EFFECT OF CLIMATIC VARIABLES AND SOWING DATE ON WINTER RAPESEED (*BRASSICA NAPUS* L.) DEVELOPMENT AND YIELD

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Weather plays an important role in agricultural production, having a profound influence on the growth, development and yields of a crop, incidence of pests and diseases, water needs and fertilizer requirements. Our climate is changing and such changes might have strong impact on agriculture, especially on crop growth and yield. Unfortunately, yield is a very complex trait due to gene action and their interaction with environment, i.e., different reaction of genotypes on changeable environmental conditions. Considering the vast diversity of agro-ecological conditions in the areas where rapeseed is grown, a constant effort is made to define optimal agricultural practices to exploit the yield potential of utilized cultivars.

Rapeseed growth stages are used to define the main components in yield estimation models. Each of them can be affected by yield-limiting factors, of which climatic conditions are the most important ones. Temperature, irradiation and precipitation directly and indirectly affect and determine the yield.

The effect of several climatic variables on the winter rapeseed developmental stages and yield in Southeast Europe has not yet been analyzed simultaneously, although their interaction is important to breeders and growers. Investigating the effect of specific climatic variables throughout rapeseed developmental stages could be used to dissect the year effect and determine which variables are the most significant for an optimal plant development at each growth stage. With that in mind, we evaluated the sources of variability for seed yield and oil content of four rapeseed cultivars affected by three sowing dates during four growing seasons. The aim was to understand year-related interactions and the effect of climatic variables in different growth stages.

Material and methods

Four rapeseed cultivars were used: (1) 'Jet Neuf', a cultivar from France; (2) 'Banaćanka', a 00 type cultivar from Serbia; (3) 'Samourai', a 00 type cultivar from France; and (4) 'Falcon', a 00 type cultivar from Germany.

The trial comprised three sowing dates (SD1, SD2, and SD3) in 10-day intervals in each year (Table 1). The seed yield was measured per plot and expressed in t ha−1. The oil content was determined using the NMR (Nuclear Magnetic Resonance) and expressed as a percentage. The rapeseed growth stages were determined using the BBCH (Biologische Bundesanstalt, Bundessortenamt und CHemische Industrie) standardized growth stage (GS) scale: germination (GS0), GS1+GS2 seedling and rosette stage, including overwintering (no growth period), budding (GS3), flowering (GS4), and ripening (GS5). The period of time with temperatures below 5°C is presented and discussed as a potential yield-determining phase.

Table 1. Onset and duration of five development stages (GS0-GS5), starting with sowing dates and ending with harvest dates

Vegetative and reproductive stages	2001/02			2002/03			2004/05			2005/06		
	SD1	**SD2**	**SD3**	**SD1**	**SD2**	**SD3**	**SD1**	**SD2**	**SD3**	**SD1**	**SD2**	**SD3**
GS 0 Germination	25.8.01	5.9.01	14.9.01	21.8.02	30.8.02	9.9.02	1.9.04	10.9.04	20.9.04	5.9.05	15.9.05	26.9.05
GS1+2 Seedling and rosette	12.9.01	23.9.01	30.9.01	1.10.02	29.9.02	4.10.02	27.9.04	4.10.04	4.10.04	24.9.05	25.9.05	5.10.05
GS3 Budding	30.3.02	30.3.02	1.4.02	19.4.03	19.4.03	20.4.03	13.4.05	14.4.05	14.4.05	12.4.06	11.4.06	13.4.06
GS4 Flowering	8.4.02	8.4.02	10.4.02	25.4.03	25.4.03	26.4.03	23.4.05	23.4.05	23.4.05	21.4.06	20.4.06	22.4.06
GS5 Ripening	6.5.02	7.5.02	7.5.02	12.5.03	12.5.03	13.5.03	19.5.05	19.5.05	19.5.05	9.5.06	9.5.06	12.5.06
Harvest	26.6.02	28.6.02	30.6.02	20.6.03	23.6.03	24.6.03	2.7.05	4.7.05	4.7.05	1.7.06	1.7.06	2.7.06
T< 5ºC	5.11.01 - 14.2.02			7.11.02 - 12.3.03			15.11.04 – 18.3.05			5.11.05 - 24.3.06		

Table 2. Summed precipitation (pr) and mean temperatures (mt) values calculated and averaged for the duration of individual growth stages (GS) based on daily values: GS0 germination (mt1, pr1), GS1+2 seedling and rosette (mt2, pr2), GS3 budding (mt3, pr3), GS4 flowering (mt4, pr4) and GS5 ripening (mt5, pr5)

Climatic factor	Climatic Variable	2001/02			2002/03			2004/05			2005/06		
		SD1	SD2	SD3	SD1	SD2	SD3	SD1	SD2	SD3	SD1	SD2	SD3
Mean temperature (°C)	mt1	16.9	14.3	15.2	17.6	16.8	14.5	16.2	14.7	13.7	17.4	15.3	14.6
	mt2	5.9	5.4	5.0	4.2	4.2	4.1	4.6	4.3	4.3	4.9	4.8	4.3
	mt3	**8.4**	**8.4**	**7.9**	12.7	12.7	13.4	11.6	11.6	11.6	12.4	12.2	13.0
	mt4	13.4	13.5	14.0	**21.2**	**21.2**	**21.8**	14.6	14.6	14.6	14.6	14.4	14.5
	mt5	20.6	20.7	20.7	22.0	22.1	22.2	19.6	19.6	19.6	18.8	18.8	19.2
Precipitation (mm)	pr1	**118**	**148**	**42**	55	46	52	48	43	38	56	47	15
	pr2	**217**	**163**	**160**	241	244	234	**387**	**381**	**381**	296	276	287
	pr3	**0**	**0**	**2**	2	2	3	15	11	11	**40**	**40**	**21**
	pr4	35	35	35	**3**	**3**	**3**	**52**	**52**	**52**	16	17	28
	pr5	101	97	107	**34**	**37**	**37**	**168**	**192**	**192**	163	163	157

Six climatic factors were observed: the temperature (minimum on 5 cm above ground - mn5cm; minimum - mn; maximum - mx; and mean - mt), total precipitation (pr), and relative air humidity (rh). Each of the climatic factors was calculated for the duration of the individual growth stage based on daily values: germination (mn1, mn5cm1, mx1, mt1, pr1, rh1), overwintering (mn2, mn5cm2, mx2, mt2, pr2, rh2), budding (mn3, mn5cm3, mx3, mt3, pr3, rh3), flowering (mn4, mn5cm4, mx4, mt4, pr4, rh4) and ripening (mn5, mn5cm5, mx5, mt5, pr5, rh5). As a result, 30 climatic variables were obtained, out of which the mean temperature and precipitation are presented in Table 2

The analysis of the experimental data from both experiments was completed by asreml-R and asremlPlus packages.

Results

A set of individual factorial regression models was developed in order to test the hypothesis about the effect of climatic variables on C x Y and T x Y interactions from ANOVA, as shown in Table 3. There was a highly significant effect of cultivars (C) and years (Y) for the seed yield and oil content, while treatments (T) were not significant (Table 3). The treatment × year (T × Y) interaction was only significant for the oil content. The cultivar × year (C × Y) interaction was highly significant for oil content, and the cultivar × treatment interaction was significant for the seed yield.

Table 3. Wald F tests on the fixed effects from the mixed model analyses of the sowing date and nitrogen rate trials.

Source of Variation	**df**	**Seed Yield**		**Oil Content**	
		F	*p*	*F*	*p*
Year (Y)	3	53.17	0.001 **	94.65	0.000 **
Treatment (T)	2	0.50	0.608 ns	0.98	0.379 ns
Cultivar (C)	3	6.19	0.001**	41.53	0.000 **
C × T	6	2.71	0.019 *	0.46	0.839 ns
T × Y	6	0.86	0.535 ns	2.69	0.017 *
C × Y	9	2.34	0.022 *	7.60	0.000 **
C × T × Y	18	1.68	0.059 ns	0.81	0.691 ns

*** significant at the 0.05 probability level, ** significant at the 0.01 probability level, ns: not significant.**

Out of thirty available climatic variables, nineteen had a highly significant effect on the C x Y interaction for the oil content. Six variables had a significant effect. The largest proportion of the explained interaction variance was obtained for precipitation at the budding stage (60.3%), the maximum temperature at overwintering (60.2%), and the relative air humidity at flowering (59.0%) (Figure 1a).

As a consequence of the decreased level of significance of the T x Y interaction for the oil content, only three climatic variables were found to be important (Figure 1b). A highly significant effect was observed only for precipitation at overwintering (81.4%), whereas the effect of the relative air humidity at the budding stage (76.4%) and precipitation at the germination stage (61.1%) accounted for a significant proportion of the T x Y interaction.

The optimal period for rapeseed sowing in the Novi Sad region is from late August to late September, depending on the environmental conditions of the year confirmed in this study. A later sowing time, including October, can affect the seed yield and oil content as a result of inadequately prepared plants for overwintering.

The C x Y and T x Y interactions were not significant for the seed yield, but only for the oil content. The precipitation at the budding stage (60.3%), maximum temperature at overwintering (60.2%), and relative air humidity at flowering (59.0%) explained the largest proportion of the C x Y interaction variance.

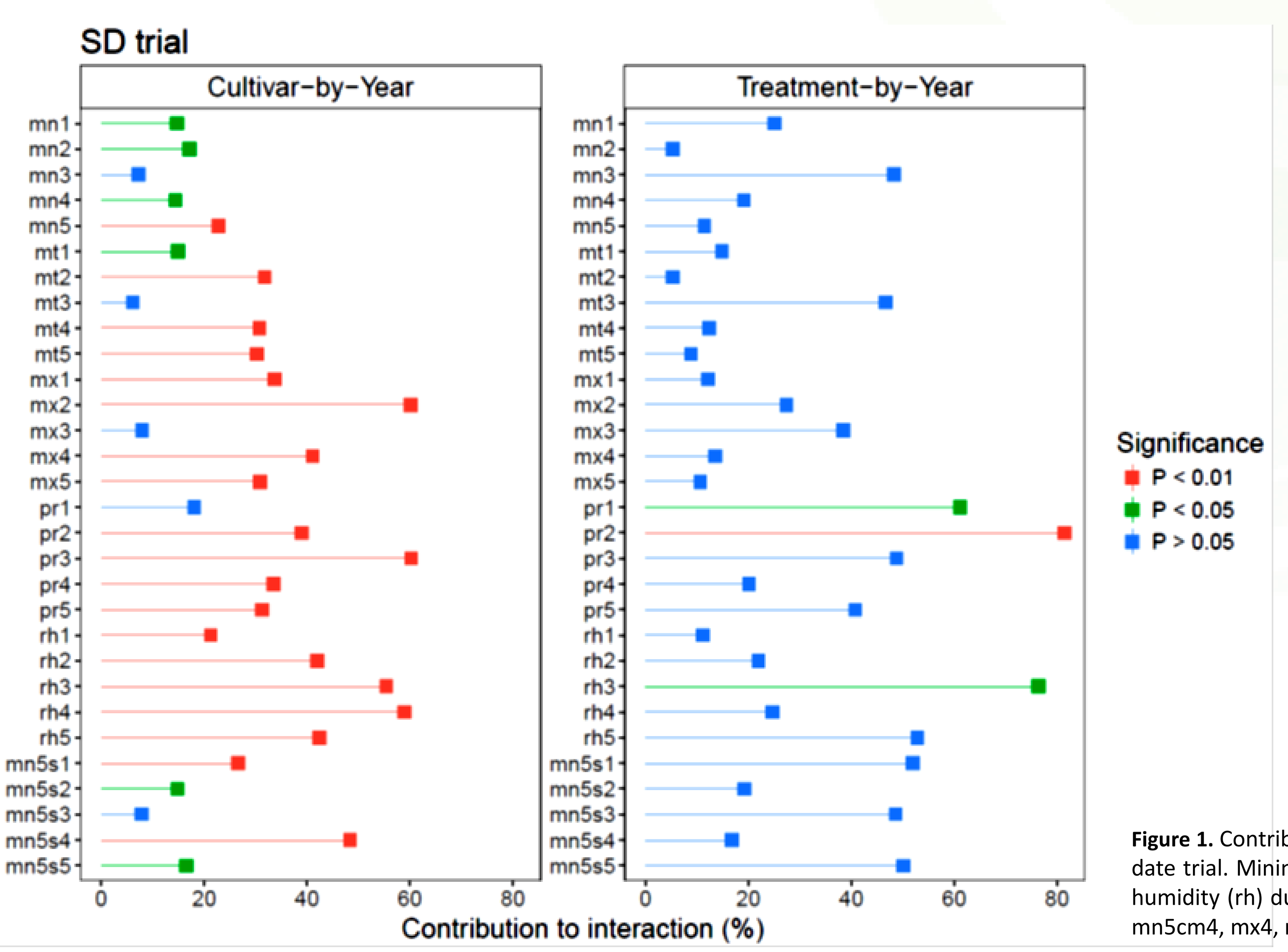

Figure 1. Contribution of the environmental variables to (a) the C × Y interaction for the oil content in the sowing date trial and to (b) the T × Y interaction for the oil content in the sowing date trial. Minimum temperature - mn; minimum temperature on 5 cm above ground - mn5cm; maximum temperature - mx; mean temperature - mt, total precipitation (pr), relative air humidity (rh) during: germination (mn1, mn5cm1, mx1, mt1, pr1, rh1), overwintering (mn2, mn5cm2, mx2, mt2, pr2, rh2), budding (mn3, mn5cm3, mx3, mt3, pr3, rh3), flowering (mn4, mn5cm4, mx4, mt4, pr4, rh4) and ripening (mn5, mn5cm5, mx5, mt5, pr5, rh5).