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RESEARCH ARTICLE — OPEN ACCESS

Effects of nitrogen rates on yield, yield components, and other related attributes of different rapeseed (*Brassica napus* L.) varieties

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Abstract – Rapeseed is one of the most important oilseed crops in the world and, in Morocco, it may contribute to the improvement of food security in edible oils through developing performant cultivars and optimizing the crops management including nitrogen fertilization. The objective of this study was to evaluate the response of different Moroccan varieties to nitrogen application. Field trials were carried out at the experimental station of National School of Agriculture in Meknes, during two cropping seasons (2017–2018 and 2018–2019). Five varieties ("Narjisse", "Moufida", "Alia", "Adila", and "Lila") were combined to different nitrogen rates (0, 30, 60, and 90 kg N ha^{-1}). The experimental design adopted is a split split-plot with three replications, where nitrogen treatment was affected to main plot, variety to subplot, and year to sub-subplot. Results showed that dry matter, harvest index, oil content, seed yield per plant and yield components were significantly affected by nitrogen rates, with an upward trend in seed yield as the nitrogen rates increased. On average, seed yield increased by 50.33% for application of 90 kg N ha^{-1} compared to the control (without N fertilization). However, oil content declined from 41.08% to 37.81% with the increase of nitrogen level from 0 to 90 kg N ha^{-1}. Additionally, for the other traits studied, the highest mean values were observed for 90 kg N ha^{-1}, except harvest index which exhibited the greatest value for 60 kg N ha^{-1}. Variation among the varieties was significantly large for all traits studied with a superiority of the variety "Alia" for seed yield per plant (9.82 g plant^{-1}), number of pods per plant (151), and number of seeds per pod (24.05).

Keywords: rapeseed / nitrogen fertilization / seed yield components / dry matter / oil content

Résumé – Effet de la dose d'azote sur le rendement, ses composantes et d'autres caractères associés de différentes variétés de colza. Le colza est l'une des cultures oléagineuses les plus importantes dans le monde. À travers le développement de cultivars performants et une bonne gestion de la culture, y compris la fertilisation azotée, le colza pourrait contribuer à l'amélioration de la sécurité alimentaire en matière d'huile végétale au Maroc. Pour l'évaluation de la réponse de cinq variétés marocaines de colza (« Narjisse », « Moufida », « Alia », « Adila » et « Lila ») à la dose d'azote appliquée (0, 30, 60 et 90 kg N ha^{-1}), deux essais au champ ont été installés sur la parcelle d'expérimentation de l'École nationale d'agriculture de Meknès, durant les campagnes agricoles (2017–2018 et 2018–2019). Le dispositif expérimental utilisé est un *split split-plot*, avec trois répétitions, où le traitement azoté est affecté à la grande parcelle et la variété est assignée à la petite parcelle. Les résultats ont montré que l'effet du traitement azoté a été hautement significatif sur tous les paramètres étudiés. Le rendement en graines a augmenté avec

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l'augmentation de la dose d'azote appliquée, avec une augmentation de 50,33 % de 0 à 90 kg N ha^{-1}. Également, pour les autres paramètres étudiés, les valeurs les plus élevées ont été observées avec 90 kg N ha^{-1}, à l'exception de l'indice de récolte qui a donné la valeur la plus élevée avec 60 kg N ha^{-1}. Également, l'effet de la variété a été significatif sur tous les paramètres étudiés, avec une supériorité de la variété « Alia » pour le rendement en graines par plante (6,82 g plante^{-1}), le nombre de siliques par plante (151) et le nombre de graines par silique (24,05).

Mots clés : colza / fertilisation azotée / rendement en graines / matière sèche / teneur en huile

Highlights

- Response of five rapeseed varieties (V) to different nitrogen (N) rates was investigated under field conditions in Morocco. N and V induce a significative effects with no interaction V × N.
- N rate of 90 kg N ha^{-1} was the best regardless of V studied. For all N rates combined, the varieties "Alia" and "Moufida" give the best seed and oil yield.

1 Introduction

Rapeseed (*Brassica napus* L.) is one of the most important oilseed crops in the world. It is mainly cultivated for its seeds, which are rich in oil (on average 43% of the total composition) but also in protein, which achieve an average of 19% of the total composition (Poisson *et al.*, 2019). Rapeseed oil is the third vegetable oil consumed in the world after soybean and palm oil, and contribute with approximately 13% of the global oil supply (Raman *et al.*, 2019). This crop covers more than 34.03 Mha all around the world, ensuring a production of about 70.51 Mt (FAOSTAT, 2021).

In Morocco, oilseed crops (sunflower and rapeseed) are cultivated on an area of 35,511 ha, with a total production of 38,549 tons (Anonymous, 2021). Rapeseed crop occupies more than 13,000 ha. The national production is thus too low showing a remarkable deficit in edible oils in Morocco, which remains heavily dependent on imports to supply the national market (Nabloussi, 2015). However, oilseed crops, including rapeseed, have high yield potential allowing it to contribute to increase the level of edible oil food security.

Nitrogen is one of the most important growth factors improving biomass, and seed yield of rapeseed (Brennan and Bolland, 2007). In fact, this crop requires high nitrogen (Ahmadi and Bahrani, 2009; Holmes, 1980; Riar *et al.*, 2020). About 25% more than wheat (Hocking *et al.*, 1997). Although rapeseed has good nitrogen uptake efficiency, only 50% of the absorbed nitrogen originating from fertilizers is mobilized to the harvested seeds (Schjoerring *et al.*, 1995). Unabsorbed nitrogen is not only a considerable economic loss, but also a serious damage to the surrounding ecosystems (Galloway *et al.*, 2013). Competitive production depends primarily on adequate nitrogen application. Choosing the correct doses, source, and timing of nitrogen fertilizer application is therefore an important aspect of successful rapeseed production. This choice depends on several factors such as climatic conditions, availability of nitrogen in the soil profile, and especially the genetic characteristics of the varieties (Zhang *et al.*, 2010).

Several studies have shown the effect of nitrogen supply on yield and yield components of rapeseed (Ahmad *et al.*, 2011; Al-Solaimani *et al.*, 2015; Hocking *et al.*, 1997; Naderifar and Daneshian, 2012; Öztürk, 2010; Zuo *et al.*, 2019). In general, appropriate application of nitrogen can increase rapeseed yield by improving vegetative growth and reproductive development, as well as increasing seed yield (Ma and Herath, 2016; Lin *et al.*, 2020). However, increasing nitrogen fertilization rates leads to a decrease in seed oil content (Jackson *et al.*, 1993; Jackson, 2000; Hocking and Stapper, 2001).

Genotype variation in rapeseed for dry matter, yield components, seed yield and oil content in response to nitrogen application has been reported by many authors (Asare and Scarisbrick, 1995; Özer, 2003; Balint and Rengel, 2008; Stahl *et al.*, 2019). Seed yield differed significantly among rapeseed genotypes especially under limiting nitrogen supply, with marked interaction with nitrogen (Schulte auf'm Erley *et al.*, 2011). In this sense, Rathke *et al.* (2006) reported that the response of rapeseed cultivars to increasing nitrogen application varied significantly and was also affected by many environmental factors such as weather, soil type, soil moisture, and residual fertilization, especially nitrogen (Fig. 1).

Between 2008 and 2017, five Moroccan rapeseed varieties were released and registered by the National Institute of Agricultural Research (INRA). They are all productive and adapted to local environmental conditions, with high seed yield and oil content. However, no information is available about their efficiency and response to nitrogen application. Therefore, the present study aims to assess and characterize these varieties' response to different nitrogen rates and to identify the most efficient ones.

2 Materials and methods

2.1 Plant material, nitrogen treatments and field experiment

Five rapeseed varieties developed by INRA, namely "Narjisse", "Moufida", "Alia", "Adila", and "Lila" (the first three varieties are lines, while the other two are synthetic varieties), were tested under four nitrogen treatments: N_0 (without nitrogen application), N_{30} (30 kg N ha^{-1} applied at sowing), N_{60} (split as 30 kg N ha^{-1} at sowing and 30 kg N ha^{-1} at rosette stage), and N_{90} (split as 30 kg N ha^{-1} at sowing, 30 kg N ha^{-1} at rosette stage and 30 kg N ha^{-1} at flowering). Treatments were applied manually by the same person.

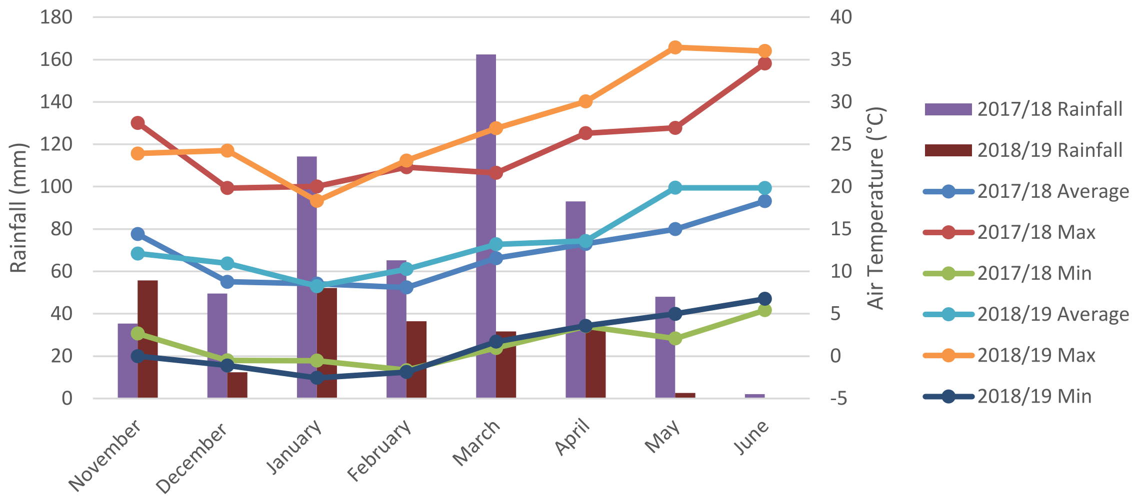

Fig. 1. Total monthly precipitation (bars) and air temperatures (lines) recorded in the experimental station during two cropping seasons (2017/2018 and 2018/2019).

The nitrogen fertilizer used was ammonium nitrate with 33.5% nitrogen.

The field experiment was conducted during two consecutive cropping seasons, 2017/2018 and 2018/2019, at the Research Farm of National School of Agriculture (ENA) in Meknes, Morocco (33°84' N, 5°47' W). The soil is a clay loam soil, belonging to the class of calcimagnesic soils, the subclass of carbonate, and the group of brown limestone. Before sowing, soil samples were taken from research field at a depth of 0–30 cm for analysis in both years and the results are shown in Table 1. The five rapeseed varieties were combined with the four nitrogen levels, according to a split split-plot experimental design with three replications. Nitrogen treatment was affected to main plots, variety treatment to subplot, and year to sub-subplot. At each replication, there were four plots having a size of 9 m × 5 m, each with five subplots (varieties). Each variety is represented by three rows of 5 m long and 0.60 m apart. Sowing depth was 2–3 cm and planting density was 30 plants per meter square.

2.2 Plant samples and measurements

At maturity, five individual plants per variety and per nitrogen treatment, from the central row in each subplot, were randomly taken for measurements and data collection. The height of the plant was the length of the main stem. Number of seeds per pod was estimated by counting the seeds of a sample of five pods per plant. Number of primary branches per plant was numbered as the branches of the main stem, while number of secondary branches was calculated as the sum of the branches developed from the primary branches. Number of pods per plant was determined for each sampled plant and 1000-seeds weight was determined using a precision balance. Regarding dry matter and seed yield per plant, the five sampled plants were sun-dried and weighted to determine the dry matter per plant. After that, each plant were threshed separately, the yield of clean seed for each plant was weighed to estimate the seed yield per plant. Harvest index was calculated as the ratio of seed yield per plant to biomass per plant. Finally, seed oil content was rapidly determined in 9% moisture seeds by Near Infra-Red Spectroscopy (NIRS) technique, using MINIFRA Smart.

Table 1. Soil characteristics before sowing for 2017/2018 and 2018/2019 cropping seasons.

Characteristic	Cropping season	
	2017–2018	2018–2019
Organic matter (%)	1.5	1.63
P_2O_5 (Olsen) (ppm)	13.9	19.2
K_2O (ppm)	26.8	35.3
Total nitrogen (%)	2.79	3.22
pH	8.78	8.65
Electric conductivity in Ms	0.29	0.3

2.3 Data analysis

Data collected from both years were subjected to analysis of variance and analysis of correlation, using the general linear model (GLM) and correlation procedures of the software package SAS for Windows (version 9.1.3). In this study, all the factors investigated were considered as fixed factor. In case of significant differences among varieties and nitrogen treatments, Duncan's new multiple range test was applied to compare the means (5% probability threshold).

3 Results

3.1 Weather conditions

The weather conditions of both cropping seasons are shown in Figure 2. There was considerable variation in rainfall distribution and amounts between the two seasons. During 2017/2018 cropping season, rainfall was relatively high (569.8 mm) and well distributed throughout the crop cycle from sowing to harvest. Whereas, during 2018/2019 cropping season, rainfall was low (224.2 mm) and poorly distributed.

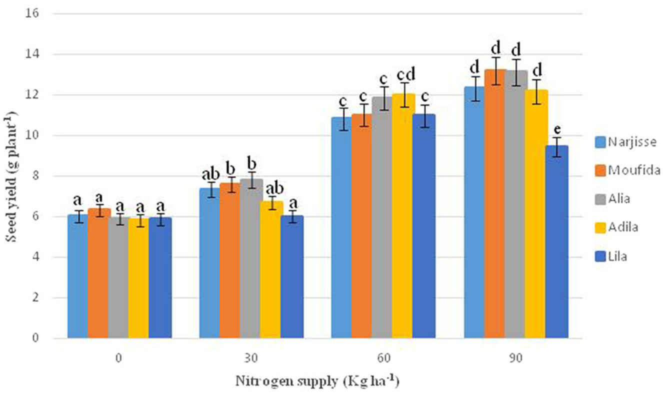

Fig. 2. Seed yield of five rapeseed varieties conducted under different nitrogen rate applied.

Precipitations of the first season were, particularly, low at the beginning of the crop cycle, which caused water stress during the early stages of rapeseed growth and development. To overcome this water deficit at those critical phases (seedling), a supplemental irrigation of 50 mm was applied at the end of December 2018. The air temperature had almost the same trend in both seasons with slightly higher temperatures in 2018/2019 than in 2017/2018. Monthly temperature averages ranged from 8.09 and 8.25 °C, recorded in February and January for the 2017/2018 and 2018/2019 seasons respectively, to 18.28 and 19.85°C, registered in June for the 2017/2018 and 2018/2019 seasons respectively. In both seasons, December, January and February were the coldest months, while May and June were the warmest.

3.2 Seed yield

Statistical analysis revealed highly significant effect of year and nitrogen rate on seed yield per plant, also the differences among varieties were statistically significant for this trait (Tab. 2). No significant effect of the interaction between nitrogen and genotype and between genotype and year on seed yield was noticed. Seed yield of all the five varieties was improved considerably by increasing nitrogen application from 0 to 90 kg N ha^{-1}. Indeed, regardless of the studied varieties, the highest yields were obtained for treatments 60 and 90 kg N ha^{-1}, with 11.33 and 12.04 g plant^{-1}, respectively, compared to 5.98 and 7.08 g plant^{-1}, respectively, registered for 0 and 30 kg N ha^{-1} treatments. However, nitrogen application of 60 and 90 kg N ha^{-1} gave seed yields statistically comparable (Tab. 2). Figure 2 illustrates the responses of cultivars to different N rates for seed yield. Regarding the variety effect, and for all N rates combined, seed yield varied from 8.20 g plant^{-1} for “Lila” which was significantly smallest than the others varieties. To 9.82 g plant^{-1} for “Alia” which was not significantly different from the remaining others varieties “Narjisse”, “Moufida”, and “Adila” which having yielded 9.29, 9.70, and 9.31 g plant^{-1}, respectively.

3.3 Dry matter

Dry matter (DM) biomass of the five varieties rose with the increase of nitrogen dose from N_0 to N_3 except for “Lila” which showed a slight decrease in dry matter from N_2 to N_3 (Fig. 2). Dry matter was significantly influenced by the main effects of the variety, year, N rate, the interaction of these two latter, and the interaction of year and N rates (Tab. 2). The increase in DM from N_0 to N_3, for all varieties combined, was 63.4%. The highest DM was 41.56 g plant^{-1} obtained by applying 90 kg N ha^{-1} (the N_{30} treatment), while the lowest DM was 25.43 g plant^{-1} produced in control treatment (absence of any N fertilization). Also, DM production varied among varieties tested; the highest DM were 34.78, 34.12, and 34.03 g plant^{-1} accumulated by “Alia”, “Adila”, and “Narjisse”, respectively, while “Lila” showed the lowest DM of 31.47 g plant^{-1}. The significant effect of variety × nitrogen interaction revealed that the different varieties arranged and reacted differently to the different nitrogen levels. Also the interaction year × nitrogen was highly significant which mean that weather conditions were an important factor that affected the nitrogen effect.

3.4 Harvest index

The year, variety, nitrogen rate, and the interaction of these two latters had a significant effect on harvest index (HI) (Tab. 2). The treatments 60 and 90 kg N ha^{-1} gave the highest HI, with an average value of 28.95% and 28.43% respectively, whereas the lowest HI, 22.95%, was observed under N_0 treatment with no nitrogen fertilization. Regardless of nitrogen rates, HI ranged from 27.42%, observed in “Alia”, to 24.90%, recorded in “Lila” (Fig. 3).

3.5 Oil content

Results of analysis of variance indicated a highly significant effect of year, variety and nitrogen rate on oil content (Tab. 2). However, no significant effect of the interaction genotype × nitrogen was observed. Indeed, oil content decreased with the increase of nitrogen supply, which submits a negative relationship between oil content and nitrogen rate (Fig. 4). It decreased significantly from 41.08% for N_0 treatment to an average of 37.99 and 37.81% for 60 and 90 kg N ha^{-1} treatments respectively (Tab. 2). Also, seed oil content varied significantly among the varieties studied. In fact, this parameter ranged from 40.11 to 37.69% in “Lila” and “Narjisse”, respectively.

3.6 Plant height

Results of analysis of variance indicated that year, nitrogen application rate, variety, and the interaction of nitrogen by variety had a significant effect on plant height (Tab. 3). The highest plant height (125 cm) was recorded with the 90 kg N ha^{-1} treatment and was statistically equal to that recorded by the 60 kg N ha^{-1} treatment (123 cm). On the other hand, the lowest plant height (105 cm) was recorded in N_0 (without N application). The five varieties studied exhibited a distinct response to N rate for plant height, with “Lila” and “Adila” being the tallest, having an average height of about 121 cm and “Moufida” the shortest with a height of 112 cm (Tab. 3).

Table 2. Mean effect of year, variety, and nitrogen rate on dry matter, harvest index, oil content, and oil yield in rapeseed (averaged data over two years).

	Seed yield (g plant^{-1})	Dry matter (g plant^{-1})	Harvest index (%)	Oil content (%)
Variety (V)				
Narjisse	9.29^{a}	34.03^{a}	$26.35^{a,b}$	37.69^{c}
Moufida	9.70^{a}	$33.42^{a,b}$	$26.99^{a,b}$	$38.80^{b,c}$
Alia	9.82^{a}	34.78^{a}	27.42^{a}	39.85^{a}
Adila	9.31^{a}	34.12^{a}	$25.84^{b,c}$	$39.29^{b,a}$
Lila	8.20^{b}	31.47^{b}	24.90^{c}	40.11^{a}
Nitrogen rate kg ha^{-1} (N)				
0	5.98^{b}	25.43^{d}	22.95^{c}	41.08^{a}
30	7.08^{b}	27.67^{c}	24.19^{b}	39.72^{b}
60	11.33^{a}	38.05^{b}	28.95^{a}	37.99^{c}
90	12.04^{a}	41.56^{a}	28.43^{a}	37.81^{c}
Year	***	***	***	***
V	*	*	***	***
N	***	***	***	***
V × N	ns	*	***	ns
Y × N	***	***	***	*
Y × V	ns	ns	**	ns
Y × V × N	ns	*	**	ns

ns: not significant; *, **, and ***: significant at 0.05, 0.01, and 0.001 probability level, respectively. For each main effect, values within columns followed by the same letters are not significantly different according to Duncan's test

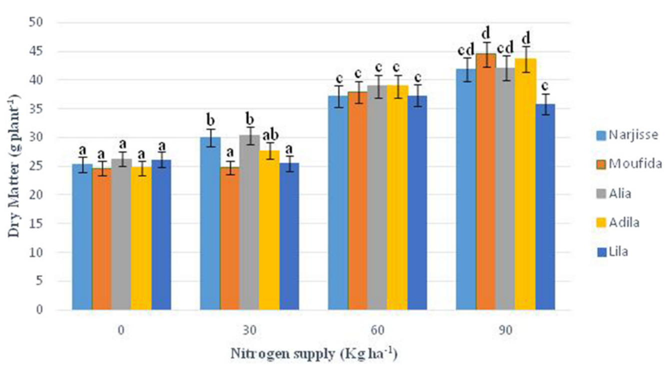

Fig. 3. Dry matter of five rapeseed varieties under different nitrogen rate applied.

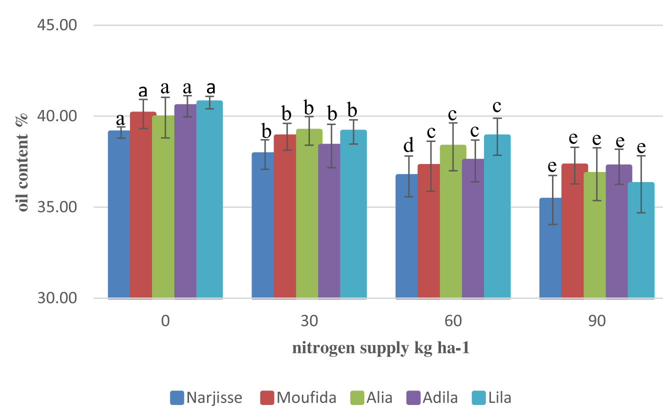

Fig. 4. Oil content of five rapeseed varieties according to nitrogen rate application (two-year average data).

3.7 Yield components

The number of primary branches (NPB) was highly and significantly influenced by variety and nitrogen rate. However, their interaction had no significant effect on it (Tab. 3). This parameter varied from 4.27 in the variety "Alia" to 4.86 in the variety "Adila". Regarding N fertilization, the highest NBP (5.12) was obtained for the highest N rate (90 kg N ha^{-1}) and the lowest NBP (4.03) for the lowest N rate (0 kg N ha^{-1}). Similarly, the number of secondary branches (NSB) was significantly affected by the year, nitrogen rate and the variety. The highest mean value (6.39), was observed with the 90 kg N ha^{-1}, while the lowest, 4.43, was recorded with the 30 kg N ha^{-1}. With regard to the investigated varieties, "Alia" exhibited the lowest branching, with an average NSB of 4.4, whereas "Narjisse" showed the highest branching, with an average NPB of 6.02. A significant effect of nitrogen rate and year on the number of pods per plant was revealed. Regardless of the varieties, this trait ranged from 112 pods, for N_0 treatment, to 180 pods, for 90 kg N ha^{-1} (Tab. 3). For all N treatments combined, number of pods per plant was varied from 139, in the variety "Lila", to 151, in the variety "Alia". For all N treatments combined, the number of pods per plant varied from 139 for the variety "Lila" to 151 for the variety "Alia". Results of analysis of variance showed no significant effect of nitrogen × variety interaction for seeds per pod. Varieties differed significantly in seeds per pod (Tab. 3). "Narjisse" and "Moufida" have similar seeds per pods with an average of 22.48 and 23.26 seeds pod^{-1}, which were the lowest, followed by "Lila" with 23.71 seeds pod^{-1}. The highest seeds pod^{-1} 23.78 and 24.05 were recorded by

Table 3. Mean effect of year, variety, and nitrogen rate on yield and yield components in rapeseed (averaged data over two years).

Source of variation	Plant height (cm)	Number of primary branches	Number of secondary branches	Pods plant^{-1}	Seeds pod^{-1}	1000-seed weight (g)
Variety (V)						
Narjisse	$115^{b,c}$	4.86^{a}	6.02^{a}	148^{a}	22.48^{b}	3.71^{a}
Moufida	112^{c}	4.4^{b}	5.23^{b}	149^{a}	23.26^{b}	3.54^{b}
Alia	116^{b}	4.27^{b}	4.4^{c}	151^{a}	24.05^{a}	3.42c
Adila	119^{a}	4.84^{a}	$5.73^{a,b}$	142^{a}	23.78^{a}	$3.52^{b,c}$
Lila	122^{a}	4.69^{a}	5.24^{b}	139^{a}	$23.71^{a,b}$	3.58^{b}
N treatment kg ha^{-1} (N)						
0	105^{b}	4.3^{b}	4.53^{b}	112^{b}	21.78^{b}	3.21^{d}
30	111^{b}	4.05^{b}	4.43^{b}	117^{b}	22.24^{b}	$3.46^{c,d}$
60	123^{a}	4.87^{a}	$5.74^{a,b}$	167^{a}	24.23^{a}	3.67^{b}
90	125^{a}	5.15^{a}	6.39^{a}	180^{a}	25.19^{a}	3.81^{a}
Year (Y)	***	***	***	***	***	***
V	***	***	***	ns	***	***
N	***	***	***	***	***	***
V × N	*	ns	ns	*	ns	ns
Y × N	***	*	***	***	**	***
Y × V	ns	***	***	*	**	ns
Y × V × N	ns	*	*	**	ns	ns

ns: not significant; *, **, and ***: significant at 0.05, 0.01, and 0.001 probability level, respectively. For each main effect, values within columns followed by the same letters are not significantly different.

"Adila" and "Alia" respectively. The nitrogen rate had a significant effect on the number of seeds per pod. Seeds pod^{-1} increase with increasing of nitrogen application rate. The highest seeds pod^{-1} were obtained for 60 and 90 kg N ha^{-1} with an average of 24.23 and 25.19 seeds pod^{-1} respectively, which were significantly greater than those obtained for N_0 and N_1 (21.78 and 22.24 seeds pod^{-1} respectively).

Finally, as shown in Table 3, year, variety and nitrogen application affected significantly the 1000-seed weight, whereas the influence of the interaction of nitrogen by variety was not significant. Nitrogen rate of 90 kg N ha^{-1} improved 1000-seed weight by about 0.6 g, raising from 3.21 g, in absence of nitrogen fertilization, to 3.81 g with application of 90 kg N ha^{-1}. Regarding the studied varieties, "Narjisse" exhibited the highest 1000-seed weight (3.71 g), while "Alia" showed the lowest one (3.42 g).

3.8 Relationships among seed yield per plant, dry matter, oil content, harvest index, and yield components

The matrix of correlation among the studied parameters is shown in Table 4. The results of correlation evidenced that seed yield per plant was positively and significantly associated with dry matter ($r = 0.949$), harvest index ($r = 0.640$), plant height ($r = 0.709$) and seed yield components, specifically number of branches per plant, number of pods per plant, and number of seeds per pod. Nevertheless no relationships were found between seed yield and seed oil content and 1000-seed weight. Seed oil content was positively associated with dry matter, branches number per plant, pod number per plant and 1000-seed weight. However, no significant correlations were revealed between this trait and seed yield, harvest index, plant height and seeds per pod (Tab. 4).

4 Discussion

Overall, the effect of growing season (year) was highly significant on all studied parameters. The significant effect of year on yield may be due to the differences of weather conditions of each growth season, particularly the rainfall and its distribution throughout the growing season. It was reported that weather conditions (rainfall, temperature) were major factors affecting yield in rapeseed and seasonal water distribution throughout the season was more critical for successful canola production than total water supply (Assefa *et al.*, 2018). The present study indicated also that seed yield was considerably improved by increasing the nitrogen level of the soil. This amelioration in seed yield is a result of an increase in the main yield components, especially number of pods per plant and number of seeds per pod. Various authors have reported that high rapeseed yields demand high N rates application to soil; 150 kg N ha^{-1} in United kingdom (Holmes, 1980), 180 kg N ha^{-1} in China (Li *et al.*, 2019), and 213 kg N ha^{-1} in Egypt (Ibrahim *et al.*, 1989). Furthermore, Ahmadi and Bahrani (2009) in Iran reported that the highest yield in rapeseed was obtained with a fertilization rate of 225 kg N ha^{-1}. This linear relationship between seed yield and N rate could be attributed to the higher number of pods per plant, and seeds per pod (Ghanbari-Malidarreh, 2010; Imran *et al.*, 2014), which supports our findings. Indeed, the relation between yield and the two yield components was yield = $-6.449 + 0.048 \times$ number of pods palnt^{-1} $+ 0.371 \times$ number of seed by pod with $R^2 = 0.871$.

Table 4. Correlation coefficients among the different studied traits of rapeseed.

Traits	Seed yield	Oil content	Dry matter	Harvest index	Plant height	Branches number	Pod number	Seeds per pod	1000-seeds weight
Seed yield	–	–	–	–	–	–	–	–	–
Oil content	0.128ns	–	–	–	–	–	–	–	–
Dry matter	0.949***	0.185*	–	–	–	–	–	–	–
Harvest index	0.640***	−0.078ns	0.407***	–	–	–	–	–	–
Plant height	0.709***	−0.021ns	0.706***	0.480***	–	–	–	–	–
Branches number	0.771***	0.245**	0.839***	0.326***	0.658***	–	–	–	–
Pod number	0.934***	0.216*	0.976***	0.421***	0.723***	0.852***	–	–	–
Seeds per pod	0.773***	0.101ns	0.765***	0.485***	0.671***	0.673***	0.730***	–	–
1000-seed weight	−0.005ns	−0.418***	−0.019ns	−0.040ns	0.038ns	−0.051ns	−0.036ns	−0.00047ns	–

ns: not significant; *, **, and ***: significant at 0.05, 0.01, and 0.001 probability level, respectively.

Our study showed a significant variation among rapeseed varieties in seed yield. the results obtained are in line with He and Yang (2017) who reported that seed yield per plant was significantly affected mainly by genotype and nitrogen rate, but not by their interaction. Many other authors found a significant effect of genotype on seed yield in rapeseed response to the nitrogen supply (Li *et al.*, 2019; Özer, 2003; Marjanović-Jeromela *et al.*, 2019; Svečnjak and Rengel, 2006; Zhang *et al.*, 2012). Regardless of the nitrogen rate applied, seed yield ranged from 8.20 to 9.82 g $plant^{-1}$, and these values are substantially higher than those reported by Svečnjak and Rengel (2006), which varied from 3.7 to 5.1 g $plant^{-1}$, even they used nitrogen dose much higher than ours. The differences recorded could be explained by the cultivars potential and the environmental conditions where those cultivars were grown.

The effect of N application level and variety on dry matter production in rapeseed has been largely studied. Generally, increasing nitrogen rate leads to an increase in dry matter accumulation of rapeseed. Similarly to seed yield, dry matter was significantly influenced by nitrogen rate and variety. This is in agreement with other previous studies (Balint *et al.*, 2008; He and Yang, 2017; Yau and Thurling, 1987). However, in other contexts, dry matter production could be increased only by raising the nitrogen rate without any significant effect of the rapeseed cultivar (Asare and Scarisbrick, 1995).

Regarding harvest index (HI), our results evidenced the significant effect of the variety, the nitrogen doses, and their interaction. Similar findings were reported by Yau and Thurling (1987). However, in other studies, HI was found to be considerably affected only by N fertilization, with no significant effect of variety or variety × nitrogen interaction (Baghdadi *et al.*, 2014; Schulte auf'm Erley *et al.*, 2011). By contrast, Svečnjak and Rengel (2006) reported that nitrogen rate did not impact significantly harvest index, which was mainly and significantly influenced by the rapeseed cultivars. In the present investigation, HI varied from 24.90% in the variety "Lila" to 27.42% in the variety "Alia" and from 22.95%, without N fertilization (N_0), to 28.43% under 90 N kg ha^{-1}. These values are much lower than those of Rafiqul *et al.* (2018) who found that HI rose from 36.22%, in absence of N fertilization, to 40.54% for application of 180 kg ha^{-1}. Besides of the impact of the nitrogen doses applied, HI was much dependent on environmental factors (Baghdadi *et al.*, 2014).

For plant height, there was a significant effect of the variety and the nitrogen application, which was in agreement with Özer (2003) and Ma *et al.* (2015). Increasing plant height through genetic approach (variety) or nitrogen application may be a good strategy to improve seed yield as there was a strong and positive correlation among both traits (0.71). Furthermore, plant height has also positively and strongly associated with branching and seed yield components as shown in Table 4. Nevertheless, higher cultivars should be resistant to lodging and grown under favorable environmental conditions, particularly characterized by the absence of drought or heat stresses.

As expected, our study showed positive effect of high nitrogen level on yield components, as well as branches number per plant, pods number per plant, seeds per pod, and seed weight. Also, previous works on rapeseed showed that high levels of applied nitrogen led to the improvement of yield components (Ahmad *et al.*, 2011; Bybordi, 2014; Kamkar *et al.*, 2011; Khan *et al.*, 2017; Ozer, 2003). The increase in some yield components, as a result of application of high nitrogen rate, may be due to the increase of leaf growth, which is considered as an important factor affecting pod and seed growth and development in rapeseed (Kamkar *et al.*, 2011). In concordance with our findings, Sana *et al.* (2002) and Kamkar *et al.* (2011) also showed a genotypic variation in yield components that may be attributed to the genetic background and the environmental conditions. Kamkar *et al.* (2011) reported that by elevating nitrogen rate from 0 to 270 kg N ha^{-1}, number of pod per plant grow up from 73 to 190, while number of seeds per pod increased from 20 to 25, which was in agreement with our findings even we used much lower nitrogen rates.

With regard to oil content, our results were in agreement with those of many previous studies having reported the significant impact of variety and nitrogen application on this parameter (Ahmad *et al.*, 2011; Balint and Rengel, 2008; Bouchet *et al.*, 2014; Poisson *et al.*, 2019; Sana *et al.*, 2002). The observed drop in seed oil content occurring with the increase of nitrogen doses, may be due to the dilution effect of increased seed yield with increased N fertilization and the inverse relationship of protein and oil content (Kutcher *et al.*, 2005). However, it was noticed that an improvement of oil yield as a result of increasing nitrogen rate, which can be due to the substantial amelioration of seed yield (Cheema *et al.*, 2001; Imran *et al.*, 2014). No significant effect of the interaction variety by nitrogen was observed by this study, which may be explained by the same ranking of the five varieties in their response to nitrogen levels.

The analysis of correlation among the traits studied revealed strong and positive associations between plant height, branch number, pods per plant, and seeds per pod. This may be explained by the fact that increment in plant height achieved to the increase in branch number and, consequently, to the increase in yield components. Our results were in good accordance with Marjanović-Jeromela *et al.* (2008). Furthermore, seed yield per plant was significantly and positively correlated with all yield components except 1000-seed weight. Similar results were reported by Cong *et al.* (2019) who stated that seed weight was an inherent trait that was mainly governed by the genotype and has showed less variability with fertilizer application. In addition, Diepenbrock (2000) reported that 1000-seed weight, being the last yield component to be accomplished during development, depended to a lesser extent on environmental conditions than other components. In our study, we observed a strong and positive relationship between seed yield and its components, number of pods per plant and number of seeds per pod. This was in perfect agreement with findings of Lu *et al.* (2011) who reported that pods per plant and seeds per pod were the most important yield components as they were the direct factors for seed yield formation. Finally, seed yield per plant was found to be strongly and positively associated with dry matter per plant ($r = 0.95$) and harvest index ($r = 0.64$). Similar results were reported by Zuo *et al.* (2019) and Ali *et al.* (2003) who also recorded positive relationship between seed yield per plant and harvest index, with a correlation coefficient of 0.57, slightly lower than ours. The association between oil content and seed yield per plant was positive but not significant with a low correlation coefficient of about 0.13. Other previous authors have registered a weak and non-significant or even no correlation between both traits (Tunçtürk and Çidot, 2007; Özer *et al.*, 1999).

5 Conclusion

The response of five Moroccan rapeseed varieties to different nitrogen rates was investigated for the first time. By increasing the level of the fertilization applied, there was a substantial improvement in seed, mainly due to a significant raise in dry matter, number of pods per plant and number of seeds per pod. Actually, the nitrogen rate of 90 kg N ha^{-1} was the best regardless of the varieties studied. Also, these varieties showed a positive response to the increase of nitrogen rate. However, no significant interaction between both factors. For all nitrogen rates combined, the varieties "Alia" and "Moufida" were found to be the best in terms of seed and oil yield. Additional studies, through different environments, on the same varieties and including higher nitrogen rates (120 and 150 kg N ha^{-1}) are needed to look for the optimal nitrogen application and identify the most efficient variety.

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