Available online at www.notulaebotanicae.ro

Print ISSN 0255-965X; Electronic 1842-4309

Not Bot Hort Agrobot Cluj, 2011, 39(1):213-219

Notulae Botanicae Horti Agrobotanici Cluj-Napoca

Effect of UV Radiation and Evaluated CO_2 on Morphological Traits, Yield and Yield Components of Canola (*Brassica napus* L.) Grown under Water Deficit Stress

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Abstract

In this study, we studied the combined effects of UV radiation, CO_2 and water stress on the morphological traits, yield and yield components of canola (*Brassica napus* cv. 'Okapi' and 'Talaye') under twelve growth conditions: complete irrigation with ambient CO_2 with UV-A (control), complete irrigation with ambient CO_2 with UV-B, complete irrigation with ambient CO_2 with UV-C, limited irrigation with ambient CO_2 with UV-A, limited irrigation with ambient CO_2 with UV-B, limited irrigation with ambient CO_2 with UV-C, complete irrigation with elevated CO_2 with UV-A, complete irrigation with elevated CO_2 with UV-B, complete irrigation with elevated CO_2 with UV-C, limited irrigation with elevated CO_2 with UV-A, limited irrigation with elevated CO_2 with UV-B and limited irrigation with elevated CO_2 with UV-C. The results showed that water stress significantly decreased all of traits except for the oil percentage. Additionally, an elevated level of CO_2 significantly increased the final yield, 1000-seed weight, oil yield, plant height, specific leaf area and number of branches per plant, whereas UV radiation decreased all of the traits in this experiment. Elevated CO_2 ameliorated the adverse effects of UV radiation in the final yield, seed weight, oil percentage, oil yield, plant height, specific leaf area and number of branches per plant. This study showed that elevated CO_2 can partially ameliorate some of the adverse effects of UV radiation in canola plants. Furthermore, in this study, we observed that the increase in the yield was due to the increase in the seed weight and number of branches caused by elevated CO_2 in canola plants. In addition, the maximum yield was obtained from the 'Talaye' cultivar under conditions of sunlight, full irrigation and elevated CO_2.

Keywords: canola, carbon dioxide, UV radiation, water stress, yield

Introduction

Drought, ultraviolet radiation and increased carbon dioxide concentration are three major environmental factors that will affect people's diet and food security in the future. This ongoing climate change may induce several stress factors, such as drought and elevated UV radiation, simultaneously. In addition, drought is a worldwide problem, and crop production is seriously influenced by drought. In natural conditions, the availability of water can vary greatly between different days and months at the same location (Drebs *et al.*, 2002). Drought severely limits photosynthesis because it causes stomata to close and reduces CO_2 diffusion, leading to a decrease in leaf area and in the biomass of stems, leaves and roots (Guarnaschelli *et al.*, 2003). On the other hand, drought stress may reduce growth and production. Consequently, the study of crop production under drought stress is of great importance.

In the last decade, many studies have reported on the effects of UV radiation in several plant species. UV radiation can inhibit photosynthesis and damage DNA, thus changing the morphology, phenology and biomass accumulation of plants (Caldwell *et al.*, 1995). Sensitivity to UV radiation depends on plant species, cultivars, developmental stage and experimental conditions (Liakoura *et al.*, 1999). In some species, UV radiation has been shown to decrease height, stem diameter, biomass accumulation and leaf area (Bassman *et al.*, 2001). Enhanced UV radiation also affects plant development, in particular biomass distribution and the reproduction stage (Kakani *et al.*, 2003). In natural conditions, the effects of UV radiation on plants are related to other environmental factors, such as photosynthetic photon flux density, CO_2, drought, elemental nutrition, temperature, ozone fumigation and heavy metals (Caldwell *et al.*, 2003). Various stress factors competing with the supplemental UV radiation have been shown to modify the effects of UV radiation (Feng *et al.*, 2000). Among these stresses is water stress, which is an important restricting factor that always affects agricultural productivity, particularly in arid and semi-arid regions. Feng *et al.* (2007) showed that the co-stresses of supplementary UV radiation and drought functioned synergistically and that one of them could alleviate the inhibitory effects of another under conditions of arid and semi-arid soils.

For the 1000 years prior to the industrial revolution, the atmospheric CO_2 concentration was stable at approximately 270 μmol mol^{-1}. Human activities have been continuously increasing the concentration of atmospheric CO_2, taking the level from approximately 280 μmol mol^{-1} at the beginning of the 19th century to its current value of 372 μmol mol^{-1}, which represents an increase of 38%. The atmospheric CO_2 concentration is predicted to reach 550 μmol mol^{-1} by the middle of the century and to surpass 700 μmol mol^{-1} by the end of the century (Alley *et al.*, 2007). Many studies have found an increase in plant organ growth and yield under high-CO_2 conditions (Hocking and Meyer, 1991). An increase in CO_2 concentration from 300-350 to 680 μmol mol^{-1} has been described as enhancing plant growth by 7% to 25% (Erice *et al.*, 2006). Besides having direct effects on primary metabolism, elevated atmospheric concentrations of CO_2 would result in an increased pCO_2/pO_2 ratio with the possible result of a reduction in reactive oxygen species (ROS) (Halliwell and Gutteridge, 1989). The elevated level of carbon dioxide concentration in the atmosphere increased crops' capabilities of CO_2 fixation and reduction as well as their water use (Grant, 1992). Responsiveness to CO_2 was greater among C_3 plants in comparison to C_4 plants at the elevated CO_2 level (Long and Drake, 1991). Carbon dioxide is essential for plant growth as the source of carbon, which is necessary for photosynthesis, and it influences the regulation of stomata, which in turn influences water vapor and gas exchange (Prior *et al.,* 1991).

Few studies have investigated the interaction of ultraviolet radiation, water stress and CO_2 concentration on plants. Our study had the following aims: (1) to determine the effects of drought stress, enhanced UV radiation and elevated CO_2 on the growth, morphological characteristics, yield and yield components of two canola cultivars and (2) to compare the adaptability of cultivars to environmental changes.

Materials and methods

The experiment was conducted at 35°59′ N latitude, 50°75′ E longitude in the 2008 and 2009 growing seasons. The experimental design was the use of randomized complete blocks in a factorial arrangement with three replicates. The first factor included two varieties of canola, and the second factor was composed of irrigation regimes (complete irrigation and limited irrigation (60% field capacity)). The third factor included two CO_2 levels (atmospheric concentration; 400 μl L^{-1} and; 900 μl L^{-1}), and the fourth factor included different levels of UV radiation (UV-A: wavelength > 320 nm or solar radiation, UV-B: 280-320 nm and UV-C: wavelength < 280 nm). In each experimental unit, there was an erected sheltered frame (1.5 m×2.5 m×2 m). The frames were covered with polyethylene plastic film for the prevention of CO_2 escape. Disinfected canola seeds ('Okapi' and 'Talaye') were sown at depths between 2 cm and 3 cm, and irrigation was performed immediately. All experimental units were irrigated at field capacity until the establishment of seedlings, at which point, in water stress units, the soil moisture was maintained at 60 percent of field capacity using time-domain reflectometry (T.D.R., soil moisture, model 4593).

During periods of water stress, plants were exposed to UV-B and UV-C radiation by UV lamps. Simultaneous with water stress and UV radiation, the CO_2 concentration was increased to 900 μl L^{-1} for treated units. One CO_2 capsule was used, and CO_2 concentration was elevated into covered frames. Carbon dioxide was adjusted to 900 μl L^{-1} through the use of an electronic sensor (Testo Co. Germany). Nitrogen fertilizer (Urea) was applied in three stages: seed sowing, stem elongation and flowering. A systemic insecticide (Metasystox) was used at the flowering stage of canola to protect the crop from aphids.

At flowering, stage-specific leaf area was calculated. Leaf area was measured by a leaf area meter (model). To evaluate leaf dry weight, harvested plants were oven-dried at 70°C for 48 h. Additionally, at the stage of physiological maturity, branch number, height, silique number per plant, seed number per silique, 1000-seed weight, yield, oil percentage, oil yield and protein percentage were measured. Oil and protein percentage were measured using an Inframatic 8620 Percor. Oil yield was calculated via product seed yield in percentage oil.

All data were processed using the SAS software, and Duncan's multiple range tests were used to measure statistical differences between treatments.

Results and discussion

The analysis of variance demonstrated that the type of treatment used in this experiment had a significant effect on the traits under examination (Tab. 1). Nonetheless, there was no significant difference in the protein percentage between cultivars; in addition, the concentration of CO_2 had no significant effect on the seed number per silique. The interactions were significant for most traits. Quadripartite interaction was significant for 1000-seed weight, oil and protein percentage and specific leaf area. It is worth mentioning that year effect was not significant for any of the traits (Tab. 1).

Comparison between 'Okapi' and 'Talaye' cultivars showed that the highest seed yield, 1000-seed weight, oil percentage, oil yield, height and number of branches were related to 'Talaye' cultivars, whereas the highest seed number per silique, silique number per plan and specific leaf area were observed in 'Okapi' cultivar (Tab. 2). 'Talaye' is known as a high-yield canola cultivar in Iran due to its numerous branches and large seeds; it seems that this cultivar has a greater final yield than that of 'Okapi' due to these characteristics.

The results showed that water stress significantly decreased yield and yield components, oil yield, protein

Tab. 1. Analysis of variance on morphological traits, yield and yield components of two canola cultivars affected by water stress, carbon dioxide and UV radiation

S.O.V.	df	Yield	1000 seed weight	Number of seeds per silique	Number of siliques per plant	Oil percentage	Oil yield	Protein percentage	Height	Specific leaf area	Number of branches
Year	1	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
R (Year)	4	ns	ns	ns	ns	ns	ns	*	ns	ns	ns
V	1	**	**	**	**	**	**	ns	**	**	**
W	1	**	**	**	**	**	**	**	**	**	**
C	1	**	**	ns	**	**	**	**	**	**	**
U	2	**	**	**	**	**	**	**	**	**	**
V*W	1	**	*	**	ns	ns	**	*	**	ns	ns
V*C	1	ns	*	ns	**	ns	ns	ns	*	**	**
V*U	2	**	**	ns	**	*	**	*	**	**	**
W*C	1	**	**	ns	**	ns	*	**	*	*	**
W*U	2	**	**	*	**	**	**	**	ns	**	ns
C*U	2	**	**	ns	**	ns	ns	**	**	**	ns
VWC	1	*	ns	*	ns	ns	ns	ns	**	ns	**
VWU	2	*	ns	**	**	ns	*	ns	**	**	ns
WCU	2	**	ns	ns	*	ns	**	ns	**	ns	**
VCU	2	ns	ns	*	**	**	ns	**	ns	*	ns
VWCU	2	ns	**	ns	ns	*	ns	**	ns	*	ns
Year (V)	1	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Year (W)	1	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Year (C)	1	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Year (U)	2	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
C.V.		6.22	10.94	10.76	3.89	4.07	7.52	4.49	2.49	5.32	8.38

R: replication; V: variety; W: water stress; C: carbon dioxide; U: UV radiation; *, ** significant at the 0.05 and 0.01 probability levels, respectively and ns no significant

percentage, height, specific leaf area and the number of branches and that the oil percentage increased as a result of water stress (Tab. 2). Decreases in growth and development and the resulting loss of yield due to water stress have been reported for many types of crops (Ribas-Carbo *et al.*, 2005; Iqbal *et al.*, 2005). Diminished leaf specific area water stressed plants (Tab. 1) would be due to reduced cell division and elongation (Boyer *et al.*, 1985). Among these traits, only oil percentage increased due to water stress. It has been reported that there is an inverse relationship between oil percentage and protein percentage under conditions of water stress (Triboi and Renared, 1999).

An increase of CO_2 concentration up to 900 µl L^{-1} increased the final yield, 1000-seed weight, oil percentage,

Tab. 2. Main effects year, variety, water stress, carbon dioxide and UV radiation on morphological traits, yield and yield components

Treatments	Levels	Yield (kg ha^{-1})	1000 seed weight (g)	Number of seeds per silique	Number of siliques per plant	Oil percentage	Oil yield (kg ha^{-1})	Protein percentage	Height (cm)	Specific leaf area	Number of branches
Year	First	2633.68a	2.64a	18.01a	255.13a	44.16a	1165.76a	19.91a	83.54a	18.79a	5.97a
	Second	2678.92a	2.71a	17.97a	249.65a	43.21a	1170.32a	20.13a	82.72a	18.43a	6.06a
Variety	'Okapi'	2482.14b	2.49b	19.08a	258.61a	43.22b	1082.23b	19.97a	80.66b	19.23a	5.57b
	'Talaye'	2785.22a	2.80a	16.94b	251.66b	45.11a	1249.31a	19.86a	84.77a	18.35b	6.56a
Water stress	Complete	2958.61a	3.22a	21.11a	277.75a	39.52b	1186.95a	22.88a	96.05a	21.61a	7.06a
	Limited	2308.75b	2.06b	14.91b	232.52b	48.80a	1144.59b	16.94b	69.38b	15.97b	5.07b
Carbon dioxide	400 ppm	2474.14b	2.41b	18.08a	257.75a	42.72b	1057.73b	20.16a	77.27b	18.05b	5.60b
	900 ppm	2793.22a	2.88a	17.94a	252.52b	45.61a	1273.81a	19.66b	88.16a	19.53a	6.53a
UV radiation	A	2950.58a	3.25a	24.58a	288.50a	50.25a	1468.77a	23.37a	93.62a	21.84a	7.23a
	B	2612.04b	2.51b	17.75b	252.41b	46.00b	1190.19b	20.04b	83.33b	20.13b	6.16b
	C	2338.4c	2.17c	11.70c	224.50c	36.25c	838.35c	16.33c	71.20c	14.40c	4.80c

Means with similar letter are not significant at the 5% probability level

Tab. 3. Two-way interaction between treatments on morphological traits, yield and yield components

Treatments		Yield (kg ha^{-1})	1000-seed weight (g)	Number of seeds per silique	Number of siliques per plant	Oil percentage	Oil yield (kg.ha^{-1})	Protein percentage	Height (cm)	Specific leaf area	Number of branches
'Okapi'	Complete	2748.72b	3.01b	21.66a	280.94a	38.66d	1081.05c	22.77a	92.72b	22.09a	6.57b
	Limited	2215.56d	1.97d	16.50c	236.27c	47.77b	1083.41c	17.16b	68.61d	16.37c	4.56d
'Talaye'	Complete	3168.50a	3.44a	20.55b	274.55b	40.38c	1292.84a	23.00a	99.38a	21.12b	7.56a
	limited	2401.94c	2.16c	13.33d	228.77d	49.83a	1205.77b	16.72c	70.16c	15.57d	5.57c
'Okapi'	400 ppm	2342.39c	2.31d	18.83a	263.55a	41.72d	987.58d	20.33a	75.61d	18.20c	5.26c
	900 ppm	2621.89b	2.67b	19.33a	253.66b	44.72b	1176.88b	19.61	85.72b	20.26a	5.87b
'Talaye'	400 ppm	2605.89b	2.51c	17.33b	251.94b	43.72c	1127.87c	20.00ab	78.94c	17.90c	5.94b
	900 ppm	2964.56a	3.10a	16.55b	251.38b	46.50a	1370.74a	19.72b	90.61a	18.80b	7.19a
'Okapi'	A	2888.08b	3.15b	25.25a	287.08a	49.58b	1422.70b	23.50a	93.66a	21.85a	6.99b
	B	2469.17e	2.48c	18.83c	259.00b	44.50d	1088.27d	19.83b	79.75c	20.24b	5.58c
	C	2089.17f	1.83d	13.16e	229.75d	35.58f	735.72f	16.58c	68.58e	15.60c	4.13d
'Talaye'	A	3013.08a	3.35a	23.91b	289.91a	50.91a	1514.84a	23.25a	93.58a	21.83a	7.47a
	B	2754.92c	2.55c	16.66d	245.83c	47.50	1292.10c	20.25b	86.91b	20.01b	6.75b
	C	2587.67d	2.50c	10.25f	219.25e	36.91e	940.97e	16.08c	73.83d	13.20d	5.48c
Complete	400 ppm	2840.56b	3.11b	21.38a	276.61a	38.11d	1095.25b	22.66b	91.05b	20.68b	6.81b
	900 ppm	3076.67a	3.33a	20.83a	278.88a	40.94c	1278.64a	23.11a	101.05a	22.53a	7.32a
Limited	400 ppm	2107.72d	1.70d	14.77b	238.88b	47.33b	1020.20c	17.66c	63.50d	15.42d	4.39d
	900 ppm	2509.78c	2.43c	15.05b	226.16c	50.27a	1268.98a	16.22d	75.27c	16.52c	5.75c
Complete	A	3332.58a	3.69a	27.41a	316.83a	46.16c	1542.18a	26.25a	106.83a	24.99a	8.23a
	B	2849.25b	3.22b	21.50b	276.08b	39.75d	1136.57d	22.33b	97.08b	23.33b	7.18b
	C	2694.00c	2.76c	14.41c	240.33d	32.66e	882.08e	20.08c	84.25c	16.50d	5.79d
Limited	A	2568.58d	2.82c	21.75b	260.16c	54.33a	1395.36b	20.50c	80.41d	18.69c	6.23c
	B	2374.83e	1.80d	14.00c	228.75e	52.25b	1243.80c	17.75d	69.58e	16.92d	5.15e
	C	1982.83f	1.57e	9.00d	208.66f	39.83d	794.62f	12.58e	58.16f	12.30e	3.82f
400 ppm	A	2787.92b	2.88b	24.16a	291.33a	48.91b	1352.14b	23.66a	88.00c	21.55b	6.70b
	B	2513.33c	2.32d	18.16b	251.33b	44.41d	1099.67d	19.91c	77.33d	18.77c	5.66c
	C	2121.17d	2.02e	11.91c	230.58c	34.83f	721.37f	16.91d	66.50f	13.82e	4.44e
900 ppm	A	3113.25a	3.63a	25.00a	285.66a	51.58a	1585.41a	23.08b	99.25a	22.13a	7.76a
	B	2710.75b	2.70c	17.33b	253.50b	47.58c	1280.70c	20.16c	89.33b	21.48b	6.67b
	C	2555.67c	2.31d	11.50c	218.41d	37.66e	955.33e	15.75e	75.91e	14.98d	5.17d

Means with similar letter are not significant at the 5% probability level

oil yield, height, specific leaf area and number of branches but decreased the number of siliques per plant, and it had no significant effect on the number of seeds per silique. Studies have shown that elevated CO_2 results in an increase in photosynthetic rates (Drake and González-Meler, 1997) and thus an increase in dry matter production. The results show that height, specific leaf area and the number of branches as growth indexes are higher due to an increase of CO_2, which leads to an increase of yield due to the expected increase in yield components. In addition, a significant difference in the yield between CO_2 treatments revealed that the larger yield production in plants exposed to elevated CO_2 could be explained by the increase in the 1000-seed weight and greater leaf area, height, specific leaf area and number of branches in these plants. Furthermore, an increase in CO_2 concentration among C_3 plants improves photosynthesis, CO_2 fixation and, ultimately, growth and production. Decreases in the silique number per plant and the protein percentage may be due to an increase in the temperature and abscission of flowers at the flowering stage and the degradation of proteins, respectively. UV radiation as a physical stress decreased the yield, yield components, oil and protein percentages and growth parameters. Among the different wavelengths, UV-C radiation was the most destructive. UV radiation led to the abscission of flowers and increased the rate of abortion of embryo seeds. In addition, high-energy UV radiation destroys the cell membrane and deceases cell division and growth rates. It is well known that the development of leaf area is the result of two phenomena: cell division and cell expansion (Tsukaya, 2003). The literature indicates that both phenomena are affected by UV-B irradiation (Tosserams *et al.*, 2001). In this case, additional effects on height, specific leaf area and number of branches could also be the

Tab. 4. Three-way interaction between treatments on morphological traits, yield and yield components

Treatments			Yield ($kg.ha^{-1}$)	1000-seed weight (g)	Number of seeds per silique	Number of siliques per plant	Oil percentage	Oil yield ($kg.ha^{-1}$)	Protein percentage	Height (cm)	Specific leaf area	Number of branches
'Okapi'	Complete	400 ppm	2621.78d	2.93c	22.00a	282.88a	37.44f	996.65d	22.77b	87.11d	20.90c	6.33d
		900 ppm	2875.67c	3.09c	21.33ab	279.00a	39.88e	1165.45b	22.77b	98.33b	23.28a	6.81c
	Limited	400 ppm	2063.00f	1.68f	15.66d	244.22c	46.00c	978.52d	17.88c	64.11g	15.50e	4.18g
		900 ppm	2368.11e	2.25e	17.33c	228.33de	49.55b	1188.31b	16.44d	73.11f	17.24d	4.94e
'Talaye'	Complete	400 ppm	3059.33b	3.30b	20.77ab	270.33b	38.77e	1193.85b	22.55b	95.00c	20.46c	7.28b
		900 ppm	3277.67a	3.58a	20.33b	278.77a	42.00d	1391.83a	23.44a	103.7a	21.793b	7.83a
	Limited	400 ppm	2152.44f	1.72f	13.88e	233.55d	48.66b	1061.89c	17.44c	62.88g	15.34e	4.59f
		900 ppm	2651.44d	2.61d	12.77e	224.00e	51.00a	1349.65a	16.00d	77.44e	15.81e	6.55cd
'Okapi'	Complete	A	3169.17b	3.58ab	28.33a	309.83b	45.66d	1449.69b	26.00a	106.16a	25.35a	8.05ab
		B	2649.6d	3.07d	21.66c	284.00c	38.00f	1007.09e	22.16b	90.66c	23.55b	6.53c
		C	2427.33e	2.38f	15.00de	249.00e	32.33g	786.37g	20.16d	81.33e	17.38d	5.13e
	Limited	A	2607.00d	2.73e	22.16c	264.33d	53.50b	1395.71b	21.00c	81.16e	18.35c	5.93d
		B	2288.67f	1.90g	16.00d	234.00f	51.00c	1169.45d	17.50e	68.83f	16.93d	4.63f
		C	1751.00g	1.28h	11.33f	210.50h	38.83f	685.07h	13.00f	55.83h	13.82f	3.13g
'Talaye'	Complete	A	3496.00a	3.80a	26.50b	323.83a	46.66d	1634.67a	26.50a	107.50a	24.63a	8.41a
		B	3048.83bc	3.38bc	21.33c	268.16d	41.50e	1266.06c	22.50b	103.5b	23.11b	7.82b
		C	2960.67c	3.15cd	13.83e	231.66f	33.00g	977.79e	20.00d	87.16d	15.63e	6.44c
	Limited	A	2530.17de	2.91de	21.33c	256.00e	55.16a	1395.01b	20.00d	79.66e	19.03c	6.53c
		B	2461.00e	1.71g	12.00f	223.50g	53.50b	1318.15c	18.00e	70.33f	16.91d	5.68d
		C	2214.67f	1.86g	6.66g	206.83h	40.83e	904.16f	12.16g	60.50g	10.77g	4.51f
Complete	400 ppm	A	3096.83b	3.41b	27.16a	317.50a	45.33e	1404.32c	26.00a	103.16c	24.43b	7.71b
		B	2793.17cd	3.21b	22.00b	267.66c	37.83g	1058.54g	21.66c	89.16d	21.96c	6.81c
		C	2631.67ef	2.71c	15.00c	244.66e	31.16i	822.89i	20.33d	80.83e	15.65f	5.90d
	900 ppm	A	3568.33a	3.96a	27.66a	316.16a	47.00d	1680.05a	26.50a	110.50a	25.55a	8.74a
		B	2905.33c	3.23b	21.00b	284.50b	41.66f	1214.60e	23.00b	105.0b	24.70b	7.54b
		C	2756.33de	2.81c	13.83c	236.00f	34.16h	941.27h	19.83d	87.66d	17.36e	5.68d
Limited	400 ppm	A	2479.00gh	2.35d	21.16b	265.16c	52.50b	1299.96d	21.33c	72.83f	18.68d	5.68d
		B	2233.50i	1.43f	14.33c	235.00f	51.00c	1140.80f	18.16e	65.50g	15.58f	4.51e
		C	1610.67j	1.33f	8.83d	216.50g	38.50g	619.85j	13.50g	52.16h	12.00g	2.98f
	900 ppm	A	2658.17de	3.30b	22.33b	255.16d	56.16a	1490.76b	19.66d	88.00d	18.71d	6.78c
		B	2516.17fg	2.18d	13.66c	222.50g	53.50b	1346.8cd	17.33f	73.66f	18.27d	5.80d
		C	2355.00hi	1.81e	9.16d	200.83h	41.16f	969.38h	11.66h	64.16g	12.60g	5.68e
'Okapi'	400 ppm	A	2734.33cd	2.80bc	24.00b	287.66ab	49.00b	1332.91c	23.83a	88.16c	21.61ab	6.68c
		B	2382.67e	2.31d	19.50c	260.66c	42.66d	1004.80e	20.16cd	74.66f	18.47c	5.16e
		C	1910.17g	1.81e	13.00f	242.33e	33.50f	625.04g	17.00e	64.00h	14.52e	3.93f
	900 ppm	A	3041.83b	3.51a	26.50a	286.50b	50.16b	1512.49b	23.16ab	99.16a	22.09a	7.30b
		B	2555.67e	2.65c	18.16cd	257.33cd	46.33c	1171.75d	19.50d	84.83d	22.01a	6.00d
		C	2268.17f	1.85e	13.33f	217.16f	37.66e	846.41f	16.16f	73.16f	16.67d	4.33f
'Talaye'	400 ppm	A	2841.50c	2.96b	24.33b	295.00a	48.83b	1371.36c	23.50ab	87.83c	21.50ab	6.71c
		B	2644.00de	2.33d	16.83de	242.00e	46.16c	1194.55d	19.66d	80.00e	19.08c	6.16d
		C	2332.17f	2.23d	10.83g	218.83f	36.16e	817.70f	16.83ef	69.00g	13.12f	4.95e
	900 ppm	A	3184.67a	3.75a	23.50b	284.83b	53.00a	1658.33a	23.00b	99.33a	22.16a	8.23a
		B	2865.83c	2.76bc	16.50e	249.66de	48.83b	1389.66c	20.83c	93.83b	20.95b	7.33b
		C	2843.17c	2.78bc	9.66g	219.66f	37.66e	1064.25e	15.33g	78.66e	13.28f	6.01d

Means with similar letter are not significant at the 5% probability level

result of the action of UV radiation on IAA concentration (Ros and Tevini, 1995) and the oxidation of tubulins (Staxen and Bornman, 1994).

Interactions between cultivars and water stress, cultivar and CO_2, cultivars and UV radiation, water stress and CO_2, water stress and UV and CO_2 and UV are shown in

Tab. 5. Four-way interaction between treatments on morphological traits, yield and yield components

Treatments				1000-seed weight (g)	Oil percentage	Protein percentage	Specific leaf area
'Okapi'	Complete	400ppm	A	3.40c	45.33e	26.00a	24.85ab
			B	3.07c	36.66h	22.33c	21.51c
			C	2.33d	30.33k	20.00fgh	16.36e
		900ppm	A	3.76b	46.00de	26.00a	25.85a
			B	3.07c	39.33fg	22.00cd	25.59a
			C	2.43d	34.33i	20.33fg	18.40d
	Limited	400ppm	A	2.20d	52.66b	21.66cde	18.37d
			B	1.56e	48.66c	18.00jkl	15.44ef
			C	1.30e	36.66h	14.00m	12.69g
		900ppm	A	3.26c	54.33b	20.33fg	18.34d
			B	2.23d	53.33b	17.00l	18.43d
			C	1.26e	41.00fg	12.00no	14.95f
'Talaye'	Complete	400ppm	A	3.43c	45.33e	26.00a	24.01b
			B	3.36c	39.00g	21.00def	22.42c
			C	3.10c	32.00jk	20.66ef	14.95f
		900ppm	A	4.16a	48.00cd	27.00a	25.25a
			B	3.40c	44.00e	24.00b	23.80b
			C	3.20c	34.00ij	19.33ghi	16.32e
	Limited	400ppm	A	2.50d	52.33b	21.00def	18.99d
			B	1.30e	53.33b	18.33ijk	15.73ef
			C	1.36e	40.33fg	13.00mn	11.30h
		900ppm	A	3.33c	58.00a	19.00hij	19.08d
			B	2.13d	53.66b	17.66kl	18.10d
			C	2.36d	41.33f	11.33o	10.25h

Means with similar letter are not significant at the 5% probability level

Tab. 3. In general, water stress and UV radiation had negative effects on different traits in this study, whereas the effect of CO_2 varied between different canola attributes. For example, the final yield, 1000-seed weight, oil percentage, oil yield, plant height, specific leaf area and number of branches of two canola cultivars were increased by increasing the CO_2 concentration. In contrast, the silique number per plant and protein percentage of these cultivars decreased. The threefold interaction among these factors is presented in Tab. 4. The highest seed yield was obtained from 'Talaye' plots, which were irrigated completely, received a high concentration of CO_2 and were subjected to UV-A (control, sunlight) treatments. In contrast, the lowest seed yield was achieved from 'Okapi' plots, which were water stressed, exposed to an ambient CO_2 concentration and subjected to UV-C or UV-B radiation. The other traits followed similar patterns. According to Tab. 5, the highest seed weight was obtained from the 'Talaye' cultivar treated with complete irrigation and elevated CO_2 and grown under sunlight radiation. The seed weights of both cultivars visibly decreased due to UV-B, UV-C and water stress under an ambient CO_2 concentration. The oil percentage of the 'Talaye' cultivar increased when it was grown under sunlight and treated with a high concentration of CO_2 under water stress (Tab. 5). The lowest oil percentage was found for the 'Okapi' cultivar with complete irrigation, ambient CO_2 and UV-C radiation. The highest and lowest protein percentages were observed for complete irrigation plots and 'Talaye' cultivars treated with limited irrigation, a high CO_2 concentration and UV-C radiation, respectively. Specific leaf area for both cultivars increased due to an increase in CO_2 concentration. Water stress and UV radiation dramatically decreased specific leaf area even under high CO_2 concentration. According to the description by Azcón-Bieto *et al.* (2004), reducing leaf area is one of the main strategies developed by plants to diminish water loss during drought periods. The lowest specific leaf area was obtained from the 'Talaye' cultivar under conditions of water stress and UV-C radiation in both CO_2 concentrations (Tab. 5). In conclusion, because of the increase in the amount of air pollution due to the emission of hazardous pollutants, the ozone layer is being destroyed, leading to an increase in UV radiation. This increase results in many adverse effects on plant growth and production. Our results confirm these effects and suggest that an increase in UV exposure decreases plant growth and development. In addition, CO_2 could improve yield, yield components and growth parameters for plants subjected to elevated levels of UV radiation.

Acknowledgements

The authors would like to acknowledge the Islamic Azad University, Varamin-Pishva Branch for financial support of this project.

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