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Article

Impact of Late-Season Water Deficiency on Agronomic Traits of Rapeseed (*Brassica napus* L.)

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Abstract: Water scarcity often affects rapeseed cultivation in the late growth stages, especially in semi-arid regions. To assess strategies for mitigating this late-season water deficiency, adapted rapeseed varieties were cultivated during the 2021-2022 and 2022-2023 seasons in Bordj Bou Arreridj, Algeria. A randomized complete block design experiment with four replications was conducted over two seasons. The primary factor was irrigation, encompassing normal irrigation after 80 mm of evaporation from a Class A pan and withholding irrigation after the flowering stage. Both the individual and interactive effects of irrigation and variety on seed yield and oil yield were significant at the 1% level. Under normal irrigation, the Zitna variety exhibited the highest seed and oil yields. In contrast, under irrigation withheld after flowering, the Trapper variety demonstrated the highest seed and oil yields. Simple correlation analysis among the experimental traits highlighted a significant positive relationship between yield components and the harvest index.

Keywords: *Brassica napus* L.; irrigation; flowering stage; yield components; drought tolerance.

1. Introduction

Water deficiency is a major limiting factor for plant growth and production. In the face of ongoing climate change, augmenting rainfall during dry periods is impractical. Therefore, the most effective approach to combat drought is by utilizing plant varieties adapted to and tolerant of water scarcity [1].

Algeria's semi-arid regions typically receive rainfall in mid-March and late April, which partially satisfies the crop's water requirements during the stem elongation stage. Consequently, rapeseed cultivation in these areas can be expanded by conserving water, particularly during flowering, pod development, and seed filling stages that coincide with early irrigation of spring crops, and identifying varieties with acceptable economic yields under deficit irrigation conditions. Certain spring rapeseed varieties, tolerant to cold conditions and winter-hardy, are sown later than autumn varieties and harvested earlier in spring. This early maturation, coupled with the absence of late-season drought, positions them as potential candidates for semi-arid regions with cool temperate climates and limited irrigation. Studies have demonstrated that the average annual yield loss due to drought globally is 17% and can exceed 70% in some years [2].

Understanding genotype-by-environment interaction and yield stability across diverse environmental conditions are crucial for evaluating the response of different genotypes to environmental stresses [3]. Previous research indicated that irrigating after 50 mm of evaporation from a Class A pan resulted in the highest rapeseed seed yield in Bordj Bou Arreridj. Irrigation after 100 mm and 150 mm of evaporation led to significant yield reductions. The flowering and seed-filling stages are considered the most sensitive to water deficiency in rapeseed [4], leading to substantial yield reductions [5]. Irrigation methods can also influence water use efficiency and seed yield [6]. Heat and drought during flowering and seed filling can disrupt flowering, reduce seed set, lower oil content, and consequently decrease seed yield [7,8].

This study aims to evaluate drought tolerance in rapeseed varieties, identifying those compatible with late-season water deficiency conditions. The goal is to select varieties capable of optimal performance in late-season drought with minimal yield loss, paving the way for rapeseed cultivation expansion in cool temperate and semi-arid regions.

2. Materials and Methods

The study was conducted at a pilot farm in Bordj Bou Arreridj, Algeria (36° 09' 50'' N, 5° 22' 11'' E, 965 m above sea level). This location experiences a hot and dry climate with 150 to 180 dry days annually, characterized by dry, wet winters and hot, dry summers, classifying it as a semi-arid region. Based on a 30-year average, the average annual rainfall in the area is 243 mm (Table 1).

Table 1. Monthly precipitation rate (mm) in 2021-2022 and 2022-2023 cropping seasons at BBA.

Year Month	September	October	November	December	January	February	March	April	May	Total
2021-2022	1.8	26.7	5.6	49.3	75.2	3.1	42.4	11.4	2.5	218
2022-2023	0.8	21.2	12.1	44.8	77.5	19.7	39.1	18.9	1.9	236

Prior to the experiment, the soil was irrigated and plowed using a moldboard plow. A disc and a trowel were then employed to break down clods and level the field. Soil samples were collected at depths of 0-30 cm and 30-60 cm for analysis, informing fertilizer application based on recommendations. A portion of nitrogen fertilizer, along with the full amounts of phosphorus and potassium fertilizers, were applied. Additionally, 2.5 L/ha of Treflan herbicide was uniformly applied and incorporated into the soil using a light disc. The remaining nitrogen fertilizer was applied at the onset of stem elongation and the emergence of the first flower buds to enhance nitrogen use efficiency.

The experiment followed a split-plot design with four replications over two years (2021-2022 and 2022-2023 cropping seasons). Irrigation was the main plot factor, with two levels: normal irrigation (irrigation after 80 mm of evaporation from a Class A pan) and withholding irrigation after the flowering stage. The plant cultivar was the sub-plot factor, encompassing a wide range of varieties (Ebonite, Elite, Talent, Olpro, Sinatra, Sahara, Celsius, Zitna, Modena, Geromino, Opera, ARC-5, ARC2, ARG-91004, Milena, Dexter, SLM046, Zarfam, Okapi, Talaye, Licord, Herkules, Vectra, GKHelena, GKOlivia, GKGabriella, Orient, RN * 3304, NKBilbao, ORW201-3001, Trapper, RG4504, Dante, and Frederic).

Each experimental plot consisted of four 4-meter rows with a 30 cm spacing between rows. Plant spacing within a row was 4 cm, with two side rows designated as margins. Data collection for phenological stages and various plant characteristics, including pods per plant, seeds per pod, seed yield, oil content, oil yield, biological yield, and harvest index, was conducted on the two middle rows.

Pest management, particularly for aphids, was implemented using pesticides like Metasystox (1.5 L/ha), Ocatin (1 L/ha), or Diamicron (0.50 L/ha).

Simple analysis of variance and mean comparisons were performed for the measured traits at the end of each year. A combined analysis of variance was conducted after the second year.

To determine traits like pods per plant, 10 plants were randomly selected from each plot. For seeds per pod, 30 pods were randomly selected from these 10 plants. After harvest, 1000-seed weight was measured by randomly selecting eight samples, each containing 100 seeds from the experimental plots. The average weight was then multiplied by 10 to calculate the 1000-seed weight.

Biological yield was measured by harvesting plants from the experimental plots before seed removal from the pods. The total weight of the plants (leaves, stem, pods, and seeds) was determined, and the biological yield per hectare was calculated.

Seed yield was determined after removing seeds from the pods, and the harvest index was obtained by dividing the seed yield by the biological yield. The oil yield was calculated by multiplying the oil content by the seed yield after determining the oil content for each experimental plot.

3. Results

The irrigation treatment significantly influenced all measured traits: plant height, pods per plant, seeds per pod, 1000-seed weight, oil content, oil yield, seed yield, biological yield, and harvest index (Figures 1, 2, 3, and 4). The individual effects of irrigation and cultivar, as well as their interaction effect, were significant (P<0.01) for all analyses except for oil content (Table 2).

Mean comparison of the irrigation by cultivar interaction revealed statistically distinct groupings of cultivars under different irrigation levels for both seed and oil yield (Table 3). The Zitna cultivar under normal irrigation had the highest average seed yield of 4,938 kg/ha, while the G.K. Olivia cultivar under withheld irrigation had the lowest average seed yield of 1,416 kg/ha (Figure 1). Conversely, the Zitna cultivar under normal irrigation achieved the highest average oil yield of 2,317 kg/ha, while the G. K. Olivia cultivar under withheld irrigation produced the lowest average oil yield of 611.7 kg/ha (Figure 2).

Table 2. Combined Analysis of variance for plant characteristics.

S.O.V	d.f	Biological yield	MS			
			Grain yield	**Oil content**	**Oil yield**	**HI**
Year (Y)	1	**76500000.0	76490700.1**	6306.0**	37433862.8**	3242.4**
Ea	6	681724.5	9744.11	1.849	4156.2	4.875
Irrigation(I)	1	4705905882.3**	459057857.2**	735.6**	101882122.3**	3026.8**
(Y ×I)	1	8500000.0**	8496850.4**	252.73**	6567452.2**	8.3**
Eb	6	34008.8	2953.12	7.145	6982.3	0.8
Variety (V)	33	41677948.5**	1514689.2**	26.6**	372647.4**	275.9**
(Y × V)	33	0.325 ns	0.2 ns	21.9**	32902.6**	1.0 ns
(I × V)	33	30165364.2**	1916869.4**	1.8 ns	397636.6**	186.9**
(Y×I × V)	33	0.323 ns	0.2 ns	3.6 ns	14542.9**	0.9 ns
E	396	516120.8	15909.6	3.4	6376	3.5
C.V (%)	-	6.07	4.66	4.35	6.75	8.17

Table 3. Mean comparison of plant characteristics.

Cultivar	Grain yield (kg h^{-1})				1 Oil yield (kg h^{-1})			
	Irrigation		Stress		Irrigation		Stress	
Ebonite	3909	F	1700	Wz	1750	Def	732.5	wxy
Elite	4503	B	1753	Vy	2047	B	743.3	vwx
Talent	4152	Cd	1669	Yz	1838	D	700.3	xyz
Olpro	3984	Ef	1797	Vy	1773	De	756.6	vwx
Sinatra	4504	B	1581	Z	2057	B	685.9	xyz
Sahara	4628	B	1416	Z	1980	Bc	577.6	z
Celsius	3981	Ef	1831	Tw	1790	De	768.7	vwx
Zitna	4938	A	1979	S	2317	A	888.9	stu
Modena	4094	De	1459	Z	1834	D	614.5	z
Geromino	3209	L	1778	Vy	1457	Kl	752.6	vwx
Opera	3576	Hi	1846	Sw	1582	Hij	770.5	vwx
ARC5	3774	G	1821	Tx	1718	Ef	778	vwx
ARC2	3609	H	1947	Stu	1625	Gh	815.3	uvw
ARG91004	3281	Kl	1894	Sv	1509	Ijk	815.7	uvw
Milena	3612	H	1444	Z	1680	Fg	641.6	z
Dexter	4036	Def	1963	St	1830	D	832	tuv
SLM046	4010	Ef	1466	Z	1803	De	617.6	z
Zarfam	3450	Ij	1681	Xyz	1564	Hij	714.6	xyz
Okapi	3544	Hi	1813	Uy	1595	Hi	769.9	vwx
Talaye	2548	O	1481	Z	1085	Q	589.2	z
Licord	2766	N	1889	Sv	1197	Op	762.6	vwx
Herkules	3346	Jk	1503	Z	1350	Mn	579	z
Vectra	2994	m	2153	Qr	1212	O	894.5	stu
G. K. Helena	3511	hi	2119	R	1552	Hij	865.5	stu
G. K. Olivia	3033	m	1497	Z	1332	N	611.7	z
G. K. Gabriella	3616	h	2292	P	1536	Hk	905	st
Orient	3491	hi	2269	Pq	1498	Jkl	916..6	st
RN*3304	4273	c	1600	Z	1956	C	693.6	xyz
N.K.Bilbao	3950	f	2153	Qr	1801	De	930.4	rs
ORW2013001	2981	m	1800	Vy	1323	N	751.3	vwx
Trapper	2761	n	2384	P	1234	O	999.8	r

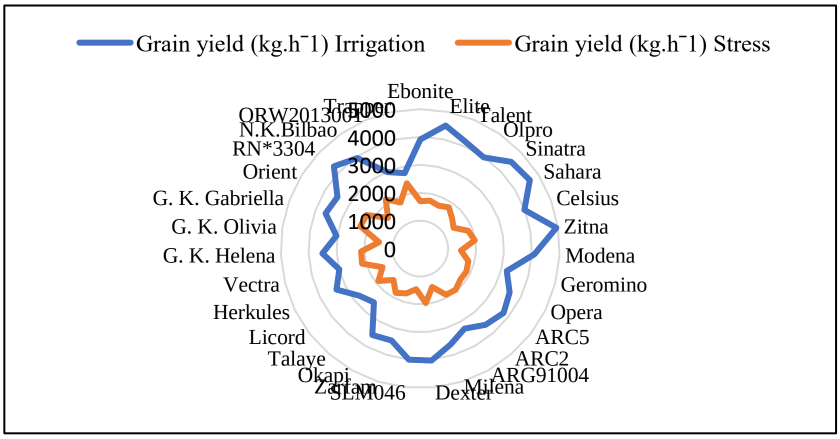

Figure 1. Mean comparison of the interaction effect of irrigation by cultivar on grain yield.

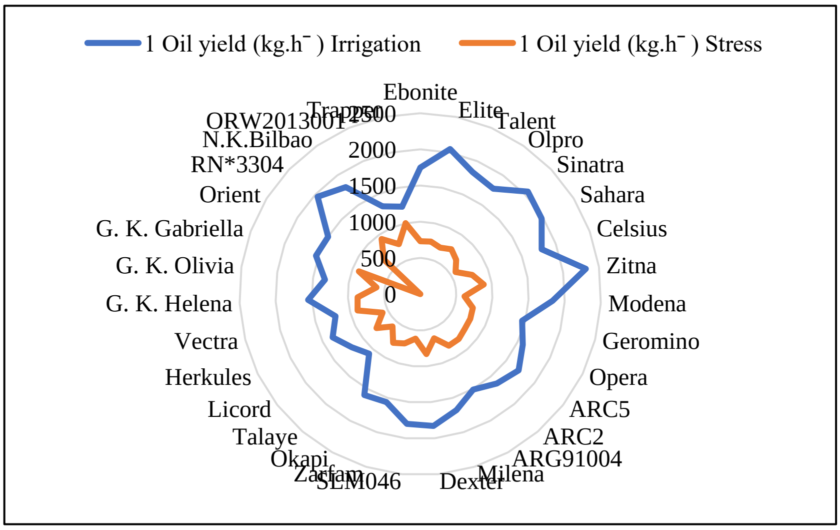

Figure 2. Mean comparison of the interaction effect of irrigation by cultivar on oil yield.

Water deficit in plants arises when water loss exceeds water uptake. This can result from excessive water loss, reduced water supply, or both. Specific symptoms of water deficiency include decreased osmotic potential and total water potential, as well as loss of turgor, stomatal closure, and stunted growth. Severe water deficiency can significantly curtail photosynthesis, disrupt physiological processes, and ultimately lead to growth inhibition.

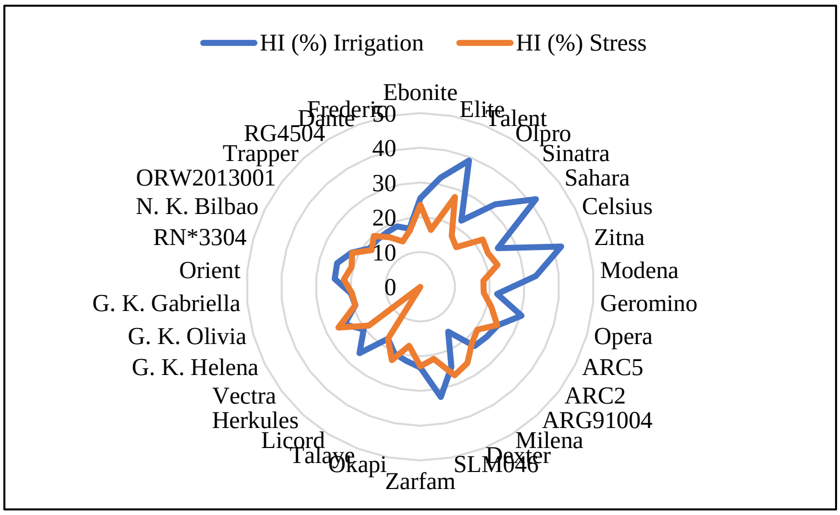

Figure 3. Mean comparison of the interaction effect of irrigation by cultivar on harvest index.

Water deficit in plants arises when water loss exceeds water uptake. This can result from excessive water loss, reduced water supply, or both. Specific symptoms of water deficiency include decreased osmotic potential and total water potential, as well as loss of turgor, stomatal closure, and stunted growth. Severe water deficiency can significantly curtail photosynthesis, disrupt physiological processes, and ultimately lead to growth inhibition.

Table 4. Mean comparison of plant characteristics.

Cultivar	Biological yield (kg h-1)				HI (%)			
	Irrigation		Stress		Irrigation		Stress	
Ebonite	15341.44	F	7206.44	tu	25.48	hk	23.59	kp
Elite	14124.84	hi	10528.52	no	31.88	cd	16.65	z
Talent	10657.08	No	6023.09	xy	38.96	b	27.71	fg
Olpro	17601.42	Cd	8011.59	rs	22.43	ot	17.21	z
Sinatra	14039.90	Hi	4928.30	z	32.08	cd	15.4	z
Sahara	11082.37	N	6276.59	xy	41.76	a	22.56	ns
Celsius	15962.30	F	7341.61	tu	24.94	il	21.8	ov
Zitna	11701.42	Lm	8548.59	qr	42.2	a	23.15	lq
Modena	12239.16	K	7981.70	rs	33.45	c	18.28	yz
Geromino	14441.94	Hi	9694.65	p	22.22	ot	18.34	yz
Opera	11794.19	Lm	8666.66	qr	30.32	de	21.3	qw
ARC5	15102.04	Fg	7286.91	tu	24.99	il	24.79	im
ARC2	15062.60	Fg	9456.04	p	23.96	jo	20.59	rx
ARG91004	14160.55	Hi	8585.67	qr	23.17	lq	22.06	ou
Milena	23654.22	A	5594.73	yz	15.27	z	25.81	gj
Dexter	16320.25	Ef	7179.95	tu	24.73	in	27.34	fgh
SLM046	12414.86	K	6938.00	w	32.3	cd	21.13	qw
Zarfam	14838.70	Fgh	7334.20	tu	23.25	lq	22.92	lq
Okapi	16212.25	ef	10473.71	no	21.68	pv	17.31	z
Talaye	12368.93	K	6527.10	vy	20.6	rx	22.69	mr
Licord	15724.84	f	10732.95	no	17.59	z	17.6	z
Herkules	12903.97	Ij	8549.84	qr	25.93	gj	17..58	z
Vectra	14719.76	gh	11581.49	lm	20.34	sy	18.59	xyz
G. K. Helena	14407.05	Hi	8057.03	rs	24.37	im	26.3	ghi
G. K. Olivia	15642.08	F	7708.54	stu	19.39	mno	19.42	wz
G. K. Gabriella	18043.91	c	11587.46	lm	20.04	mn	19.78	vy
Orient	14122.16	hi	10271.61	op	24.72	cf	22.09	ou
RN*3304	17188.25	De	7782.10	stu	24.86	cde	20.56	rx
N. K. Bilbao	17857.14	C	9822.08	p	22.12	ij	21.92	ov
ORW2013001	16254.08	ef	10262.25	op	18.34	opq	17.54	z
Trapper	15054.52	fg	12028.25	k	18.34	opq	19.82	vy
RG4504	16361.15	De	8468.89	qr	18.33	opq	16.72	z
Dante	18823.21	b	10890.94	n	18.61	nop	14.03	z
Frederic	15500.58	f	11502.43	lm	16.98	q	16.44	z

Means in each column followed by similar letter(s) are not significantly different at 5% probability level using Duncan's Multiple Rang Test.

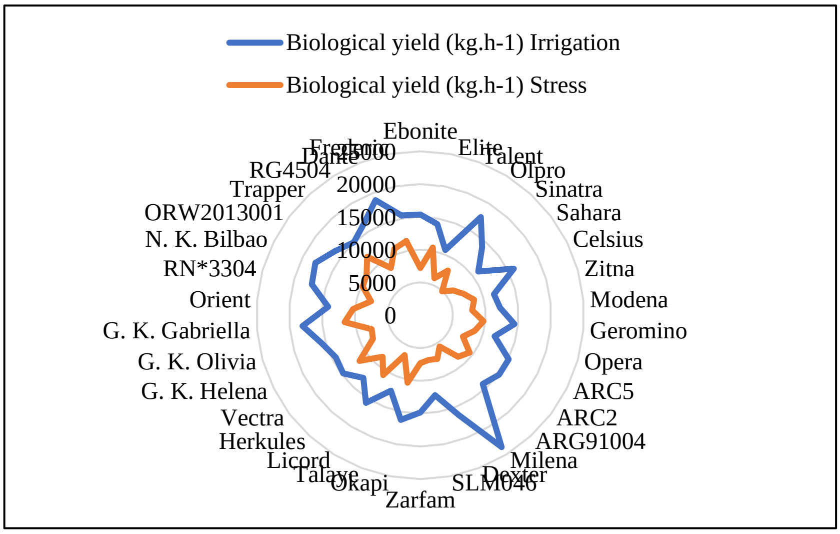

Figure 4. Mean comparison of the interaction effect of irrigation by cultivar on biological yield.

Table 5. Simple correlation coefficients between plant characteristics.

Characteristics	Plant height	Pod per plant -¹	Grain per pod-¹	1000 Grain weight	Grain yield	Biological yield	Oil content	Oil yield	Harvest index
Plant height	1	0.836**	0.842**	0.568**	0.779**	0.664**	0.578**	0.402*	0.423*
Pod.plant -1		1	0.747**	0.475*	0.68**	0.538**	0.45*	0.225 ns	0.392 ns
Grain.Pod-1			1	0.626**	0.807**	0.722**	0.639**	0.406*	0.491*
1000 Grain weight				1	0.506**	0.51**	0.47*	0.299 ns	0.329 ns
Grain yield					1	0.691**	0.528**	0.319 ns	0.408*
Biological yield						1	0.975**	0.668**	0.666**
Oil content							1	0.703**	0.674**
Oil yield								1	-0.23 ns
Harvest Index									1

ns, Non-significant; * and **, Significant at 5% and 1% probability levels, respectively.

4. Discussion

Water deficiency significantly reduces photosynthesis by causing stomatal closure, which restricts ATP and Rubisco synthesis [9]. Heat and drought during flowering and seed filling can disrupt flowering, decrease seed set, lower oil content, and ultimately reduce seed yield [7,8].

Water deficiency diminishes photosynthesis and the production of photosynthates in leaves, leading to reduced translocation of photosynthates to the seeds, ultimately affecting seed formation [10]. Normal irrigation exhibited significant superiority over withholding irrigation from the flowering stage onwards. Water deficiency during flowering and pollination has the most detrimental impact on rapeseed seed yield [11]. Pods per plant is a crucial yield component, as pods provide the capacity for seed formation, and their green membranes contribute to seed filling through photosynthesis [12].

Research by [13] indicated that 1000-seed weight decreased in the Modena and Zarfam varieties due to drought. This reduction is likely attributable to the diminished production and transport of photosynthates to the seeds, as drought might impede the plant's ability to translocate these materials effectively.

The Zitna cultivar under normal irrigation demonstrated the highest seed yield, oil yield, and harvest index (Figures 1, 2, and 3). Seed yield and harvest index under drought conditions are reliable indicators of genotype tolerance to water deficiency [14]. [15] reported that the decrease in harvest index when irrigation is limited to the flowering stage in rapeseed is primarily due to reduced seed number per pod.

Under non-irrigated conditions from the flowering stage onwards, the Trapper cultivar exhibited the highest seed and oil yield (Figures 1 and 2). Fluctuations in yield components due to environmental, climatic, and genetic variations contribute to changes in seed yield. Reports indicate the negative impact of water deficiency on pod formation and pod number per plant [16]. However, increasing seed number per pod has limitations, as this yield component is primarily influenced by genetic factors, as evidenced by studies conducted by [17].

5. Conclusions

The individual effects of irrigation and cultivar, as well as their interaction effect, were significant ($p<0.01$) for all traits except oil content. Normal irrigation proved significantly superior to withholding irrigation from the flowering stage onwards. The Zitna cultivar under normal irrigation (irrigation after 80 mm evaporation from a Class A pan) and the Trapper cultivar under drought conditions (non-irrigated from the flowering stage) exhibited the highest seed and oil yields, respectively.

Simple correlation analysis revealed a highly significant positive relationship between seed yield and pods per plant, seeds per pod, oil content, seed oil yield, biological yield, and harvest index.

Conflicts of Interest: The authors declare no conflict of interest.

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