits measured in this study are presented in Table 4. As shown in Table 4, it was found that the beginning of flowering correlated significantly with agronomic traits and fatty acids. Traits related to flowering are especially important for seed crops. In this study, the correlations between agronomic traits were relatively significant. The beginning of flowering positively and significantly correlated with the duration of flowering. Thus, this indicates that when the beginning of flowering is delayed, the duration of flowering decreases and vice versa. The beginning of flowering was also significantly, but negatively, correlated with seed yield, which implies that late flowering results in lower seed yields.

High oil content in rapeseed is the most important breeding objective. Oil content was positively and significantly correlated with all measured fatty acids except for oleic acid, which was significant but negatively correlated. Similar results have been found in previous studies. For example, one study revealed that the most important fatty acid in rapeseed is oleic acid with 70%-80% content and all the fatty acids investigated, except oleic acid, were positively correlated to oil content and each other (Schierholt 2000). The correlation coefficients between oleic acid and some other fatty acids such as linoleic acid (r: –0.84) and linolenic acid (r: –0.48) were especially high, indicating that this is directly related with the steps needed for oil synthesis (Schopfer and Brennicke 1999). In addition, high oleic acid content is favourable for increasing the shelf life of the oil by slowing down the process of oxidative rancidity.

Table 4. Coefficient of correlation (r) for agronomic and quality traits in 8 rapeseed genotypes.

Traits	Beginning of flowering	Duration of flowering	Plant height	Seed yield	Oil content	Protein content	GSL	Sinapine	C16:0	C18:0	C18:1	C18:2
Flowering duration	0.74**											
Plant height	–0.40**	0.15*										
Seed yield	–0.62**	–0.18*	0.23**									
Oil content	–0.18*	–0.22**	0.08	0.15*								
Protein content	0.07	–0.08	0.05	0.12	–0.65**							
GSL	–0.11	–0.08	0.07	0.02	–0.04	–0.38**						
Sinapine	–0.08	–0.05	0.07	0.12	–0.24**	0.67**	0.65**					
C16:0	–0.50**	0.12	0.28**	0.41**	–0.13	0.16*	0.19*	0.18*				
C18:0	–0.43**	0.06	0.30**	0.18*	0.43**	–0.06	0.38**	0.26**	0.26**			
C18:1	0.64**	–0.22**	–0.38**	–0.31**	–0.01	–0.11	–0.36**	–0.24**	–0.62**	–0.56**		
C18:2	–0.46**	0.22**	0.26**	0.23**	–0.26**	0.18*	0.19*	0.14*	0.49**	0.15*	–0.84**	
C18:3	–0.45**	–0.13	0.22**	0.33**	0.39**	–0.07	0.27**	0.13	0.21**	0.49**	–0.48**	0.06
C20:1	–0.14*	0.21**	0.16*	–0.19*	0.20*	–0.05	0.26**	0.17*	–0.05	0.38**	–0.41**	0.21**

*: $P < 0.05$ and **: $P < 0.01$

Conclusion

The rapeseed genotypes responded differently to different sowing times. Both yield and quality decreased with delayed sowing time. In this experiment, among the 8 genotypes used, Titan was determined to be the most suitable for the first 3 sowing times in terms of seed yield, whereas H604038 was a more suitable genotype for late sowings. In a region receiving precipitation in the late autumn and no precipitation after mid-spring, sowing time is the most important factor to consider in order to obtain desirable seed yield and quality. In such regions, late sowing is unfavourable and the preference of early genotypes can be advantageous. Therefore, choosing a suitable rapeseed cultivar for a given region is essential depending upon growing conditions and cultivation practices such as sowing time. According to this 2-year experiment, it can be suggested that the most appropriate sowing time for a desire seed yield and quality in rapeseed was early October for the experimental region. In conclusion, the determination of sowing time is critical in rapeseed production in terms of both seed yield and quality traits.

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