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REGULAR ARTICLE

Impact of water regime and phosphorus fertilization and their interaction on the characteristics of rapeseed (*Brassica napus*) and fatty acid profile of extracted oil

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ABSTRACT

A field experiment was conducted to evaluate the effects of phosphorus (P) fertilization rates and water stress levels on the morphological characteristics, seed yield, seed oil content and fatty acid profile of *Brassica napus* under the natural conditions of Agricultural Experimental Station (Nobaryia, Beheira governorate, Egypt). Morphological characteristics, seed yield and seed oil content of rapeseed were significantly lowered with the rise in water stress levels. Investigated traits increased significantly with the increase in P dose. The best morphological traits, seed yield and seed oil yield were obtained from plants irrigated with 1250 (m^3 fed^{-1}) combined with P (200 Kg fed^{-1}) calcium super phosphate (15.5%, P_2O_5). The highest oil recovery was obtained from plants irrigated with 1000 (m^3 fed^{-1}) combined with P (200 Kg fed^{-1}). Different treatments did not affect fatty acid profile in general. Monounsaturated fatty acids followed by polyunsaturated fatty acids were the main fatty acids while saturated fatty acids were found in lower levels. The predominant fatty acids were oleic acid followed by linoleic acid and linolenic acid.

Key Words: *irrigation; vegetable oils; phosphorus; morphological traits; seed yield; rapeseed (Brassica napus).*

Abbreviations: SFA- Saturated fatty acids; MUFA- Monounsaturated fatty acids; PUFA- Polyunsaturated fatty acids; fed- Feddan (=0.42 hectares or 1.038 Acres)

INTRODUCTION

Rapidly increasing population and changes in dietary habits associated with urbanization increased demands for food and fuel. Global cultivation of oilseed rape (*Brassica napus* L.) has been gradually increasing over the last years, reaching about 31.5 Mha in 2010 (Schoenenberger and D'Andrea 2012). Rapeseed is an annual crop belonging to *Brassicaceae* family (*Cruciferae*) originating from either the Mediterranean area, Asia or Northern Europe. Today rapeseed is one of the top five oilseed crops cultivated worldwide (Miri 2007, Khattab et al. 2012, Liersch et al. 2013). It is mainly utilized for its oil, which is one of the most common edible and healthy cooking oils due to its low content of saturated fatty acids (SFA, 7.0%), high content of the monounsaturated fatty acids (MUFA, 60.0%), and adequate content of polyunsaturated fatty acids (PUFA, 8.0 -12.0%) (Rice 1994, World Health Organization 1994, Starner et al. 1999). In addition, rapeseed seed is rich in tocols and phenolic compounds (Ackman 1994, Naczk et al. 1998, Oraby and Ramadan 2015).

Rapeseed has a short domestication history of 400–500 years (Pop et al. 2012). During the breeding history of rapeseed, the most outstanding event is the introduction of two traits, zero seed erucic acid and low seed glucosinolate content (so called double-low, canola quality 00). *Brassica napus* used to produce edible oil that is fit for human consumption because it has lower levels of erucic acid and glucosinolates (Pop et al. 2012).

Unfortunately, rapeseed has high erucic acid content. With amelioration technologies of plants, levels of erucic acid reduced to 1-2% in the rapeseed oil then to zero erucic acid type (zero erucic) (Brown and Brown 1996). Accountable to the market needs, rape types produced for oil have no erucic acid and glucosinolates. Through decreasing of erucic acid content, the oleic acid proportion increased from 14-20 % to over 64%, and the linoleic acid from 13-15% to 24%, which increased the alimentary quality of rape oil (Pop et al. 2012, Liersch et al. 2013).

Rapeseed oil contains both omega-6 and omega-3 fatty acids in a ratio of 2:1; it also has much omega-3 fatty acid, being worse only than flax oil. Rapeseed oil has been authorized according to a qualified health claim from the US Food and Drug Administration (FDA) based on its ability to reduce the risk of coronary heart disease due to its unsaturated fat content (FDA 2006).

Water limitation is one of the most important factors to reduce agricultural crop production, which is related to global climate changes, especially drought and heat stress (Ciais et al. 2005). Drought stress (water deficit or low water availability) is a widely distributed abiotic problem (Chaves and Oliveira 2004, Kijne 2006, Passioura 2007). The drought environment has been reported as key factor to limit plant growth and development prior to the loss of productivity, especially of rapeseed (Stoker and Carter 1984, Mendham and Salisbury 1995, Zakirullah et al. 2000, Gan et al. 2004, Sinaki et al. 2007, Nasri et al. 2008). Thus, irrigation management practices are required to ensure efficient use of water for optimal yields. There is increasing evidence that the function of phosphorus (P) is to limit the effect of biotic and abiotic stress. Therefore, plants suffering from water stress have a larger internal requirement for P to become more tolerate to water shortages (Ma et al. 2006, Said-Al Ahl and Abdou 2009, Gaj 2011). For maximum yield potential of rapeseed proper P content in the soil is recommended (Gaj 2011, Slaton et al. 2009). Even in the conditions of optimum soil richness, various reasons (i.e., drought and pH) caused disturbance of P uptake processes. Phosphorus is an essential macronutrient for plant growth and development, being required in the synthesis of nucleic acids, phospholipids, and ATP (Schachtman et al. 1998, Mudge et al. 2002, Lambers et al. 2006).

The goal of this investigation was to study the effects of water regime and P fertilization and their interaction on the characteristics of *Brassica napus* and fatty acid composition of the extracted seed oil.

MATERIALS AND METHODS

EXPERIMENTAL PROCEDURE

Two field experiments were conducted at the Agricultural Experimental Station of the National Research Center (Nobaryia Sector, Beheira governorate, Egypt) during the two successive seasons of 2010/2011 and 2011/2012 (Latitude 31.156597 and Longitude 29.864106). The physical and chemical properties of the soil sample were determined according to Black (1965) and presented in Table 1.

Table 1. Soil physical and chemical properties at the experimental site.

Physical properties				
Particle size distribution (%)			θ_w (w/w)	Texture class
Sand	Silt	Clay	Field capacity	
71.00	24.89	4.11	20.11	Sandy loam

Chemical properties												
pH 1:2.5	Ec dSm^{-1}	Soluble cations (meq L^{-1})				Soluble anions (meq L^{-1})				Total	Available	
										mg/100 g soil		
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--}	HCO_3^{-}	SO_4^{--}	CL^{-}	N	P	K
7.9	0.15	2.88	2.01	2.04	0.31	0	2.14	0.73	4.37	10	1.12	4.48

Seeds of *Brassica napus* L cv. serw 1 were obtained from Agricultural Research Center (Ministry of Agriculture, Egypt). The seeds were sown on 15 November (low temperature 14˚C and high temperature 24˚C), during both seasons, into 3×3.5 m plots, on rows with 60 cm apart and 20 cm between hills. The seedlings were thinned 21 days after sowing to leave two plants per hill to give 170 plants per plot. The experimental layout was split-plot (water regimes in the main plots and the calcium super phosphate treatments were distributed randomly in the subplots) in four replicates.

The irrigation system was subsurface drip irrigation system (4 liter/h GR, buried 20 cm depth under the soil surface). Evapo-transpiration was calculated from the metrological data of the NRC Metrological Station in Nobaryia (latitude 31.156597 and longitude 29.864106) using the empirical equation of modified Benman-Monteith (FAO Irrigation and drainage paper 56, 1998).

Irrigation treatments were irrigation with 100%, 80%, 60% and 40% of the crop evapotranspiration (ETc) (calculated from the metrological data for canola plants in the studied region, 1250, 1000, 750 and 500 m^3/fed/season, respectively). Calcium super phosphate (P_2O_5, 15.5%) was applied before sowing at the rate of 0.0 (P0), 100 (P1) and 200 (P2) kg calcium super phosphate fed^{-1}. Ammonium sulfate (20.5%, N) and potassium sulphate (48-50%, K_2O) were added at the rate of 100 kg ammonium sulfate fed^{-1} and 50 kg potassium sulphate fed^{-1} in two equal doses at 21 and 45 days after sowing, respectively. In both seasons, plants were harvested on 20th May (low temperature 15˚C and high temperature 25˚C) at full fruits ripening, by uprooting the plants from the soil by hand. The average temperatures during the vegetation seasons were 14-24˚C in November, 10-19˚C in December, 14-20˚C in January, 14-20˚C in February, 17-22˚C in March and 21-27˚C in April. Plant morphological traits, namely height, number of branches and number of pods per plant and seed yield (kg fed^{-1}), were measured.

EXTRACTION OF SEED OIL

Brassica napus seeds were crushed and grounded with a grinding mill (Petra electric, Burga, Germany). The oil was extracted from the ground material with *n*-hexane at 50-60˚C in a Soxhlet apparatus for 6 h following the AOCS method (1993). The content of total lipids was determined as a percentage of the extracted total lipids to the sample weight (w/w). The oil obtained was stored at 4˚C for further investigation.

GAS LIQUID CHROMATOGRAPHY (GLC) ANALYSIS OF FATTY ACID METHYL ESTERS (FAME)

The fatty acid profile of total lipids extracted from *B. napus* was determined following the International Organization of Standards (ISO, 2000). One drop of oil was dissolved in 1 mL of *n*-heptane, then 50 µL of 2 M sodium methanolate in methanol was added, and the closed tube was agitated vigorously for 1 min. The tube was centrifuged at 45,000g, after addition of 100 µL of water, for 10 min; then the lower aqueous phase was removed. Fifty µL of 1 M HCl was added to *n*-heptane phase, the two phases were mixed, and the lower aqueous phase was discarded. About 20 mg of sodium hydrogen sulphate (monohydrate, Merck, Darmstadt, Germany) was added, and after centrifugation at 45009g for 10 min, the top *n*-heptane phase was transferred into a vial and injected into a Varian 5890 gas chromatograph equipped with CP-Sil 88 capillary column, (100 m long, 0.25 mm ID, film thickness 0.2 µm). The temperature program was from 155°C to 220°C (1.5 °C/min.), 10 min isotherm; injector 250°C, detector 250°C; carrier gas 1.07 mL/min hydrogen; split ratio 1:50; detector gas 30 mL min^{-1} hydrogen; 300 mL min^{-1} air and 30 mL min^{-1} nitrogen and manual injection less than 1 µL. The integration software computed the peak areas, and percentages of FAME were obtained as weight percent by direct internal normalization.

STATISTICAL ANALYSIS

All data were subjected to analysis of variance, and differences were compared with the Duncan's multiple range test ($p<0.05$). Combined data for the two seasons were statistically analyzed using the methods described by Snedecor and Cochran (1990), with the model for two-factor Randomized Complete Block Design combined over years (so, with block nested within year).

RESULTS AND DISCUSSION

MORPHOLOGICAL CHARACTERISTICS AND SEED YIELD

Decreasing irrigation water significantly decreased plant height, number of branches and number of pods per plant as well as seed yield (kg fed^{-1}) (Table 2). Irrigation at 1250 m^3 fed^{-1} resulted in the highest values of these parameters, followed by that of 1000 m^3 fed^{-1}, 750 m^3 fed^{-1}, and 500 m^3 fed^{-1}. Increasing of water stress reduced growth characters, which may be due to reduction in photosynthesis and plant biomass. Under increasing water stress levels, photosynthesis was limited by low CO_2 availability due to reduced stomatal and mesophyll conductance. The pronounced effect of increased irrigation on growth may be attributed to the availability of sufficient moisture throughout the root system (Singh et al., 1997). Usually, fluctuations of plant height are the most conspicuous characteristic of genetic conditions and environmental changes in most plants. Applying water deficit stress caused reduction in the plant height. This reduction in the plant height due to water deficit stress is probably related to decline in photosynthetic products as a result of soil moisture decrease, which eventually causes the plant to not reach its genetic potential. Sadaqat et al. (2003) have also reported a significant decrease in the stem height of rapeseed cultivars under water stress conditions. Occurrence of drought stress during the flowering and fertilization stages increased pod seedlessness due to insufficient fertility and flower abscission; as a result, it reduced the number of seeds per silique (Wright et al. 1996). In rapeseed, it has been reported that plant height, number of branches and number of pods per plant as well as seed yield decreased significantly under water stress conditions (Bitarafan and Shirani-Rad 2012, Moosavia et al. 2014, Nazemi and Alhani 2014, Rad et al. 2014a, Rad et al. 2014b, Zakerin et al. 2014).

P fertilization significantly increased plant height, number of branches and number of pods per plant as well as seed yield (kg fed^{-1}) when compared with unfertilized treatments (Table 3). The maximum values of these parameters were observed from plants fertilized with 200 kg fed^{-1}. An increase in growth and yield was probably due to increased efficiency of metabolism by P supply and formation of structural carbohydrates (Ghosh and Gulati

2001). Phosphorus uptake leads to increased net CO_2 fixations with increased rate of photosynthesis and thereby more photosynthates to develop more pods per plants (Badsra and Chaudhary 2001). Phosphorus leads to synthesis and deposition of seeds reserves (starch, lipid, protein and phytin), which ultimately produce higher seeds per pod (Jat et al. 2000).

Wahid (2008) found that increased P levels significantly increased plant height, number of branches and number of pods per plant as well as seed yield in rapeseed. Malik et al. (2002) reported that P application significantly increased numbers of branches, pods and seed yield of *Brassica napus*. Also, McKenzie et al. (2003) found that high rates of P increased seed yield significantly due to the increased P levels, which is possibly due to more availability and P uptake at high P levels. Phosphorus is essential for increasing yield, as part of the production of ATP and increased grain yields are achieved only with P supply in quantities compatible with crop demands; thus excessive phosphates applications are required, since no other nutrient limits production. This explains the high grain yields from higher P_2O_5 rates applied (Rogério et al. 2013). It becomes evident that P fertilization is responsible for higher yield gains, as is confirmed by several studies performed with rapeseed and environmental conditions (Cheema et al. 2001, Liu et al. 2009, Wahid et al. 2009, Yin et al. 2010, Madani et al. 2011, Motlagh et al. 2012, Vassilina et al. 2012, Nejad 2013).

The interaction between irrigation treatments and P application resulted in a significant increment of plant height, number of branches and number of pods per plant as well as seed yields (Table 4). The maximum values were recorded from the combination of irrigation at 1250 m^3 fed^{-1} and fertilization with 200 Kg fed^{-1} calcium super phosphate. While, the minimum values were resulted from the treatment of irrigation at 500 m^3 fed^{-1} and unfertilized treatment. Improved P nutrition appears to stimulate processes which reduce plant water stress. Physiological studies under well-watered conditions showed that suboptimal P levels reduce root hydrautic conductivity, decreasing the plant's water potential. Furthermore, P-fertilized plants had lower stomatal conductance and net photosynthesis rate (Dosskey et al. 1993). These findings are in agreement with those of Motlagh et al. (2012) and Pirzad and Motlagh (2013).

Table 2. Effect of water regimes on morphological traits, seed yield and oil content of rapeseed (combined data of 2010/2011-2011/2012 seasons)*.

Water regime (m^3 fed^{-1})	Plant height (cm)	Branches (No/plant)	Pods (No/plant)	Seed yield (kg fed^{-1})	Oil (%)	Oil yield (kg fed^{-1})
500	75.36	2.33	71.67	471.6	33.8	159.6
750	105.4	3.78	140.5	762.9	33.9	259.3
1000	106.4	4.44	157.0	892.5	34.9	312.5
1250	113.0	5.33	194.2	1048	34.5	362.3
LSD at 5%	1.77	0.59	16.17	36.7	0.2	9.7

*Mean from all plants

SEED OIL CONTENT AND FATTY ACID PROFILE

Oil yield percentage (%) significantly responded to irrigated treatments of both seasons (Table 2). Increasing applied water quantities significantly increased oil percentages, which reached their highest mean values in plants irrigated at 1000 m^3 fed^{-1}, followed by those of 1250 m^3 fed^{-1}, 750 m^3 fed^{-1}, and 500 m^3 fed^{-1}. Oil yields increased significantly with increasing levels of irrigation from 500 m^3 fed^{-1} to 1250 m^3 fed^{-1}. The results indicated that under water-stress conditions, the decrement of oil yield with an increase in moisture stress was largely due to the adverse effect of moisture stress on crop seeds (Singh et al. 1997). This conclusion agrees with Jensen et al. (1996), Hashem et al. (1998) and Rad et al. (2014), who reported decreasing in the seed oil yield of rapeseed upon increasing severity of drought stress. The important reason for oil yield decrease is reducing seed yield under condition of drought stress. Wright et al. (1995), Hashem et al. (1998) and Moaveni et al. (2010b) reported that drought stress led to decrease in seed yield and finally decrease in oil yield. Shirani Rad and Zandi (2012) showed that applying water deficit stress reduced oil yield in comparison with the normal irrigation treatment, which was in conformity with the results of Naeemi et al. (2007). The results obtained showed that seed oil yield in comparison with oil content was more affected by the shortage of soil moisture, which had been caused by a much more control of the oil content over genetic factors and oil yield being more affected by the seed yield variations relative to oil content.

The same significant response was observed with application of P to plants of both seasons (Table 3). Increasing P significantly increased oil percentage and oil yield. These results are in accordance with others who showed that P deficiency affected the content and quality of rapeseed oil. Malik et al. (2002) reported that P significantly increased oil yield of *Brassica napus*, for which reason P deficiency may become a production constraint in the future. As far as oil content of rapeseed at high levels of P is concerned, our results are in agreement with previous studies (Lickfett et al. 1999, Motlagh et al. 2012, Vassilina et al. 2012, Nejad 2013).

Table 3. Effect of P fertilization on morphological traits, seed yield and oil content of rapeseed (combined data of 2010/2011-2011/2012 seasons)*.

P (kg fed^{-1})	Plant height (cm)	Branches (No/plant)	Pods (No/plant)	Seed yield (kg fed^{-1})	Oil (%)	Oil yield (kg fed^{-1})
0	91.35	3.08	115.3	649.5	34.0	221.5
100	102.5	4.00	144.7	804.3	34.4	276.4
200	106.3	4.83	162.5	927.9	34.6	322.3
LSD at 5%	1.87	0.62	11.36	19.0	0.1	6.1

*Mean from all plants

Table 4. Impact of the interaction between water regime and P treatments on morphological characteristics, seed yield and oil content of rapeseed (combined data of 2010/2011-2011/2012 seasons)*.

Water regime (m^3 fed^{-1})	P (kg fed^{-1})	Plant height (cm)	Branches (No/plant)	Pods (No/plant)	Seed yield (kg fed^{-1})	Oil (%)	Oil yield (kg fed^{-1})
500	0	64.85	1.67	52.33	359.5	33.4	120.2
	100	76.98	2.33	68.00	475.1	33.8	160.9
	200	84.24	3.00	94.67	580.3	34.0	197.7
750	0	98.56	3.00	110.33	608.8	33.8	206.2
	100	108.52	4.33	147.33	822.8	34.0	279.7
	200	109.34	4.00	164.00	857.3	34.0	291.8
1000	0	97.22	3.67	135.00	778.7	34.5	268.9
	100	109.22	4.00	162.33	905.6	34.6	314.1
	200	112.47	5.67	173.67	993.1	35.7	354.7
1250	0	104.78	4.00	163.67	851.1	34.1	290.9
	100	114.94	5.33	201.33	1013.6	34.6	351.1
	200	119.46	6.67	217.67	1280.8	34.7	445.1
LSD at 5%		3.74	1.24	22.72	38.1	0.3	12.2

*Mean from all plants

The rapeseed oil content varied from 33.4 to 52.6% (Li et al. 2014). The interaction between water irrigation quantities and P fertilization significantly affected oil percentages (Table 4). The highest oil percentage (35.7%) occurred in plants irrigated with 1000 m^3 fed^{-1}

which received P at 200 kg calcium super phosphate fed^{-1}. and the highest oil yield (445.1 kg fed^{-1}) obtained from plants irrigated with 1250 m^3 fed^{-1} which received P at 200 kg calcium super phosphate fed^{-1}. The lowest percentage (33.4%) and yield (120.2 kg fed^{-1}) of oil production was from plants receiving 500 m^3 fed^{-1} without P fertilization.

The treatments did not affect fatty acids composition from rapeseed oil (Tables 5-7). Varying conditions of drought and P fertilization did not differ in the percentages of fatty acids. The main fraction of fatty acids in *B. napus* samples was MUFA followed by PUFA. Saturated fatty acids (SFA) in *B. napus* oils were detected in low levels. The predominant fatty acids were oleic acid (C18:1) followed by linoleic acid (C18:2) and linolenic acid (C 18:3). In general, fatty acid compositions are within the ranges for *B. napus* total lipids specified in the Codex Alimentarius (2005). *B. napus* samples in our study did not contain *trans*-fatty acids. Zanetti et al. (2009) reported that fatty acid composition varied among varieties and changed upon environmental conditions. Recent studies mentioned that the amounts of oleic, linoleic and linolenic acids in different cultivars of rapeseed ranged as follows: 10.7-72.0%, 12.0-29.0%, and 2.4-18.3%, respectively (Zanetti et al. 2009, Szydlowska-Czerniak et al. 2010). The oil from 00-quality oilseed rape contains 60% MUFA (C18:1), 30% PUFA [20% linoleic acid (C18:2) and 10% linolenic acid (C18:3)], 2.0% eicosenoic acid (C20:1), 7.0% SFA [mainly palmitic (C16:0) and stearic acids (C18:0)] and 1.0% other acids (Mollers 2002).

A low erucic acid content is necessary for human health while a high content is necessary for industrial use (Metzger and Bornscheuer 2006, Wang et al. 2010, Li et al. 2014). Erucic acid-free oilseed rape oils are ideal for human nutrition and for use as biofuel. A typical rapeseed oil with a 2:1 ratio of MUFA to PUFA is very good according to dietary recommendations. The nutritional quality of rapeseed oil can be improved through development of cultivars combining high oleic acid and low linolenic acid (Spasibionek 2006, Wittkop et al. 2009, Federico and Federico 2011).

Different irrigation treatments affected the percentages of SFA, MUFA and PUFA (Table 5). Irrigation treatment by 750 m^3 fed^{-1} gave the highest percentage of SFA and MUFA but the lowest percentage of PUFA. The irrigation treatment of 500 m^3 fed^{-1} gave the highest percentage of PUFA and also the lowest percentage of both SFA and MUFA.

Table 5. Effect of water regimes on the fatty acids profile of rapeseed oil (combined data of 2010/2011-2011/2012 seasons).

Water regime (m^3 fed^{-1})	SFA%					Unsaturated Fatty Acids				
						MUFA%			PUFA%	
	Palmitic acid	Stearic acid	Arachidic acid	Behenic acid	Lignoceric acid	Palmitoleic acid	Oleic acid	Gondoic acid	Linoleic acid	α-Linolenic acid
	C 16:0	C 18:0	C 20:0	C 22:0	C 24:0	C 16:1	C 18:1	C 20:1	C 18:2	C 18:3
500	3.73	1.79	0.71	0.32	0.22	0.28	58.72	1.22	21.72	11.29
750	3.76	1.82	0.65	0.33	0.23	0.31	58.75	1.26	21.72	11.18
1000	3.74	1.80	0.69	0.32	0.21	0.31	58.69	1.26	21.74	11.24
1250	3.76	1.79	0.66	0.32	0.21	0.30	58.71	1.26	21.73	11.26
LSD at 5%	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

Irrigation of 750 m^3 fed^{-1} led to the highest values of palmitic, stearic, behenic, lignoceric, palmitoleic, oleic, and gondoic acids. The highest percentages of arachidic and α-linolenic acids were under irrigation of 500 m^3 fed^{-1}. Plants irrigated with 1000 m^3 fed^{-1} gave the highest percentage of linoleic acid. Also, no significant differences were observed within the fatty acids profile, but increased water deficit led to decreased palmetic, stearic, palmitoleic, and linoleic acids and increased lignoceric acid. Similar results have been observed by Zarei et al. (2010), who found that irrigation intervals were not significant for the oleic acid, linoleic acid and linolenic acid, but significant for the palmitic acid. Decreasing irrigation intervals had a significantly higher palmitic acid than increasing irrigation intervals.

Applying P at 100 (Kg fed^{-1}) gave the highest percentages of SFA and MUFA and the lowest percentage of PUFA while control plants gave lower percentages of SFA and MUFA and higher levels of PUFA (Table 6). Applying P at 200 (Kg fed^{-1}) gave the highest percentage of arachidic acid whereas 100 (Kg fed^{-1}) P fertilizer gave the highest percentages of lignoceric, oleic and α-linolenic acids. Higher percentages of palmitic, stearic, behenic, palmitoleic, gondoic and linoleic acids were obtained for control plants.

P fertilizer led to an increase in α-linolenic, lignoceric and oleic acids levels, at the same time reducing the levels of linoleic, gondoic, palmitoleic acids (Table 6). Bhardwag and Hamama (2009) observed that an increased P rate increased the content of C18:3 fatty acid, thus higher rates of P fertilizer may lead to obtaining comparatively healthier oil since higher rate of C18:3 are considered desirable for human diet. Erucic acid, an undesirable and unessential fatty acid, dramatically decreased after application of P. Moreover, P fertilizers had no effects on the linolenic acid content (Liu et al. 2009).

Table 6. Effect of P treatments on the fatty acids profile of rapeseed oil (combined data of 2010/2011-2011/2012 seasons).

P fertilizer (Kg fed^{-1})	SFA%					Unsaturated Fatty Acids				
						MUFA%			PUFA%	
	Palmitic acid	Stearic acid	Arachidic acid	Behenic acid	Lignoceric acid	Palmitoleic acid	Oleic acid	Gondoic acid	Linoleic acid	α-Linolenic acid
	C 16:0	C 18:0	C 20:0	C 22:0	C 24:0	C 16:1	C 18:1	C 20:1	C 18:2	C 18:3
0	3.75	1.81	0.68	0.32	0.21	0.31	58.69	1.26	21.74	11.23
100	3.75	1.79	0.67	0.32	0.22	0.28	58.75	1.25	21.72	11.25
200	3.74	1.81	0.69	0.32	0.22	0.30	58.73	1.23	21.72	11.24
LSD at 5%	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

The highest percentages of SFA were recorded for plants irrigated with 500, 1000 (m^3 fed^{-1}) and /or 1250 (m^3 fed^{-1}) +200 (Kg fed^{-1}) P as well as plants irrigated with 750 (m^3 fed^{-1}) + 100 (Kg fed^{-1}) P fertilizer. The highest value of SFA was obtained by plants irrigated with 750 (m^3 fed^{-1}) + 100 (Kg fed^{-1}) P fertilizer and/or irrigated with 500 (m^3 fed^{-1}) +200 (Kg fed^{-1}) P fertilizer. In the case of MUFA, treatments of 500 and 750 (m^3 fed^{-1}) +200 (Kg/fed) P fertilizer and also 1000 or 1250 (m^3 fed^{-1}) + 100 (Kg fed^{-1}) P fertilizer gave the highest percentages. The best results were found when 200 (Kg fed^{-1}) P fertilizer + irrigation rate at 750(m^3 fed^{-1}) applied. As for the PUFA, irrigation levels at 1000 or 1250 (m^3 fed^{-1}) + 200 (Kg fed^{-1}) P fertilizer and also 750 (m^3 fed^{-1}) without P fertilizer as well as 500 (m^3 fed^{-1}) + 100 (Kg fed^{-1}) P fertilizer gave the highest percentages.

Irrigation at 750 (m^3 fed^{-1}) gave the highest percentages of palmitic and linoleic acids whereas 750 + 100 (Kg fed^{-1}) P gave the highest percentages of oleic acid (Table 7). Moreover, the same irrigation rate of 750 (m^3 fed^{-1}) + 200 (Kg fed^{-1}) P fertilizer gave the highest percentage of behenic acid. Fertilized plants with 200 (Kg fed^{-1}) P fertilizer + irrigated at 500 (m^3 fed^{-1}) gave the highest percentages of stearic acid, but 500 (m^3 fed^{-1}) + 100 (Kg fed^{-1}) P fertilizer gave the highest percentage of α-linolenic acid while plants irrigated with 500 (m^3 fed^{-1}) without P gave the highest percentage of arachidic acid. The highest percentage of palmitoleic acid was obtained with irrigation at 1000 (m^3 fed^{-1}) without P.

Table 7. Effect of the interaction between water regime and P treatments on the fatty acids profile of rapeseed oil (combined data of 2010/2011-2011/2012 seasons).

Water regimes (m^3 fed^{-1})	P fertilizer (kg fed^{-1})	SFA%					Unsaturated Fatty Acids				
							MUFA%			PUFA%	
		Palmitic acid	Stearic acid	Arachidic acid	Behenic acid	Lignoceric acid	Palmitoleic acid	Oleic acid	Gondoic acid	Linoleic acid	α-Linolenic acid
		C 16:0	C 18:0	C 20:0	C 22:0	C24:0	C 16:1	C 18:1	C 20:1	C 18:2	C 18:3
500	0	3.74	1.77	0.72	0.32	0.21	0.28	58.67	1.25	21.73	11.32
	100	3.73	1.76	0.71	0.32	0.20	0.26	58.74	1.22	21.73	11.34
	200	3.73	1.84	0.70	0.32	0.23	0.31	58.77	1.20	21.69	11.21
750	0	3.77	1.81	0.65	0.33	0.22	0.32	58.70	1.28	21.75	11.18
	100	3.75	1.82	0.66	0.32	0.24	0.30	58.79	1.24	21.69	11.21
	200	3.75	1.82	0.64	0.34	0.23	0.32	58.76	1.27	21.73	11.15
1000	0	3.73	1.83	0.72	0.33	0.21	0.35	58.63	1.28	21.74	11.19
	100	3.77	1.80	0.64	0.32	0.21	0.30	58.77	1.25	21.75	11.20
	200	3.74	1.77	0.72	0.32	0.21	0.28	58.67	1.25	21.73	11.32
1250	0	3.77	1.81	0.62	0.32	0.20	0.31	58.72	1.25	21.73	11.26
	100	3.77	1.77	0.67	0.32	0.22	0.29	58.69	1.31	21.73	11.25
	200	3.74	1.80	0.70	0.31	0.21	0.29	58.73	1.21	21.74	11.27
LSD at 5% level		N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

CONCLUSIONS

In conclusion, water regime and P fertilization significantly affected the compositions and quality of *B. napus* seeds. The results of our investigation showed that morphological characteristics, seed yield and seed oil recovery of rapeseed were significantly decreased by water stress. In addition, studied parameters increased with the increase in the P fertilization dose. The best levels of morphological characteristics, seed yield and seed oil recovery were obtained when rapeseed plants were irrigated with 1250 m^3 fed^{-1} combined with fertilization of P (200 Kg fed^{-1}) and calcium super phosphate (15.5%). In general, the treatments did not affect fatty acid profile. In future research, better understanding of interactions between water regime and P fertilization under field conditions is crucial.

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