Correlation and Path Analysis of Quantitative Traits in Winter Rapeseed (*Brassica napus* L.)

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Summary

In the paper presented, 30 rapeseed cultivars were studied. Seed yield components and their interrelations were analyzed using simple coefficients of correlation. The direct and indirect effects of such components on seed yield per plant were estimated using path analysis. The following traits were considered: plant height, height of the first lateral branch, number of lateral branches, number of pods per plant, seed oil content, 1000 seed weight and seed yield per plant. The highest seed yield per plant was estimated for cultivars 'Sremica', 'B-009', 'Jet Neuf' and 'Falcon'. There was a complete correlation between plant height and height of the first lateral branch and a very strong one between plant height and seed oil content, as well as between plant height and seed yield per plant. The strongest direct effect on seed yield per plant was estimated for plant height, followed by the effect of number of pods per plant. This kind of investigation helps rapeseed breeders to optimize their breeding programs.

Key words

winter rapeseed (*Brassica napus* L.), cultivar, correlations, path analysis, seed yield

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Introduction

The field area cultivated by rapeseed (*Brassica napus* L.) have been almost doubled in the World over the last fiveteen years and nowdays it is grown on approximately 27 million hectares. In Europe, it is grown on 3.5 million hectares with increasing tendency. The largest field areas cultivated by rapeseed in Europe belong to Germany, France and Poland (FAOSTAT Database, 2006). It is primarily grown because of both, high quality oil, which meets criteria of the most demanding nutritionists, and proteins that are used as a feed pellets for the majority categories of livestock species (Marjanović - Jeromela at al., 2007; Pospišil et al., 1997). Rapeseed has also been used for biodiesel production since recently. Besides above mentioned, its importance in bee keeping as well as agrotechnical measure of weed control by asphyxiation should not be neglected. It also leaves the soil quite early, thus enables in-time soil tillage for the next planting season. Rapeseed breeding strategies are mostly dealing with developing varieties characterized by high and stable seed and oil yield, as well as by low content of glucosinolates and erucic acids. Seed yield is a quantitative trait, which expression is the result of genotype, environmental effect and genotype-environment interaction (Huhn and Leon, 1985; Engqvist and Becker, 1993; Marinković et al., 2003; Gunasekera et al., 2006). Complexity of this trait is a result of diverse processes that occur during plant development (Evans 1983, Sudarić, 1999). Knowing the relationship among these processes and investigating other quantitative traits make breeding programs and their success more optimistic and secure (Mijić et al., 2006). The investigation presented in this paper shows the results of correlation between plant height, height of the first lateral branch, number of lateral branches, number of pods per plant, seed oil content, 1000 seed weight and seed yield per plant. Path analyses were also performed in order to determine yield related traits that could serve as selection criteria in rapeseed breeding programs.

Material and methods

Experimental material consisted of 30 rapeseed cultivars (Table 1).

Table 1. Investigated cultivars

Origin	Cultivar	Origin	Cultivar
Institute of Field and Vegetable Crops Novi Sad, Serbia	Sremica	Germany	Falcon
	Banaćanka		K-571
	UM-1		K-1550
	UM-2		Alaska
	UM-5		Aligator
	UM-6		H-450
	UM-8		Valesca
	UM-9		Orkan
	UM-10		Pronto
	UM-11		Artus
	UM-12	France	Samouri
	UM-13		Jet Neuf
	UM-14		B-009
Hungary	Oktavija		Duna
	Jana	Sweden	Casino

The field trial was arranged in a Randomized Complete Block Design with three replications at Rimski Šančevi location (near Novi Sad, Serbia) during three growing seasons. Manual planting was carried out. The distance between rows was 25 cm. Thinning procedure at HB 3 stage (Harper and Berkenkamp, 1975) provided 5 cm distance between plants within a row. Each cultivar was planted in four rows and every row was 4 meters long. The trial was set up at chernozem type of soil, according to pedodynamic classification (Vasin et al., 2002). The soil was characterized by 2.8 % humus content, moderate content of phosphorus and potassium and pH 6.92. Following traits were analized: plant height, height of the first lateral branch, number of lateral branches, number of pods per plant, seed oil content, 1000 seed weight and seed yield per plant. Optimal agricultural practices were carried out in all investigated seasons. Plant height was measured from plant root collar to the top of central branch at HB 5.4. stage. Height of the first lateral branch was measured as a distance from the root collar to appearance of the lowest lateral branch on the central one. Number of lateral branches and pods per plant were determined by counting. Seed oil content was measured by magnetic resonance analyzer (Newport 4000 NMR analyzer). 1000 seed weight and seed yield per plant were determined in laboratory, after every plant was harvested. Analysis of variance and LSD test were carried out for determination of significant differences between cultivar means and average of the field trial. The relationship between investigated traits was examined by simple coefficients of correlation. Direct and indirect effects of all above-mentioned investigated traits on seed yield per plant were estimated according to Dewey and Lu (1959). Correlations strength and their direction were determined by Roemer-Orphal scale (Vasilj, 2000). MSTATC and SAS System Software were used for all analyses performed in this investigation.

Results and discussion

Table 2 presents mean values of traits across cultivars. The obtained differences for all investigated traits point out the diversity of investigated material. Winter rapeseed breeding programs are dealing with plant height as a quantitative trait that determines final plant density. Besides genetic effects, environmental effects also play an important role in expression of this trait. The lowest plants were determined in Samouri cultivar (109.6 cm), whereas the highest plants were found in 'Aligator' and

Table 2. Mean values for analyzed traits of rapeseed cultivars, from 1997 to 2000, Rimski Šančevi, Novi Sad

Cultivar	Plant height (cm)	Height of the first branch (cm)	Number of lateral branches	Number of pods per plant	Seed oil content (%)	1000 seed weight (g)	Seed yield per plant (g)
Sremica	126.6	52.6	6.8	147.9	44.03	3.83	11.48
Banaćanka	124.8	52.4	6.7	120.0	46.42	3.88	8.88
Samouri	109.6	40.5	6.1	118.0	46.23	3.39	8.99
Falcon	125.4	56.4	6.2	130.9	45.18	3.52	10.40
Jet Neuf	116.6	47.3	6.9	144.3	46.24	4.13	11.03
Oktavija	122.3	46.9	7.1	140.8	47.77	4.14	10.00
Jana	122.8	51.4	6.6	114.4	47.06	3.42	8.38
B-009	128.0	46.5	7.1	165.7	46.28	3.55	11.23
UM-1	127.0	62.1	6.8	104.9	45.45	3.94	9.32
UM-2	119.5	57.5	6.1	108.5	45.50	4.20	7.43
UM-5	116.4	52.3	6.4	112.0	43.06	3.41	7.96
UM-6	124.7	59.9	6.3	117.2	43.56	3.60	8.88
UM-8	126.9	58.1	6.9	142.6	43.95	3.62	10.03
UM-9	119.7	42.9	6.2	122.0	45.97	3.55	7.83
UM-10	124.6	54.7	6.4	136.6	43.08	4.01	9.13
UM-11	131.5	68.8	8.1	125.6	46.29	3.57	7.55
UM-12	118.8	61.6	5.8	170.8	43.45	3.68	6.87
UM-13	119.6	57.2	7.1	108.0	41.97	3.96	6.51
UM-14	119.8	53.2	7.3	107.9	42.41	3.96	6.24
K-571	132.1	59.7	7.2	138.0	46.18	3.53	9.87
K-1550	117.4	50.9	6.2	126.6	44.98	3.52	10.04
Alaska	123.6	61.2	5.6	135.4	45.44	3.53	9.60
Aligator	132.1	61.7	5.2	121.2	45.21	4.02	7.64
H-450	123.5	53.6	6.4	126.3	43.54	3.75	9.63
Casino	129.0	59.5	6.1	124.9	43.90	4.05	8.76
Valesca	130.1	62.0	5.4	112.3	46.08	3.83	9.52
Duna	124.7	47.9	6.0	157.8	43.61	3.77	9.52
Orkan	124.1	53.3	5.4	122.6	45.60	4.05	8.33
Pronto	116.4	59.5	6.1	120.1	43.50	3.55	9.85
Artus	127.3	46.8	7.0	117.3	44.02	3.86	9.50
Average	123.5	54.6	6.5	128.0	44.87	3.76	9.01
LSD 0.05	5.3	4.4	0.7	13.1	1.11	0.14	1.29

'K- 571' cultivars (132.1 cm). Other significantly higher plants than average were found in 'UM- 11', 'Valesca' and 'Casino' cultivars. Significantly lower plants than the trait average were determined in five cultivars. Height to the first lateral branch is an important trait, especially during harvest season, which makes rapeseed breeders eager for developing high yielded cultivars with desirable plant architecture. Regarding this trait, the highest values were found in cultivar UM-11 (68.8 cm) and the lowest in cultivar Samouri (40.5 cm). Significantly higher values than average were determined in nine more cultivars, whereas seven cultivars showed significantly lower values (Table 2). Significantly higher number of lateral branches was found in 'UM- 11' (8.1) and 'UM- 14' (7.3), whereas 'Aligator' (5.2), 'Valesca' and 'Orkan' (5.4) cultivars showed significantly lower number of lateral branches. The highest value of pods per plant number was found in 'UM- 12' (170.8), 'B- 009', 'Duna', 'Sremica', 'Jet Neuf' and 'UM- 8' cultivars and the lowest in 'UM- 1' (104.9) and six other cultivars (Table 2). According to Schroder and Makovski (1996) it is necessary to achieve 120-150 pods per plant in order to reach 40-45 dt/ha of seed yield. This was actually obtained in most of the investigated cultivars. Seed oil content, besides seed yield, is one of the highly demanding criteria in developing rapeseed cultivars (Engqvist and Becker, 1993; Marinković et al., 2003; Si and Walton, 2004). The highest seed oil content was determined for 'Oktavija' (47.77%). 'Jana', 'Banaćanka', 'UM- 11', 'B- 009', 'Jet Neuf', 'Samouri', 'K- 571' and 'Valesca' cultivars had significantly higher seed oil content than the mean over cultivars (Table 2). The lowest seed oil content was determined for 'UM- 13' (41.97%). 1000 seed weight is very interesting trait for both rapeseed breeders and seed industry. It is also an important component of seed yield (Grosse et al., 1992; Diepenbrock, 2000). The highest value for this trait was determined in cultivar UM-2 (4.20 g) and the lowest in Samouri cultivar (3.39 g). Furthermore, for ten cultivars significantly higher values from the average were determined, whereas for twelve cultivars significantly lower values were found. The most yielding cultivars in this investigation were 'Sremica' (11.48 g), 'B-009' (11.23 g), 'Jet Neuf' (11.03 g) and 'Falcon' (10.40 g).

Correlations

All calculated correlations were positive and highly significant (Table 3). A complete correlation was estimated between plant height and height of the first lateral branch. Very strong correlation was found between plant height and

Table 3. Phenotypic correlation coefficients between analyzed traits, from 1997 to 2000, Rimski Šančevi, Novi Sad

Trait	Height of the first branch	Number of lateral branches	Number of pods per plant	Seed oil content	1000 seed weight	Seed yield per plant
Plant height	0.906**	0.398**	0.633**	0.785**	0.470**	0.768**
Height of the first lateral branch		0.177**	0.464**	0.749**	0.366**	0.595**
Number of lateral branches			0.547**	0.243**	0.277**	0.533**
Number of pods per plant				0.466**	0.337**	0.706**
Seed oil content					0.299**	0.609**
1000 seed weight						0.503**

F test significancy at level P<0.01**

seed oil content as well as between plant height and seed yield per plant. Strong correlation was estimated between plant height and number of pods per plant. Moderate correlation was determined between plant height and 1000 seed weight and low between plant height and number of lateral branches. Such results imply the possibility of plant height increase along with values of other seed yield components so this trait should be paid attention to in rapeseed breeding programs. Kis et al. (2006) reached similar inferences regarding correlations between plant height and seed yield per plant as well as between plant height and height of the first lateral branch. However, authors found no correlation between plant height and number of lateral branches. Ozer et al. (1999) and Ali et al. (2003) calculated negative correlations between plant height and number of lateral branches and low positive correlation between plant height and seed yield. Ogrodowczyk and Wawrzyniak (2004) determined significant positive correlation between plant height and seed yield. Tusar- Patra et al. (2006) reached the similar conclusions for black mustard cultivars. However, Degenhart and Kondra (1984), as well as Gillani et al. (1993) estimated strong negative correlation between plant height and seed yield.

Strong correlation was determined between height of the first lateral branch and seed oil content as well as between height of the first lateral branch and seed yield per plant. Lower coefficient values were estimated between height of the first lateral branch and number of pods per plant as well as between 1000 seed weight and number of lateral branches. Kis et al. (2006) calculated strong but non-significant correlation between height of the first lateral branch and seed yield per plant. The same authors calculated very low non-significant correlation between height of the first lateral branch and number of lateral branches.

Strong correlation was determined between number of lateral branches and number of pods per plant as well as between number of lateral branches and seed yield per plant. However, correlation was low between number of lateral branches and 1000 seed weight and very low between number of lateral branches and seed oil content. Similar results were obtained by Guo et al. (1987) and Kis et al. (2006) who analysed correlation between number of lateral branches and seed yield per plant. These results were not in accordance to the results obtained by Marinković and Marjanović-Jeromela (1996).

While the correlation between the number of pods per plant and seed yield per plant kept strong, estimated correlations between the number of pods per plant and seed oil content as well as number of pods per plant and 1000 seed weight were not (Table 3). Guo et al. (1987), Behl et al. (1989) and Ozer et al. (1999) reached to the quite similar results. Pospišil and Mustapić (1995) calculated complete correlation between number of pods per plant and seed yield per plant but they found no correlation between number of pods per plant and 1000 seed weight. Ali et al. (2003) determined negative correlation between number of pods per plant and 1000 seed weight.

Significant positive correlation estimated between seed oil content and seed yield per plant (0.609**) leads to the conclusion that simultaneous selection regarding oil content and seed yield per plant is possible to be done. Ozer et al. (1999) calculated significant correlation between seed oil content and seed yield per plant.

In our investigation the correlation between seed oil content and 1000 seed weight was low, which is in correspondence with the investigation performed by Engqvist and Becker (1993), whereas Ozer et al. (1999) estimated significant positive correlation for these traits. Strong correlation was also estimated between 1000 seed weight and seed yield per plant, which pointed out that seed yield increase per field area unit can be obtained by target selection of rapeseed toward increasing 1000 seed weight. It probably would not affect seed oil content since there is low correlation between 1000 seed weight and seed oil content. Many authors estimated significant positive correlation between 1000 seed weight and seed yield (Thurling, 1974; Ozer et al., 1999; Ali et al., 2003). However, Pospišil and Mustapić (1995) did not confirm such inferences.

Path coefficient analysis

The advantage of path analysis is that it permits the partitioning of the correlation coefficient into its components. One component is the path coefficient (or standardized partial regression coefficient) that measures the direct effect of a predictor variable upon its response variable. The other component is the indirect effect(s) of a predic-

Table 4. Path coefficient analysis between yield and yield related traits, from 1997 to 2000, Rimski Šančevi, Novi Sad

Trait	Direct effect	Indirect effect via						r* Seed yield per plant
		Plant height	Height of the first lateral branch	Number of lateral branches	Number of pods per plant	Seed oil content	1000 seed weight	
Plant height	0.636	–	–0.233	0.046	0.164	0.086	0.068	0.768
Height of the first lateral branch	–0.257	0.576	–	0.021	0.120	0.082	0.053	0.595
Number of lateral branches	0.117	0.253	–0.045	–	0.142	0.027	0.033	0.533
Number of pods per plant	0.260	0.403	–0.119	0.064	–	0.051	0.049	0.706
Seed oil content	0.109	0.499	–0.192	0.028	0.109	–	0.044	0.609
1000 seed weight	0.146	0.299	–0.094	0.026	0.087	0.033	–	0.503

r*– Correlation coefficient; Determination coefficient: R^2= 0.721

tor variable on the response variable through the predictor variables (Dewey and Lu, 1959).

Estimated correlation coefficient at phenotypic level between plant height and seed yield per plant was 0.768. Its direct effect to seed yield per plant was also high (0.636). Indirect effect to the height of the first lateral branch was low and negative but positive for number of pods per plant. Other traits had almost no effect on seed yield per plant (Table 4). Although phenotypic coefficient of correlation showed strong correlation between height of the first lateral branch and seed yield per plant (0.595), its direct effect was low and negative indeed (-0.257). It was indirectly realized via plant height (0.576).

Estimated phenotypic coefficient of correlation between number of lateral branches and seed yield per plant was 0.533, but partial analysis of correlation coefficients showed low direct effect of number of lateral branches on seed yield per plant (0.117). All other indirect effects were low as well.

The relationship between number of pods per plant and seed yield per plant was strong, as was pointed out by phenotypic coefficient of correlation (0.706). However, its direct effect was low indeed (0.260), covered by the indirect effect of plant height.

Strong positive correlation was estimated between seed oil content and seed yield per plant (0.609). However, direct effect of seed oil content on seed yield per plant was very low (0.109). It was indirectly realized via both, plant height and number of pods per plant positively, but the indirect effect of height of the first lateral branch was negative.

Overall correlation estimated between 1000 seed weight and seed yield per plant was strong (0.503). However, its direct effect to seed yield per plant was low (0.146). It was also realized via plant height.

Thurling (1974), Ozer et al. (1999) and Ali et al. (2002) have estimated strong direct effect of number of pods per plant on seed yield per plant. However, Marinković et al. (2003) did not confirm such conclusions. Ali et al. (2003) emphasized the strongest direct positive effect of harvest index on seed yield, followed by 1000 seed weight and number of pods per plant. Ozer et al. (1999) estimated positive direct effect of 1000 seed weight on seed yield. Marinković et al. (2003) estimated the strongest direct effect of time from germination to the end of flowering on seed yield. Ogrodowczyk and Wawrzyniak (2004) found out that flowering duration has the strongest direct effect on seed yield. Tusar- Patra et al. (2006) concluded that the strongest effect on seed yield was estimated for number of pods per plant followed by number of seeds per pod and 1000 seed weight.

Conclusions

Based on investigation presented the following conclusions were reached:

- The most yielded winter rapeseed cultivars were 'Sremica', 'B-009', 'Jet Neuf' and 'Falcon'. These varieties can be recommended for wide area production, and they also present a valuable germplasm source material for including in further breeding programs.
- Very strong correlation was estimated between plant height and seed yield per plant and strong correlations between height of the first lateral branch, number of lateral branches, number of pods per plant, seed oil content, 1000 seed weight and seed yield per plant.
- A complete correlation was estimated between plant height and height to the first lateral branch, very strong correlation between plant height and seed oil content and strong correlation between plant height and pods per plant number, then height of the first lateral branch and seed oil content, and finally between number of lateral branches and pods per plant number.
- The strongest direct effect to seed yield per plant was estimated for plant height followed by number of pods per plant. Therefore, these traits could be used as selection criteria in winter rapeseed breeding programs.
- Other investigated traits didn't show strong direct effect in determination of seed yield per plant. The effect of

these traits was covered by the indirect effect of plant height.

– The coefficient of determination (R^2=0.721) represents the influence of the traits involved in the study on total variability of seed yield per plant. The remaining 0.279% could be attributed to factors that are not included in this study.

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