International Journal of
Agriculture, Environment and Food Sciences

JAEFS e-ISSN : 2618-5946 DOI: 10.31015/jaefs.2020.4.2 www.jaefs.com

Research Article Int J Agric Environ Food Sci 4 (4): 400-405 (2020)

# Photosynthetic performance responses in different phyiological development stages of some *Brassica juncea* genotypes in field condition

**Fatma Kayacetin**[1,*] **Banu Efeoglu**[2] **Oguzhan Aydin**[1]

[1]Central Research Institute for Field Crops, Oil Seed Crops Unit, Yenimahalle, Ankara/Turkey
[2]Central Research Institute for Field Crops, Biotechnology Research Center, Yenimahalle, Ankara/Turkey

[*]Corresponding Author: fatmakayacetin@gmail.com

**Abstract**

In this study *Brassica juncea* genotypes were planted as fall sowing at the experimental fields located at Yenimahalle-Ankara location based on randomized block design. In order to investigate photosynthetic performances of three *B. juncea* genotypes; net photosynthetic rate = $P_N$ [µmol($CO_2$) $m^{-2}s^{-1}$], transpiration = $E$ (mmol $m^{-2}s^{-1}$), stomatal conductance = $g_s$ (mmol $m^{-2}s^{-1}$), intercellular/ambient $CO_2$ air= $C_i$ [µmol ($CO_2$) $mol^{-1}$(hava)], mesophyll conductance= $g_m$ [mmol($CO_2$)/$m^2s^1$] and photosynthetic water use efficiency = PWUE [µmol($CO_2$)/mol($H_2O$)] parameters (model LCi Photosynthesis System, ADC Bioscientific Ltd., Hertfordshire, UK) were measured and phenological aspects were recorded at different physiological stages as booting, anthesis and grain filling during experiment. Photosynthetic rate and stomatal conductance were associated with seed yield in *B. juncea* genotypes and the selection of genotypes with high gas exchange may provide development of mustard (*B. juncea*) genotypes with high yield.

**Keywords:** *Brassica juncea*, Gas exchange, Stomatal conductance, Yield

## Introduction

Brassicaceae family includes economically important industrial oilseed, spice, vegetable, and fodder crops and exhibits extreme morphological diversity and many crop species (Li et al., 2017). This family, comprises a number of plant species. The dicotyledonous family Brassicaceae has 338 genera and 3709 species (Warwick et al., 2006). The species which belong to the family *Brassica* L., Turkish natural flora of *Sinapis alba* (white mustard), *S. arvensis* (wild mustard), *B. juncea* (brown mustard), *B. rapa* syn. *B. campestris* (field mustard) and *B. nigra* (black mustard) are the most important among them (Babac, 2004; Guner et al., 2012). Brown mustard belonging to the family *Brassicaceae* are cultivated for different usage, especially for spice and energy industries. Brown mustard is tap rooted, herbaceous, upright growing, multi-branched, yellow-flowered and seed and grow as an annual plant cultivated worldwide for the industrial oilseed, spice, vegetable and fodder crop species (Kayacetin 2019; Mulligan and Bailey, 1975). In India, *B. juncea* is dominant, whereas in Europe and Canada, *B. juncea* is planted in minor areas just for condiment use (Sovero 1993). Fertilization of ovules generally stem from self-pollination, with interplant outcrossing rates

**Cite this article as:**
Kayacetin, F., Efeoglu, B., Aydin, O. (2020). Photosynthetic performance responses in different phyiological development stages of some *Brassica juncea* genotypes in field condition. Int. J. Agric. Environ. Food Sci., 4(4), 400-405
**DOI:** https://doi.org/10.31015/jaefs.2020.4.2
**ORCID:** Fatma Kayacetin : 0000-0003-3428-8121 Banu Efeoglu: 0000-0002-4053-5806 Oğuzhan Aydın: 0000-0003-3374-6813
**Received:** 21 May 2020 **Accepted:** 29 September 2020 **Published Online:** 15 November 2020
**Year:** 2020 **Volume:** 4 **Issue:** 4 (December) **Pages:** 400-405
**Available online at :** http://www.jaefs.com - http://dergipark.gov.tr/jaefs

of 20-30% (Rakow and Woods, 1987). *B. rapa* [AA (n:10)] and *B. nigra* [BB (n:8)] are two basic diploid species and their natural interspecific cross lead to amphidiploid species, *B. juncea,* [AABB (n:18)] (Nagaharu, 1935). Brown mustard, which is among the genetic resources of our country, is one of the important non-edible that can be cultivated for industrial oil purposes on marginal areas (Kayacetin, 2019).

Photosynthesis measurements have been succesfully used to demonstrate genetic diversity in performance and to explain physiological responses to environmental effects and crop inputs. Direct mesurements of photosynthesis from gas exchange are performed with an infrared gas analyzer (IRGA) which measures the carbon dioxide flux within a sealed chamber containing a leaf sample. Measurements of gas exchange have become increasingly valuable in presicion phenotyping studies. The eficiency of utilazing the absorbed photosynthetically active radiation (PAR) for biomass production can change with variation in plant growth stage, field management practices and environmental stress intensity (Orange and Ebadi, 2012). In present paper photosynthetic performance responses and phenological aspects in different phyiological development stages of some *B. juncea* genotypes in field condition were compared.

**Materials and Methods**

The field experiment was carried out during fall season of 2017-2018 at Central Research Institute for Field Crop at the experimental fields under fall sowing condition. The study made use of three brown mustard genotypes as research material which were selected from among a large number of genotypes belonging to different origin obtained from the USA gene bank.

Table 1. The long-term and 2017-2018 monthly agro-climatic meteorological data pertaining to vegetation period (September to August) conditions of Yenimahalle location (925 m altitude)

| Climatic factors | Years | Months | | | | | | | | | | Total or mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | S | O | N | D | J | F | M | A | Ma | Ju | |
| Precipitation (mm) | Long years | 17.5 | 31.8 | 34.2 | 42.0 | 40.2 | 33.0 | 36.7 | 46.7 | 49.9 | 34.2 | 366.2 |
| | 2017-2018 | 3.2 | 10.0 | 37.2 | 41.5 | 48.0 | 43.5 | 62.0 | 2.6 | 86.2 | 37.4 | 371.6 |
| Relative humidity (%) | Long years | 49.1 | 60.5 | 69.7 | 76.5 | 76.4 | 70.7 | 63.2 | 59.0 | 56.5 | 52.1 | 63.4 |
| | 2017-2018 | 34.2 | 55.1 | 70.0 | 78.3 | 77.0 | 73.3 | 63.2 | 44.4 | 60.0 | 53.1 | 60.9 |
| Mean temp. (ºC) | Long years | 19.0 | 13.1 | 6.8 | 2.3 | 0.4 | 2.3 | 6.4 | 11.5 | 16.2 | 20.3 | 9.8 |
| | 2017-2018 | 22.6 | 12.4 | 7.2 | 4.8 | 3.1 | 6.6 | 10.2 | 15.4 | 18.0 | 21.4 | 12.2 |
| Maximum temp. (ºC) | Long years | 32.6 | 27.6 | 19.7 | 13.9 | 11.9 | 14.7 | 21.4 | 25.7 | 29.3 | 33.6 | 33.6 |
| | 2017-2018 | 37.7 | 23.7 | 18.6 | 17.0 | 11.4 | 15.6 | 22.7 | 28.1 | 28.9 | 33.9 | 37.7 |
| Minimum temp. (ºC) | Long years | 6.6 | 1.1 | -3.8 | -8.2 | -11.5 | -9.9 | -5.9 | -0.8 | 4.1 | 8.1 | -11.5 |
| | 2017-2018 | 7.7 | 3.2 | -1.9 | -4.6 | -3.9 | -2.7 | -2.8 | 0.6 | 9.1 | 12.4 | -4.6 |

(S, September; O, October; N, November; D, December; J, January; F, February; M, March; A, April; Ma, May; Ju, June)
The data were obtained from Yenimahalle Meteorology Station of Central Field Crops Research Institute, Ankara Turkey

Table 2. The soil analysis during 2017, performed out of the soil taken at a depth of 0-20, 21-40 cm of Yenimahalle location

| Depth (cm) | Texture | Saturation content (%) | Total salt (%) | pH | Lime (%) | Phosphorus (P) | Potassium (K) | Organic Substance (%) |
|---|---|---|---|---|---|---|---|---|
| 0-20 | Clay loamy | 56.0 | 0.025 | 7.81 | 5.3 | 9.3 | 126.0 | 1.35 |
| 21-40 | Clay loamy | 56.0 | 0.025 | 7.81 | 5.2 | 10.5 | 240.0 | 1.28 |
| Mean | | 56.0 | 0.025 | 7.81 | 5.3 | 9.9 | 183.0 | 1.32 |

Data were obtained from Soil Fertilizer and Water Resources Institute

Genotypes were planted as fall sowing at the experimental fields located at Yenimahalle location 39°12′ - 43°6′ N, 35°58′ - 37°44′ E, and 925 m altitude, rainfed conditions.

The montly meteorological data pertaining to vegetation period (September to June) of long term and 2017-2018 agro climatic conditions of Yenimahalle, Ankara are given in Table 1. There was total precipitation of 366.2 and 371.6 mm, mean temperature of 9.8 and 12.2 °C, and an mean humidity of 63.4% and 60.9%, respectively at Yenimahalle location.

The soil analysis during 2017, performed out of the soil taken at a depth of 0-20, 21-40 cm showed low organic matter (1.35% and 1.28% respectively), in alkaline (pH 7.81), limey (5.3% and 5.2%, respectively), and clay-loamy soils (Table 2).

Each genotype was planted as two rows, 3 m plots with 30 cm row spacing and three replicates. In this study, the thousand seed weight and seed yield were determined as described by Kayacetin (2019).

The crude oil content was determined by grinding 10 g of powdered mustard seed samples and extracting by hexane that were used with Gerhardt 2000 soxhlet apparatus (Singh et al., 2014).

Genotypes were grown under natural conditions without using any fertilizer or pesticide to measure their potential under natural conditions. The seeds of these genotypes were considered mature and harvested on achieving 8.5% moisture content (CFIA, 1999).

At Yenimahalle location sowing date was 31th October 2017, emergence date was 12th November 2017, harvest date 13th-17th June 2018, days to maturity 225-229 d. Phenological aspects were (days to emergence, days to 50% flowering and days to maturity, plant height, number of branches) recorded

Statistical analysis: All data were statistically analyzed using AVCI's analysis of variance technique and the treatment means were compared using LSD test at 0.01 probability level (Steel & Torrie 1984).

In order to investigate photosynthetic performances of three brown mustard genotypes; net photosynthetic rate = $P_N$ ***[μmol(CO$_2$***) m$^{-2}$s$^{-1}$], transpiration = *E* (mmol m$^{-2}$s$^{-1}$), stomatal conductance = $g_s$ (mmol m$^{-2}$s$^{-1}$), intercellular/ambient $CO_2$ air= $C_i$ [μmol ($CO_2$) mol$^{-1}$(hava)], mesophyll conductance= $g_m$ [mmol ($CO_2$)/ m$^2$s$^1$] ve photosynthetic water use efficiency = PWUE [μmol($CO_2$)/mol($H_2O$)] parameters (model LCi Photosynthesis System, ADC Bioscientific Ltd., Hertfordshire, UK) were measured at different physiological stages as booting, anthesis and grain filling during experiment.

Measurements were made from full developed youngest leaves at PAR of 892 to 2055 [μmol (foton) m$^2$s$^1$] and environmental $CO_2$ concentration value of 272-368 ppm. Mesophyll conductance was calculated by dividing Pn by Ci (Fischer et al., 1998). Photosynthetic water use efficiency (PWUE) was calculated by dividing Pn by gs (Ahmadi and Siosemardeh, 2005).

**Results and Discussion**

Significant ($p$<0.05) differences were noted among different genotypes regarding some phenological aspects and yield components characters of *Brassica juncea* genotypes in different growth stages. The Izmir genotypes showed higher plant height (132.90 cm), number of branches (12.60 branch plant$^{-1}$), number of capsules (282.71 capsule plant$^{-1}$), thousand seed weight (2.88 g), seed yield (290.76 g m$^{-2}$) and crude oil content (29.06%) than the other genotypes. India genotypes showed lower plant height (100.27 cm), number of branches (8.27 branch plant$^{-1}$), number of capsules (215.07 capsule plant$^{-1}$), thousand seed weight (2.53 g), seed yield (213.17 g m$^{-2}$) and crude oil content (25.65%) than other genotypes. Days to emergence, days to 50% flowering and days to maturity did not change among the genotypes (Table 3. and 4).

Net photosynthetic rate (A) was higher at anthesis stage than booting and grain filling stages in all *Brassica juncea* genotypes. Transpiration rate (E) was different among all stages and genotypes. Transpiration (E) increased in the same way in Izmir and Tekirdag genotypes while it increased through late stages in India genotype. Photosynthesis and transpiration are both physiologically complex processes. Plants are thought to optimize water use efficiency by adjusting the rate of photosynthesis in relation to the rate of transpiration (Farqual et al., 2002). Intercellular $CO_2$ concentrations (Ci) was highest at booting stage in Izmir and Tekirdag genotypes and was highest in grain fillling stage in India genotype. Intercellular $CO_2$ concentrations ($C_i$) was almost inversely related with photosynthesis rate in India genotype. Stomatal conductance (Gs) was highest at booting stage in all genotypes and decreased through later stages.

Mesophyll conductance (MC) was highest at anthesis stage in all *Brassica juncea* genotypes. Photosynthetic water use efficiency (PWUE) was highest at grain filling period in Izmir and Tekirdag genotypes and at booting stage in India genotype. PWUE (photosynthetic water used efficiency) gives the information about the assimilation of dry mass produced per unity of lost water through transpiration process. This parameter is important for indicating water management to agricultural productivity. PWUE increased from booting through grain filling period in the genotypes. A geat value of PWUE parameter does not mean the increased assimilation of plant. At ripening stage, a higher value means a higher water consumer (Acatrinei, 2010). The resulted relationships in different growth stages with decreasing slope toward the end of growing season show the possibility to save water with withdrowing water application during last growth stages (Azizian and Sepaskhah, 2014). Similar findings were also reported for wheat (Abbate et al., 2004) and potato (Ahmedi et al., 2010). Increased yields have been achieved by (i) increased or extended photosynthesis per unit land area and (ii) increased patitioning of crop biomass to the harvested product. The first has mainly been achieved by irrigation schemes and improved agronomic practices, in particular the use of inorganic fertilizers, but also to elevated atmosphere $CO_2$ concentrations, whereas the second has largely been due to plant breeding (Richards 2000). It has been showed positive correlations between grain yield, photosynthetic rate, and stomatal conductance in irrigated short spring wheats (Fischer et al., 1998; Shimshi and Ephrat, 1975), *Phaseolus vulgaris* L. and *Phaseolus coccineus* L. (Rodriguez & Estrada 2005). Higher stomatal conductance in plants is known to increase $CO_2$ diffusion into leaves thereby favouring higher photosynthetic rates. Higher net assimilation rates could in turn favour a higher biomass and higher crop yields (Taiz and Zeiger, 1998). Recent studies have shown possitive correlation between yield increases and increases in stomatal conductance (Rodriguez and Estrada, 2005).

Traits related to stomatal conductance may prove useful for improving selection for yield potential. Higher yield-potential wheats had greater stomatal conductance and, therefore, cooler canopies than older, lower yield potential releases (Fischer et al., 1998).

Table 3. Variation of some photosynthetic parameters of *Brassica juncea* genotypes in different growth stages

| Genotypes | Net photosynthetic rate µmol $CO_2$ $m^{-2}$,$s^{-1}$ | | | | Transpiration mmol $m^{-2}$,$s^{-1}$ | | | | Intercellular/ambient air $CO_2$ (Ci/Ca) µmol $mol^{-1}$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Anthesis | Grain filling period | Booting | Mean | Anthesis | Grain filling period | Booting | Mean | Anthesis | Grain filling period | Booting | Mean |
| Izmir | 26.35 | 12.82 | 4.78 | 14.65 | 3.55 | 2.10 | 163.83 | 56.49 | 120.00c | 164.50b | 0.28d | 94.93b |
| Tekirdag | 21.20 | 17.13 | 4.10 | 14.14 | 4.56 | 3.41 | 183.25 | 63.74 | 160.00b | 147.00bc | 0.21d | 102.40ab |
| India | 21.93 | 9.15 | 3.78 | 11.62 | 5.40 | 6.33 | 142.17 | 51.30 | 144.67bc | 223.67a | 0.18d | 122.84a |
| Mean | 23.16a | 13.03b | 4.22c | | 4.50b | 3.94b | 163.08a | | 141.56b | 178.39a | 0.22c | |
| F $value_G$ | | | | 2.81 | | | | 1.38 | | | | 3.77* |
| F $value_S$ | | | | 95.91* | | | | 298.01* | | | | 159.69* |
| F $value_{GxS}$ | | | | 2.87 | | | | 1.84 | | | | 4.20* |
| CV (%) | | | | 21.55 | | | | 27.87 | | | | 20.92 |

Table 4. Variation of some photosynthetic parameters of *Brassica juncea* genotypes in different growth stages

| Genotypes | Stomatal resistance mmol $m^{-2}$,$s^{-1}$ | | | | Mesophyll conductance(A/Ci) mmol $m^{-2}$,$s^{-1}$ | | | | Photosynthetic water use efficiency (A/gs) µmol $CO_2$ / mol $H_2O$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Anthesis | Grain filling period | Booting | Mean | Anthesis | Grain filling period | Booting | Mean | Anthesis | Grain filling period | Booting | Mean |
| Izmir | 0.22c | 0.11c | 30.57b | 10.30b | 0.22 | 0.08 | 17.83 | 6.04 | 125.15a | 109.05ab | 0.16d | 81.23a |
| Tekirdag | 0.20c | 0.14c | 30.90b | 10.41b | 0.13 | 0.11 | 19.49 | 6.58 | 124.82a | 88.08bc | 0.13d | 78.11a |
| India | 0.25c | 0.15c | 34.87a | 11.75a | 0.15 | 0.04 | 20.38 | 6.86 | 118.71a | 64.39c | 0.11d | 50.86b |
| Mean | 0.22b | 0.13b | 32.11a | | 0.17b | 0.08b | 19.23a | | 105.28a | 104.79a | 0.13b | |
| F $value_G$ | | | | 22.33* | | | | 0.48 | | | | 38.10* |
| F $value_S$ | | | | 2324.73* | | | | 343.18* | | | | 278.63* |
| F $value_{GxS}$ | | | | 42.75* | | | | 0.54 | | | | 48.54* |
| CV (%) | | | | 3.89 | | | | 27.51 | | | | 19.75 |

Table 5. Variation of some phenological aspects and yield components of *Brassica juncea* genotypes in different growth stages

| Genotypes | Days to 50% flowering (d) | Days to maturity (d) | Plant height (cm) | Number of branches (branch plant$^{-1}$) |
|---|---|---|---|---|
| Izmir | 198 | 261 | 132.90a | 13.60a |
| Tekirdag | 198 | 261 | 112.87ab | 11.87ab |
| India | 198 | 261 | 100.27b | 8.27b |
| F value$_G$ | | | 26.83* | 16.35* |
| CV (%) | | | 4.77 | 10.36 |

Table 6. Variation of some phenological aspects and yield components of *Brassica juncea* genotypes in different growth stages

| Genotypes | Number of capsules (capsul plant$^{-1}$) | Thousand seed weight (g) | Seed yield (g m$^{-2}$) | Crude oil content (%) |
|---|---|---|---|---|
| Izmir | 282.71 | 2.88a | 290.79a | 29.06a |
| Tekirdag | 238.67 | 2.69ab | 246.99a | 25.82b |
| India | 215.07 | 2.53b | 213.17b | 25.65b |
| F value$_G$ | 3.05 | 7.60* | 31.31* | 8.83* |
| CV (%) | 13.92 | 4.15 | 8.01 | 4.17 |

## Conclusion

Higher photosynthetic rates could in turn favor a high crop yield and higher stomatal conductance appears to favor higher yields. These results suggest that Izmir genotype, which is the highest yielding genotype, has substantial reserve capacity for photosynthesis. In conclusion photosynthetic rate and stomatal conductance were associated with seed yield in *Brassica juncea* genotypes and the selection of genotypes with high gas exchange may provide development of brown mustard genotypes with high yield.

## Compliance with Ethical Standards

**Conflict of interest**

The authors declare that for this article they have no actual, potential or perceived the conflict of interests.

**Author contribution**

The contribution of the authors is equal. All the authors read and approved the final manuscript. All the authors verify that the Text, Figures, and Tables are original and that they have not been published before.

**Ethical approval**

Not applicable.

**Funding**

No financial support was received for this study.

**Data availability**

Not applicable.

**Consent for publication**

Not applicable.

## References

Abbate, P E. Dardanelli, J L. Cantarero, M. Maturano, M. Melchiori, J R M. and Suero, E E. (2004). Climatic and water availability effects on water use efficiency in wheat. Crop Science, 44(2), 474-483. Doi: https://doi.org/10.2135/cropsci2004.4740

Acatrinei, L. (2010). Photosynthesis rate, transpiration and stomatal conductance of vegetable species in protected organic crops. Lucrari Stiintifice sera Agronomie, 53(1), 32-35. Retrieved from http://www.uaiasi.ro/revagrois/PDF/2010_1_34.pdf

Ahmadi, A. and Siosemardeh, A. (2005). Investigation on the physiological basis of grain yield and drought resistance in wheat: leaf photosynthetic rate, stomatal conductance and non stomatal limitation. International Journal of Agriculture and Biology, 7(5), 807-811.

Azizian, A. and Sepaskhah, A R. (2014). Maize response to different water, salinity and nitrogen levels: agronomic behavior. International Journal of Plant Production. 8(1), 107-130. Retrieved from https://www.researchgate.net/profile/Abolfazl_Azizian2/publication/272829165_Maize_response_to_different_water_salinity_and_nitrogen_levels_Agronomic_behavior/links/54f0c87f0cf2b36214aae4f8/Maize-response-to-different-water-salinity-and-nitrogen-levels-Agronomic-behavior.pdf

Babac, M T. (2004). Possibility of an information system on plants of South–West Asia with particular reference to the Turkish Plants Data Service (TUBIVES). Turkish Journal of Botany, 28, 119-127. Retrieved from https://journals.tubitak.gov.tr/botany/issues/bot-04-28-1-2/bot-28-1-2-11-0301-7.pdf

CFIA. (1999). List of Varieties Which Are Registered in Canada. Variety Section. Canadian Food Inspection Agency, Canada, Ottawa.

Farquhal, G D. Buckley, T N. and Miller, J M. (2002). Optimal stomatal control in relation to leaf area and nitrogen. Silva Fennica, 36(3), 625-637. Retrieved from https://www.researchgate.net/profile/Graham_Farquhar/publication/228991418_Stomatal_control_in_relation_to_leaf_area_and_nitrogen_content/links/0912f5074979b00fe4000000/Stomatal-control-in-relation-to-leaf-area-and-nitrogen-content.pdf

Fischer, R A. Rees, D. Sayre, K D. Lu, Z M. Condon, A G. and Larqué Saavedra, A. (1998).Wheat yield progress is associated with higher stomatal conductance, higher photosynthetic rate and cooler canopies. Crop Science, 38, 1467-1475. Doi: https://doi.org/10.2135/cropsci1998.0011183X003800060011x

Guner, A. Aslan, S. Ekim, T. Vural, M. and Babac, M T. (2012). Turkiye Bitkileri Listesi (Damarli Bitkiler). Nezahat Gokyigit Botanik Bahcesi Yayinlari Flora Dizisi I, ISBN: 978– 605–60425–7–7, Istanbul (in Turkish).

Kayacetin, F. (2019). Morphological characterization and relationship among some important wild and domestic Turkish mustard genotypes (*Brassica* spp.). Turkish Journal of Botany, 43 (4,: 499-515. Retrieved from https://journals.tubitak.gov.tr/botany/issues/bot-19-43-4/bot-43-4-7-1810-4.pdf

Li, P. Zhang, S. Li, F. Zhang, S. and Zhang, H. (2017). A phylogenetic analysis of chloroplast genomes elucidates the relationships of the six economically important *Brassica* species comprising the triangle of U. Frontiers in Plant Science 8, 111. Doi: https://doi.org/10.3389/fpls.2017.00111

Mulligan, G A. and Bailey, L G. (1975). The biology of Canadian weeds. 8. *Sinapis arvensis* L. Canadian Journal of Plant Science, 55, 171-183. Doi: https://doi.org/10.4141/cjps75-026

Nagaharu, U. (1935). Genome analysis in *Brassica* with special reference to the experimental formation of *B. napus* and peculiar mode of fertilization. Journal of Japanese Botany, 7, 389-452.

Orange, M J. and Ebadi, A. (2012). Responses of phenological stages of spring safflower to complementary irrigation. African Journal of Biotechnology, 11(10), 2465-2471. Doi: https://doi.org/10.5897/AJB10.1628

Rakow, G and Woods, D. (1987). Outcrossing in rape and mustard under Saskatchewan prairie conditions. Canadian Journal of Plant Science, 67, 147-151. Doi: https://doi.org/10.4141/cjps87-017

Richards, R A. (2000). Selectable traits to increase crop photosynthesis and yield of grain crops. Journal of Experimental Botany, 51, 447-458. Doi: https://doi.org/10.1093/jexbot/51.suppl_1.447

Rodriguez, M G. and Estrada, J A E. (2005). Association between stomatal conductance and yield in *Phaseolus vulgaris* and *Phaseolus coccineus*. Reports of Bean Improvement Cooperative and National Dry Bean Council Research Conference Annual report. pp. 150-151. Retrieved from https://www.semanticscholar.org/paper/Association-between-stomatal-conductance-and-yield-Rodr%C3%ADguez-Estrada/bae7a7c72b5e3c6b51f660a939db21879ae01357?p2df

Singh, M P. and Lallu-Singh, N B. (2014). Thermal requirement of indian mustard (*Brassica juncea*) at different phenological stages under late sown condition. Indian Journal of Plant Physiology, 19(3), 238-243. Doi: https://doi.org/10.1007/s40502-014-0072-0

Sovero, M. (1993). Rapeseed, a new oilseed crop for the United States. pp. 302-307. In: J. Janick and J.E. Simon (eds.), New crops. Wiley, New York.

Taiz, L. and Zeiger, E. (1998). Plant physiology, 2nd edn. Sinauer Associates, Sunderland, Mass.

Warwick, S I. Gugel, R. and McDonald, T. (2006). Genetic variation and agronomic potential of Ethiopian mustard (*Brassica carinata*) in Western Canada. Genetic Resources and Crop Evolution, 53 (2), 297-31. Doi: https://doi.org/10.1007/s10722-004-6108-y