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Morphophysiological Basis of Variation in Rapeseed (*Brassica napus* L.) Yield

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ABSTRACT

In order to determinate morphological and physiological traits associated with yield improvement in rapeseed, field experiments were conducted on 16 cultivars. The traits, grain yield, yield components, harvest index, plant height, days to flowering and from flowering to physiological maturity, photosynthetic rate (P_a) and stomatal conductance (g_s) in flowering and pod formation were measured. The results indicated that harvest index, number of pods per plant, plant height, leaf P_a at flowering stage and g_s at flowering and pod formation were significantly correlated with the grain yield. The length of sowing to flowering period also had significant correlation with the grain yield. In summary the results suggested that there were some yield related traits in rapeseed that could be used in breeding programs for increasing the grain yield of rapeseed.

Key Words: Rapeseed; Yield components; Harvest index; Physiological and morphological traits

INTRODUCTION

Oil seed rape (*Brassica napus* L.) is now one of the most important oil crops in the world. Yield improvement is the main goal in rapeseed breeding. For this purpose, the first stage is to increase our understanding of genetic, physiological and morphological basis for seed yield and utilization of physiological and morphological traits as selection criteria in yield improvement programs. In other word yield improvement would be limited without recognition of physiological characters that determine potential yield. In experiment with nine summer rapeseed Chango and McVetty (2001) observed that total dry matter and harvest index had a significant correlation with grain yield, but there was no correlation between chlorophyll or water use efficiency. Ali *et al*. (2003) also showed that harvest index had a significant correlation with grain yield. In the yield components, days to flowering and number of pods per plant were correlated significantly with grain yield (Ozer *et al*., 1999). Also a significant correlation was observed between pod number per plant and grain yield in species of *B. napus* and *B. compestris* (Thurling, 1974b). This showed that among yield component number of pods had greatest and seed per pod and seed weight had weak influence on grain yield.

Although photosynthesis is the main factor controlling plant growth and yield, the relationship between photosynthetic rate and grain yield is complicated and hence, inconsistent results were observed regarding relation of photosynthesis and yield (Chango & McVetty, 2001). McVetty *et al*. (1989) observed different photosynthesis rate in *Brassica* and *Moricandia* species, seemingly leaves played an important role in supplying assimilate only before flowering stage. Chapman *et al*. (1984) showed that during flowers and pods development, the leaves were not significant exporters of photosynthates. In other crop such as soybean (*Glycine max* L.) high yielding cultivars had higher photosynthesis rates (Dornhoff & Shibles, 1974; Wells *et al*., 1982). In wheat, it was observed that photosynthesis had not been genetically improved in Argentinean cultivars released between 1964 and 1990 (Calderini *et al*., 1995). Fischer *at al*. (1998) achieved a consistent relationship between the increase in yield potential in CIMMYT semidwarf varieties since they were first introduced in early 1960s and flag leaf photosynthesis rate and stomatal conductance, as a yield increase of 29% corresponded with an increase of 23% in photosynthesis rate.

The physiological basis for the association of yield with photosynthesis rate and traits like stomatal conductance is un-known. Expression of higher photosynthetic rate in the absence of significant changes in yield could be the pleiotropic effect of improved partitioning for yield driven by high demand for assimilates during grain filling (Raynolds *et al*., 1999) or could be attributed to measurement of photosynthetic rates (i.e., on single leaves for a short period of time) in the experiment (Zelitch, 1982). The objective of this experiment was to study the relationship between some physiological and morphological traits and grain yield in rapeseed cultivars.

MATERIALS AND METHODS

Experimental procedures. Field studies were conducted in 2004 and 2005 at the research station of the College of Agriculture of Arsanjan Azad University in Arsanjan (1690 m from sea level, longitude 53°, 19′, latitude 29°, 55′) Iran. The meteorological data of the experimental locations during rapeseed growing seasons are shown in Table I. Sixteen winter rapeseed cultivars used in this study were:

Tlayeh, Elite, Elvis, Elicator, Bomerang, Rigent*Cobra, Hayolla 308, Hayolla 60, Hayolla 401, Orient, SLM046, Okapi, Opera, Parade, Tokan and Licord. The trials were set up in a complete randomized block design (RCBD) with four replications. The experimental fields were mould-board ploughed and seedbed preparation consisted of two passes with a tandem disk. Seed were hand planted on 1 October and 29 September in 2004 and 2005, respectively. Seeding was 2 cm deep in 2.5 × 4 m plots each contained 7 rows with 40 cm space using a seeding rate of 7 kg ha^{-1}. General crop production operations included broadcasting urea (split-applications) and phosphate fertilizers prior to planting, weed control (hand weeding) and chemical control of rapeseed aphid (*Rhopalosiphum pseudobrassica*).

Crop assessment. During the growing of the rapeseed leaf photosynthesis rate and the stomatal conductance (g_s) were measured using a portable photosynthetic system with an infra-red gas analyzer in a closed chamber system (model ADC-Lci-England). The measurements were conducted in the 09:00 to 13:00 h of the day in final fully expanded leaves in 5 plants of each plot. These measurements were done at flowering and early pod formation stages. During the measurement the photosynthetically active radiation (PAR) was between 1400 to 1900 µmol m^{-2} s^{-1}.

Time of reaching plants to main growing stages such as flowering and ripening were record to calculate the length of these growing stages. At the physiological maturity, the aboveground plant parts of the two middle rows from each plot were hand harvested to measure yield, yield components, plant height and biological yield. Harvest parts were air dried and then weighed to determine total dry matter production. The numbers of pods per plant and seeds per pod were counted from 40 randomly selected pods after hand threshing. The weight of 400 seeds was taken to determine the seed 1000 weight. Main stem length was measured as the plant height. Harvest index was determined as the ratio of seed yield to total dry matter. Data were subjected to analysis of variance (ANOVA) for each year using SAS and SPSS software.

RESULTS AND DISCUSSION

Grain yield. In both seasons Talayeh and Hayolla-308 produced highest and lowest grain yield, respectively (Table II). The grain yield of cultivars can be divided in three groups; high (Tlayeh, Orient, Elvis, Elite & Elikator), medium (Locord, Parade, Bomerang, Okapi & Hayolla-401) and low yield cultivars (Opera, Rigent*Cobra, Tokan, Hayolla-60, SLM046 & Hayolla-308). Average grain yield in these yield group were 332.2, 238.7 and 149.7 in 2004 and 324.3, 229.1 and 154.3 in 2005 for high, medium and low yield cultivars, respectively.

Pod number per plant. There was a significant difference in number of pod per plant between cultivars (Table II). The highest pod number was observed in cultivars with high grain yield (Tlayeh, Oreint & Elvis) in both years. Hayolla-308 and SLM in 2004 and Hayolla-308 and Hayolla-60 in 2005 had the lowest pod number. These results showed that the pod number in high yield cultivars was higher than others. The number of pod had a close relationship with grain yield in rapeseed and this trait is determined by the number of branches, buds, flowers and by the capacity of source, the supply of nutrients and water (Allen & Morgan, 1975; Tayo & Morgan, 1975; Diepenbrock, 2000). Ali *et al.* (2003) observed significant correlation between pod number and yield in rapeseed. Thurling (1974b) reported that in *B. campestris* there was a significant correlation between yield and pod numbers while in *B. napus* this was not fond. Ozer *et al.* (1999) suggested that pod number could be a good selection criterion for increasing grain yield in rapeseed.

Number of seed per pod. Seed number per pod was ranged from 17.8 to 23.6 in 2004 and from 18.3 to 23.0 in 2005 (Table II), but this difference only was significant in Tokan and Hayolla-60. There was no distinct relation between number of seed per pod and grain yield. For instance the highest value of this trait was observed in cultivars such as Hayolla-401 that had medium grain yield. Ozer *et al.* (1999) and Ali *et al.* (2003) fond no correlation between number of seed per pod and grain yield. Thurling (1974b) reported that number of seed per pod was correlated with yield in *B. napus* but not in *B. campestris*. This difference between species was due to the relationship between the number of pod and seed in one hand and the plant potential for increasing pod or seed number on the other. Because of this, in general, there is a negative relation between these two parameters of yield.

Seed weight. As shown in Table II, average 1000 seed weight for each year was relatively lower in Hayolla-60 in 2004 and Bomerang in 2005. SLM and Parade had greatest seed weight in 2004 and 2005, respectively. There was no distinct relation between seed weight and grain yield, as some low yielding cultivars, such as Tokan, Rigent*Cobra, Hayolla-60, Opera and SLM, had greater seed weights than high yielding cultivars. This probably was due to the compensatory relation between yield components, as in cultivars with low grain yield the number of pod and seed per pod was low and available assimilates partition between lower number of seeds and each seed receive more assimilate in comparison with high yield cultivars with greater number of seed per produced assimilates. Evans (1993) mentioned the seed size depends on environmental conditions, genotype and the potential of the genotype in producing seed number. It seemed that the genotype had small effects on seed weight in comparison with environment. Allen and Morgan (1975) and Thurling (1974b) found no constant relation between seed weight and grain yield in rapeseed.

Total dry matter and harvest index. Cultivars with high grain yield (Tlayeh, Elvis, Elite, Elikator, Orient) produced more dry matter and had higher harvest index (HI) than medium and low yielding ones (Table III). Talayeh and Elvis in both seasons had greatest and Hayolla-308 had

Table I. Meteorological data of Arsanjan during rapeseed growing season

Month	Min temperature (°C)		Max temperature (°C)		Mean temperature (°C)		Relative humidity (%)		Precipitation (mm)	
	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005
Oct	13.0	12.6	26.7	27.0	19.9	19.8	21.7	22.7	0.0	0.0
Nov	7.6	7.1	19.9	18.2	13.8	12.7	39.0	50.0	23.3	41.9
Dec	1.5	5.4	10.0	16.4	5.8	10.9	64.0	46.7	29.6	22.2
Jan	-0.4	0.1	11.6	10.8	5.6	5.5	54.7	54.0	102.8	67.7
Feb	1.4	5.5	13.2	16.1	7.3	10.8	48.7	47.3	37.6	27.9
Mar	6.2	5.7	20.0	19.6	13.1	12.7	41.3	43.3	11.2	13.2
Apr	11.4	10.7	25.5	23.1	18.5	16.9	26.3	40.3	0.0	35.0
May	14.3	17.3	28.6	31.7	21.5	24.5	22.0	20.3	0.0	0.0
Gun	19.8	20.3	35.2	35.4	27.5	27.9	16.0	12.3	0.0	0.0

Table II. Cultivars mean and least significant differences (LSD) for yield and yield components in 2004 and 2005

Cultivars	2004				2005			
	Grain yield (gm^{-2})	Pods no plant^{-1}	Seeds pod^{-1}	Seed 1000 weight (g)	Grain yield (gm^{-2})	Pods no plant^{-1}	Seeds pod^{-1}	Seed 1000 weight (g)
Talayeh	348.0	381.6	22.9	4.21	346.8	378.1	22.5	3.86
Orient	326.0	366.8	22.9	3.85	309.2	368.2	23.1	3.75
Elvis	324.0	366.2	21.8	3.70	324.1	361.8	21.7	3.94
Elite	321.9	141.0	22.3	3.89	312.5	314.0	22.3	4.13
Elikator	320.1	223.2	21.1	4.24	329.1	318.1	21.0	4.11
Parade	296.1	182.0	22.2	4.25	289.2	176.8	22.1	4.33
Okapi	230.6	203.9	22.2	4.16	226.7	195.0	22.2	4.13
Hayolla 401	229.6	191.4	23.6	3.84	218.1	199.1	23.6	3.72
Bommerang	222.6	203.6	21.8	3.73	211.1	208.1	21.8	3.69
Licord	214.7	207.8	21.4	3.94	200.2	222.4	21.6	3.96
Tokan	179.3	169.0	17.8	3.79	169.0	168.6	18.3	3.91
Rigent*Cobra	170.2	205.9	22.4	4.12	165.6	204.3	22.7	4.08
Hayolla 60	154.5	183.0	17.7	3.57	165.6	152.3	18.8	3.89
Opera	143.5	181.3	21.3	3.79	144.3	184.0	21.4	3.88
SLM 046	142.5	151.7	20.7	4.26	144.4	158.0	21.1	4.08
Hayolla 308	108.4	115.2	20.3	4.00	136.9	130.3	21.5	4.20
Mean	233.3	217.1	21.4	3.96	230.8	233.7	21.6	3.98
L.S.D. (p=0.05)	34.73	67.78	4.23	0.54	34.40	21.64	2.50	0.42

Give means ± s.e

lowest total dry Matter (TDM) in both seasons. The highest HI was observed in Parade, Orient and Elite in 2004 and Parade, Talayeh and Elite in 2005. Rigent*Cobra had the lowest HI in both seasons. In other experiments the similar results were obtained due cultivar differences in HI and TDM in rapeseed (Thurling, 1974a; Allen & Morgan, 1975; Ali *et al*., 2003). Chango and McVetty (2001) showed that both TDM and HI contributed to higher yields of cultivars from high-yield group over medium and low-yield group.

In soybean it was observed that there was a significant difference in HI among cultivars released over 58 years in Canada. With increasing grain yield, HI was increased by 0.5% per year, while there was no consistent change in TDM with year of release (Morrison *et al*., 1999). Significant relationship was also observed between TDM and grain yield in corn (Tollenaar, 1991) and peas (Hobbs & Mahon, 1982). HI had also an important role in increasing grain yield of wheat (Austin *et al*., 1980; Sinha *et al*., 1981; Karimi & Siddique, 1991; Sayre *et al*., 1997) and rice (Takeda *et al*., 1984).

Plant height. Orient and Talayeh had the highest shoot length in 2004 and 2005, respectively. Other high-yield cultivars also had partially greater plant height. Some low-yield cultivars such as, Rigent*Cobra had high stem length and lower HI (Table III). It seemed that in such cultivars plant tallness consumed greater assimilates thereby reducing their allocation to yield components and consecuently decreased was obtained. In comparison in high-yield cultivars probably more assimilates were partitioned between stem and yield components, therefore the competition between these sinks declined. Ozer *et al*. (1999) also reported positive and significant correlation between plant height and grain yield in rapeseed.

Phenology. The length of period from sowing to flowering in different cultivars was between 167 to 172 and 165 to 171 in 2004 and 2005, respectively (Table III). Among the cultivars, this period was longest for Orient and the shortest for Rigent*Cobra and Tokan in both seasons. A positive correlation existed between length of this period and grain yield in cultivars. The length of flowering to ripening period was also different among the cultivars (Table III). Although some high-yield cultivars such as Elikator had greater post-flowering period length, there is no clear relationship between this trait and grain yield. With prolonged pre-flowering period, plants could produce and store more assimilates for yield components (pod & seed number).

Table III. Cultivars mean and least significant differences (LSD) for total dry matter (TDM), harvest index (HI), plant height, days from sowing to flowering and ripening

Cultivars	2004					2005				
	TDM (gm^{-2})	HI (%)	Height (cm)	Sowing to flowering (d)	Flowering to ripening (d)	TDM (gm^{-2})	HI (%)	Height (cm)	Sowing to flowering (d)	Flowering to ripening (d)
Talayeh	999.0	24.86	98.6	171.3	55.8	1058.0	32.78	100.6	**169.8**	55.0
Orient	913.8	37.94	103.7	172.3	56.3	981.3	31.69	93.7	170.8	55.5
Elvis	981.0	33.34	99.3	170.3	55.8	1090.0	30.02	97.9	168.8	55.0
Elite	872.2	37.12	96.5	170.8	53.5	951.1	32.89	95.8	168.3	53.5
Elikator	932.5	34.50	96.6	168.5	58.5	1056.0	31.40	88.6	168.3	56.5
Parade	713.2	41.74	95.3	170.3	57.0	731.6	39.52	88.3	169.3	55.8
Okapi	807.5	28.58	88.6	168.0	56.3	855.3	26.53	85.2	166.8	55.0
Hayolla 401	718.3	31.97	90.9	168.0	57.0	752.9	28.88	88.4	166.5	55.5
Bommerang	870.5	25.91	93.6	171.3	55.8	899.0	23.45	89.1	169.8	55.0
Licord	824.6	26.06	92.2	171.5	55.8	871.5	22.98	87.5	170.3	55.0
Tokan	684.4	26.21	83.9	167.0	52.8	719.8	23.58	81.3	164.8	52.5
Rigent*Cobra	697.0	24.58	100.1	167.0	57.5	800.6	20.73	91.4	166.3	55.8
Hayolla 60	572.1	27.13	66.0	168.3	53.8	577.7	28.63	68.8	166.3	53.5
Opera	575.0	25.19	91.4	168.0	56.3	598.1	24.33	87.0	166.8	55.0
SLM 046	520.3	27.50	85.5	168.0	57.0	549.1	26.36	86.0	167.0	55.5
Hayolla 308	367.8	29.96	71.6	167.3	53.8	451.3	30.22	72.5	165.3	53.3
Mean	753.1	30.16	90.9	169.2	55.8	809.0	28.37	87.6	167.8	54.8
L.S.D. (p=0.05)	103.6	5.18	6.79	2.14	2.18	104.3	4.39	10.71	2.06	2.10

Give means ± s.e

Therefore with prolonged flowering period the number of these yield components was increased. It seemed that high-yielding cultivars had faster growth rate in post-flowering period than other cultivars. On the other hand the cultivars with longer post-flowering period had heavier seed weight (Example g., Parde & Elikator). In other studies on rapeseed the length of pre-flowering period was correlated significantly with grain yield or total dry matter (Thurling, 1974a; Ozer *et al*., 1999), whereas Ali *et al*. (2003) noted such a correlation with seed weight only. In soybean and pea the pre-flowering period had positive relation with grain yield and total dry matter, while there is no correlation between grain filling period and grain yield (Hobbs & Mahon, 1982; Ashley & Boerma, 1989; Voldeng *et al*., 1997; Morrison *et al*., 1999).

Leaf photosynthesis rate. The rate of leaf photosynthesis varied from 18 to 38 µmoL $m^{-2} s^{-1}$ and from 24 to 40 µmoL $m^{-2} s^{-1}$ at flowering and pod formation stages, respectively (Table IV). At flowering Elvis and Elite showed highest photosynthetic rate (P_a) in 2004, while in 2005, Talayeh had the highest P_a. High-yield cultivars generally had greater P_a at flowering than medium and low-yield cultivars. The lowest photosynthesis was observed in cultivars with low grain yield such as, Hayolla-308, Hayolla-60, SLM and Opera. At pod formation the differences of photosynthesis between high and medium yield cultivars became smaller and some cultivars with medium grain yield (such as Bomerang) had high P_a. In general at flowering higher P_a in high-yield cultivars in comparison with other cultivars was well evident, while at pod formation this was not observed. This suggested that leaves are important sources of photosynthesis at flowering stage, while at pod formation other sources, such as pods, became more important exporters of photosynthates than leaves. Similar results were reported in other studies about the role of leaf in supplying photoassimilate at vegetative and grain filling period (Chapman *et al*., 1984; Chango & McVetty, 2001). In soybean Buttery *et al*. (1981) observed significant correlation between leaf P_a and grain yield. Wells *et al*. (1982) and Morrison *et al*. (1999) reported significant correlation between grain yield and photosynthesis. In wheat, consistent correlation existed between increase in potential achieved for CIMMYT semidwarf cultivars introduced from 1962 to 1988 and flag-leaf photosynthesis (Fischer *et al*., 1998).

Stomatal conductance. At flowering stage Elvis, Orient, Elite and Talayeh in 2004 and Tlayeh, Elvis, Elikator and Elite (all with high grain yield) in 2005 had the highest stomatal conductance (g_s) among cultivars. Hayolla-60 had the lowest g_s in both years (Table IV). A consistent relationship existed between grain yield and g_s in cultivars at flowering. At pod formation Orient and Hayolla-60 in 2004 and Bomerang and Parade in 2005 had the lowest g_s, as at this stage little differences was evident between cultivars with high, medium and low-yield for this attribute. In addition the overall g_s of cultivars was higher at flowering than pod formation stage (0.31 & 0.39 moL $m^{-2} s^{-1}$ in 2004 in comparison with 0.26 & 0.32 moL $m^{-2} s^{-1}$ in 2005 at flowering & pod formation, respectively). The lake of consistent relation between g_s and grain yield of cultivars at pod formation is probably due to, the change of the environmental conditions, as at pod formation the air temperature increased. Since plant coincides with warmer atmosphere and evaporative demand the environmental condition determines the potential of evaporation rate and g_s not crop characteristics. Because of this the association of g_s with grain yield at pod formation in comparison with flowering was little. McVetty *et al*. (1989) reported a

Table IV. Cultivars mean and least significant differences (LSD) for leaf photosynthesis rate (P_a) and stomatal conductance (g_s)

Cultivars	2004				2005			
	Flowering		Pod formation		Flowering		Pod formation	
	P_a (μmol m^{-2} s^{-1})	g_s (mol m^{-2} s^{-1})	P_a (μmol m^{-2} s^{-1})	g_s (mol m^{-2} s^{-1})	P_a (μmol m^{-2} s^{-1})	g_s (mol m^{-2} s^{-1})	P_a (μmol m^{-2} s^{-1})	g_s (mol m^{-2} s^{-1})
Talayeh	**36.47**	**0.379**	**30.54**	**0.250**	38.07	0.512	34.67	0.352
Orient	37.36	0.404	30.19	0.360	37.61	0.315	33.61	0.369
Elvis	38.28	0.499	40.57	0.340	37.72	0.475	35.35	0.271
Elite	38.03	0.390	28.32	0.225	35.79	0.505	36.60	0.378
Elikator	34.27	0.333	24.35	0.178	37.08	0.568	30.36	0.322
Parade	30.64	0.330	29.45	0.243	31.45	0.450	32.45	0.252
Okapi	29.75	0.266	34.28	0.285	31.75	0.342	30.32	0.263
Hayolla 401	32.69	0.359	35.02	0.200	33.65	0.355	32.33	0.317
Bommerang	34.03	0.298	38.52	0.350	36.33	0.402	32.60	0.387
Licord	32.79	0.285	33.08	0.317	35.23	0.401	34.26	0.364
Tokan	30.89	0.315	27.72	0.230	26.57	0.357	33.33	0.255
Rigent*Cobra	35.76	0.364	31.50	0.312	28.77	0.273	32.03	0.271
Hayolla 60	18.63	0.119	21.17	0.148	26.20	0.225	27.43	0.350
Opera	26.26	0.258	31.74	0.308	28.49	0.293	28.69	0.320
SLM 046	27.44	0.212	27.86	0.270	28.29	0.467	28.33	0.306
Hayolla 308	23.07	0.149	24.94	0.182	18.18	0.285	25.71	0.396
Mean	31.65	0.310	30.58	0.262	31.95	0.389	31.75	0.323
L.S.D. p=0.05)	6.39	0.119	6.89	0.045	6.47	0.110	5.9	0.042

Table V. Correlation coefficient between traits in 2004 (upper value) and 2005 (lower value)

Traits	1	2	3	4	5	6	7	8	9	10	11	12	13
1- GY	1												
2-TDM	0.89**	1											
	0.86**												
3-HI	0.79**	0.43^{ns}	1										
	0.66**	0.20^{ns}											
4- Plant height	0.72**	0.76**	0.42^{ns}	1									
	0.72**	0.79**	0.19^{ns}										
5-Pods no./plant	0.81**	0.81**	0.47^{ns}	0.65**	1								
	0.88**	0.89**	0.36^{ns}	0.79**									
6-Seeds/pod	0.54*	0.43^{ns}	0.45^{ns}	0.76**	0.46^{ns}	1							
	0.40^{ns}	0.38^{ns}	0.24^{ns}	0.63**	0.41^{ns}								
7-Seed weight	0.16^{ns}	0.03^{ns}	0.28^{ns}	0.28^{ns}	-0.07^{ns}	0.35^{ns}	1						
	0.01^{ns}	-0.21^{ns}	0.37^{ns}	0.16^{ns}	-0.24^{ns}	-0.06^{ns}							
8-Photosynthesis rate (flowering)	0.77**	0.83**	0.42^{ns}	0.91**	0.69**	0.66**	0.16^{ns}	1					
	0.81**	0.91**	0.22^{ns}	0.82**	0.82**	0.46^{ns}	-0.36^{ns}						
9-Stomatal conductance (flowering)	0.78**	0.79**	0.49^{ns}	0.87**	0.74**	0.61*	0.02^{ns}	0.93**	1				
	0.70**	0.61*	0.44^{ns}	0.62*	0.56*	0.17^{ns}	0.22^{ns}	0.62**					
10-Photosynthesis rate (pod formation)	0.25^{ns}	0.47^{ns}	-0.07^{ns}	0.55*	0.37^{ns}	0.570*	-0.18^{ns}	0.56*	0.59*	1			
	0.57*	0.79**	0.15^{ns}	0.80**	0.68**	0.33^{ns}	0.22^{ns}	0.77**	0.50*				
11-Stomatal conductance (pod formation)	0.20^{ns}	0.40^{ns}	-0.13^{ns}	0.64**	0.44^{ns}	0.44^{ns}	-0.09^{ns}	0.52*	0.47^{ns}	0.74**	1		
	0.19^{ns}	0.25^{ns}	0.02^{ns}	0.16^{ns}	0.35^{ns}	0.17^{ns}	-0.52*	0.42^{ns}	0.11^{ns}	0.21^{ns}			
12-Sowing to flowering	0.71**	0.68**	0.51*	0.53*	0.67**	0.44^{ns}	-0.10^{ns}	0.55*	0.46^{ns}	0.24^{ns}	0.47^{ns}	1	
	0.68**	0.68**	0.34^{ns}	0.64**	0.67**	0.46^{ns}	-0.21^{ns}	0.81**	0.47^{ns}	0.58*	0.54*		
13-Flowering to ripening	0.24^{ns}	0.26^{ns}	0.15^{ns}	0.55*	0.13^{ns}	0.59*	0.56*	0.30^{ns}	0.27^{ns}	0.26^{ns}	0.26^{ns}	0.03^{ns}	1
	0.35^{ns}	0.38^{ns}	0.12^{ns}	-0.49^{ns}	0.31^{ns}	0.59*	0.02^{ns}	0.52^{ns}	0.34^{ns}	0.08^{ns}	-0.01^{ns}	0.49*	

*, ** and ns are significant at the 0.05 and 0.01 probability levels and non significant, respectively

positive correlation between g_s and grain yield of different *Brassica* species. In soybean also, significant correlation between g_s, P_a and grain yield was observed (Morrison *et al*., 1999). Fischer *et al*. (1998) showed that yield progress across short wheats released between 1962 and 1988 was closely associated with increased g_s. A yield increase of 29% in this period corresponded with increases of 63% in g_s (Fischer *et al*., 1998).

Correlations. Grain yield significantly correlated with number of pod per plant, TDM, HI, plant height, P_a and g_s at flowering and the period of sowing to flowering in both growing years (Table V). Among yield components pod number and seed weight had greater and lower correlation with grain yield, respectively. Number of seed per pod had low correlation with grain yield only in 2004. These results were consistent with findings of other studies for rapeseed in which pod number per plant had the greatest correlation with grain yield (Thurling, 1974b; Ozer *et al*., 1999). TDM and HI were significantly correlated with grain yield (Table V). In other studies also high correlation between HI and TDM with grain yield have been reported in rapeseed (Thurling, 1974a; Chango & McVetty, 2001; Ali *et al*., 2003), wheat (Austin *et al*., 1980, 1989; Sinha *et al*., 1981; Karimi & Seddique, 1991; Sayre *et al*., 1997), soybean (Morrison *et al*., 1999) and rice (Takeda *et al*., 1984).

Photosynthetic rate and g_s at flowering significantly correlated with grain yield and TDM (Table V). Although little or no significant correlation was reported between photosynthesis and yield in rapeseed (Chango & McVetty, 2001), in other crops such as soybean high correlation was observed between this character and yield (Wells *et al*., 1982; Ashley & Boerma, 1989; Morrison *et al*., 1999). These different results about association of photosynthesis with yield in crops are partially, because of the measurement of photosynthesis in a few numbers of plant leaves and for short period of time. The P_a at flowering was correlated significantly with pod number in this experiment, which indicated an important role of assimilate supply at the time that potential number of pod is determined. At pod formation a low correlation exists between photosynthesis rate and grain yield (Table V). This implied that at this stage other sources (such as pods & stem) became more important in supplying assimilates than leaves.

The length of sowing to flowering period had significant correlation with grain yield and TDM (Table V). Thurling (1974a) and Ozer *et al*. (1999) also observed significant correlation between duration of sowing to flowering with grain yield in rapeseed. The length of this period also had significant correlation with plant height and pod number in the present study (Table V). This revealed that increased growth duration and production of sufficient assimilate in pre-flowering period had an important role in determining the potential number of yield components.

In conclusion, HI, TDM, plant height, number of pod per plant and length of pre-flowering period correlated significantly with grain yield. These traits can be useful selection criteria in rapeseed breeding. The P_a and g_s at flowering also had significant correlation with grain yield, which can be used for increasing rapeseed yield in breeding programs. On the other hand, measuring other source of photosynthats, especially pod photosynthesis, at pod formation and grain filling period may determine better grain yield in rapeseed.

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