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Research Article

Microclimatic Modificantions Through Row Spacing in *Raya* under Central Punjab Conditions

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ABSTRACT

The research experiment was conducted at the Research Farm, Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana during *rabi* seasons of 2019-20 and 2020-21. The experiment comprised two varieties (PBR 91 and PBR 357) and row directions (North-South and East-West) in a factorial-split plot design with three replications. For raising the crop, all the agronomic practices were followed as recommended by the *PAU Package of Practices*. The results showed that PAR interception was highest in variety PBR 357, and it was greater in the N-S-oriented crop. Biomass accumulation was also higher (147.35 q/ha) in variety PBR 357 and in N-S oriented crop (146.61 q/ha) than in PBR 91 and E-W row spacing treatments. Leaf area index and dry matter accumulation were correlated with PAR interception, and results depicted R^2 values of 0.84 and 0.90 during 2019-20 and 2021-22, respectively, between LAI and PAR interception, while during 2019-20 and 2020-21, the R^2 value of 0.84 and 0.96, respectively, was obtained between dry matter accumulation and PAR interception. Among the varieties, PBR 357 achieved higher yield, contributing characteristics such as higher seed yield (20.46 q/ha), biological yield (87.14 q/ha), and straw yield (66.83 q/ha). Among the row orientations, the N-S-oriented crop achieved high yield attributes of 20.91, 87.10, and 66.79 q/ha for seed yield, biological yield, and straw yield, respectively. The N-S-oriented crop performed better, and variety PBR 357 outperformed the other treatments. So, small modifications in the row direction can help increase yield in *raya* without any extra cost.

Key words: Microclimate modification, Row direction, PAR interception, Leaf area index, Biomass, *raya* yield

Introduction

Rapeseed-mustard is an immensely important oilseed crop that contributes significantly to India's economy after cereal crops. This group comprises a large number of species and subspecies which are widely cultivated in India. Out of the species, Indian mustard, *toria,* yellow sarson, brown sarson, *ghobi sarson*, karanrai, and black mustard have a wide range of importance. In Punjab, rapeseed and mustard were grown on 43.9 thousand hectares, with a production of 69.3 thousand tonnes and an average yield of 15.79 q/ha in 2021-22 (Anonymous, 2023-24).

Rapeseed-mustard is a temperate-climate crop but can also be grown at higher elevations in the tropics. Also, this group is adapted to a range of soil types, but well-drained, loamy soils are considered favourable for the crop's better vigour. The genetic potential of any crop is greatly influenced by weather parameters, which play a crucial role in determining the crop growth, development and yield. Any deviation from the normal weather conditions can

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cause detrimental effects on the crop. In Punjab, the optimal sowing time for mustard is generally from mid-October to mid-November, as the optimal conditions for raya growth fall within this period. Among the weather parameters, temperature is the most important, as it affects seed germination, photosynthesis, water relations, membrane stability, and the production of reactive oxygen species. Mustard requires about 18-25°C temperature and low humidity, especially no rainfall at the time of flowering. Increase in maximum temperature from normal (above 25°C) in *Brassica* caused flower abortion and reduction in seed yield (Jha *et al.,* 2015). Mustard seeds cannot germinate in soil temperatures as low as 4.4°C (Iraddi *et al.,* 2008). Cold temperature, bright sunshine and enough soil moisture increase the oil content of seed. High rainfall and humidity weaken the plant during flowering (Singh *et al.,* 2017). Mustard takes 135-150 days to attain its maturity. Particularly *raya* under Punjab conditions matures in the month of March, when warm and dry winds prevail (Singh *et al.,* 2018).

Microclimate refers to the unique climatic conditions that exist within the cropped area. By making small adjustments in the microclimate, more favourable conditions for crop growth and development can be created. Among the various techniques for microclimate modification, sowing with different row orientations is a technique to capture the maximum photosynthetic radiation. Growth and development of any crop is a function of solar energy received during the whole growing season (Keerthi *et al.,* 2017). Direction of sowing may influence sunlight exposure, wind patterns, and water distribution, which will definitely affect the growth and yield-contributing characteristics of any crop (Goyal *et al.,* 2018). Keeping this in view, the study was planned to evaluate the effects of different row directions and varieties on the growth and yield of mustard.

Material and Methods

Treatment details

The field experiments were conducted at the Research Farm, Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana, during the *rabi* seasons of 2019-20 and 2020-21. The study site is located at a latitude and longitude of 30°90′N and 75°85′E, respectively, and an altitude of 244 m above mean sea level in the Central Plain Zone of Punjab. The experiment comprised two *raya* varieties (PBR 91 and PBR 357). The crop was sown in the 1st week of November in both consecutive years in two directions, *viz.,* North-South and East-West. The agronomic practices, irrigation and fertilizer application were done following the *Package of Practices for Rabi Crops of Punjab*.

Weather and soil details

The daily meteorological data, including maximum and minimum temperatures, morning and evening relative humidity, evaporation and rainfall (Figs. 1 and 2), were recorded at the meteorological observatory located near the experimental site at Punjab Agricultural University, Ludhiana. The mean monthly maximum temperature ranged between 12.0 and 32.5°C and 12.5 and 35.4°C during 2019-20 and 2020-21, respectively. While the range of minimum

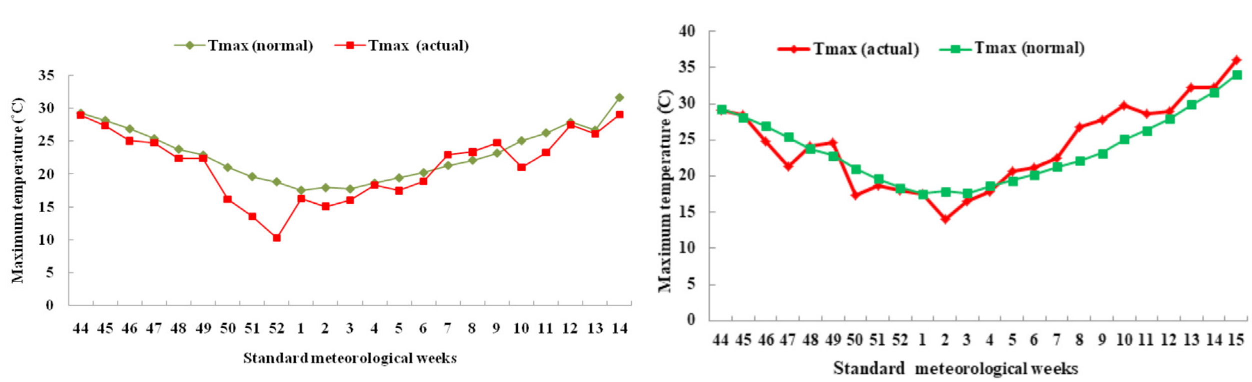

Fig. 1. Comparison of maximum temperature and normal during 2019-20 (a) and 2020-21 (b)

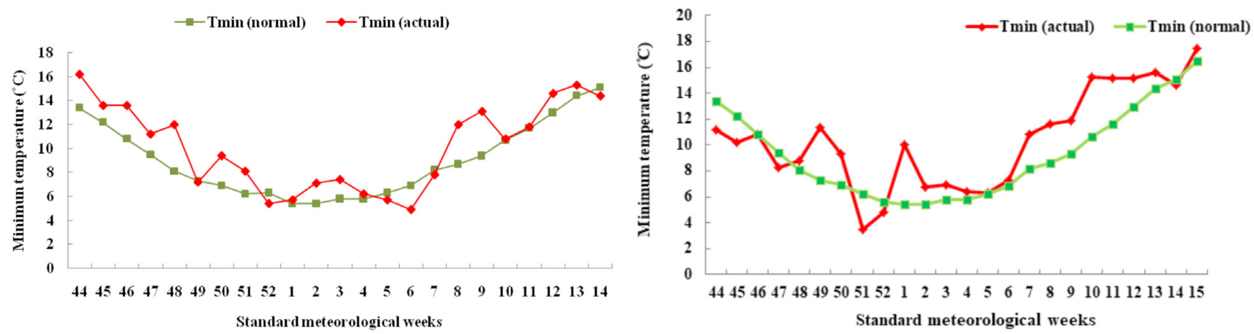

Fig. 2. Comparison of minimum temperature and normal during 2019-20 (a) and 2020-21 (b)

temperature was 4.5 to 11.5°C during 2019-20, it was 4.9 to 12.0°C during 2020-21. The total rainfall recorded during the 2019 and 2020 crop-growing seasons was 196.8 mm and 115.1 mm, respectively.

Biometric and microclimate observations

The periodic measurements of leaf area index (LAI), photosynthetic active radiation (PAR) interception and dry matter accumulation were recorded at every 15-day interval, starting from 30 days after sowing (DAS) up to 120 days after sowing. The relationships of LAI and biomass with PAR interception were computed. Apart from the periodic measurements, yield and yield attributing characteristics (number of primary branches/plant, number of secondary branches/ plant, number of siliquae/ plant, 1000- seed weight, number of seeds/ siliquae were also measured at harvesting. The LAI was measured with a Plant Canopy Analyser. Dry matter accumulation was recorded after oven drying of plant samples at 105°C for 24 hours. A line quantum sensor was used to measure the amount of incoming, reflected and transmitted PAR. The PAR interception was calculated using the following formula:

$$\text{PAR interception (\%)} = \frac{\text{PAR (I)} - [\text{PAR (T)} + \text{PAR (R)}]}{\text{PAR (I)}} \times 100$$

Where,

PAR (I) – PAR incoming above the canopy

PAR (T) – PAR transmitted to the ground

PAR (R) – PAR reflected from the canopy

Results and Discussion

Effect of different varieties and row direction on leaf area index

Leaf area index (LAI) is an important physiological determinant of a crop that influences the rate of photosynthesis, water use, nutrient use and carbon balance. It also helps improve understanding of growth, canopy light interception rate, photosynthesis, and yield. Leaf area increased up to 90 days after sowing (DAS) and then decreased as the crop reached the reproductive and senescence stages (Table 1). Among the varieties, at 90 DAS, the maximum LAI of 3.07 was found in variety PBR 357, and 2.91 in variety PBR 91. On the other hand, minimum values were observed at the initial stage, i.e., 30 DAS, with 1.15 and 1.29 for varieties PBR 91 and PBR 357, respectively. The results are in conformity with the findings of Dalirie *et al.* (2010), which also depict the decreased leaf area index as the crop moves towards the senescence stage. LAI increased with the number of leaves per unit ground area (Ainsworth *et al.,* 2005). Singh *et al.* (2017) also reported a significantly high leaf area index in mustard (4.46) at 90 DAS, with a decreasing trend thereafter. Significant variations in leaf area index across varieties were observed, with a maximum value for BINAsarisha-5 compared to other varieties (Awal and Gani, 2020).

Significant effects of row direction were observed on leaf area index of the crop with a maximum value under North-South (N-S) direction as compared to East-West (E-W) direction (Table 1). This may be because N-S-oriented crops intercepted more PAR and produced more biomass, including

Table 1. Periodic leaf area index of *raya* varieties under different row directions (Pooled data for 2019-20 and 2020-21)

Treatments	Days after sowing					
	30	45	60	75	90	105
			Varieties			
PBR 91	1.15	1.52	2.16	2.66	2.91	2.32
PBR 357	1.29	1.71	2.47	2.80	3.07	2.53
CD (p=0.05)	0.08	0.11	0.31	0.08	0.13	0.20
			Row Direction			
E-W	1.11	1.61	2.26	2.62	2.86	1.83
N-S	1.33	1.82	2.58	2.86	3.02	2.06
CD (p=0.05)	0.05	0.09	0.12	0.10	0.26	0.09

leaf biomass, which in turn increased LAI. These results are similar to those reported in the present studies, which show that crops sown in the N-S direction had the highest leaf area index compared to the E-W row direction (Singh *et al.,* 2018). The highest leaf area index was recorded in N-S row direction compared to E-W row direction (Lunagaria *et al.,* 2006). Also, leaf area index of mustard was significantly affected under different planting geometry (Yadav and Brar, 2003). Numerically, a 9.35 per cent higher leaf area index was found in the N-S oriented crop than in the E-W sown mustard (Goyal *et al.,* 2018).

Relationship between leaf area index and PAR interception

It is a well-established fact that the amount of PAR interception by a crop primarily depends on the distribution of leaf area in time and space. The LAI and dry matter accumulation are useful indicators of crop productivity and are closely related to PAR interception. Light interception and crop growth rate are largely determined by leaf area index. Thus, accurate prediction of leaf area index is important for calculating light interception (Sandhu and Dhaliwal, 2018).

The relationship between PAR interception and leaf area index was computed by using regression analysis during the two crop years (Fig. 4). The following equations were obtained as: Y= 69.84+5.222X (R^2 = 0.85) during 2019-20, and Y= 73.24+3.547X (R^2 = 0.90) under 2021-22, where Y is the independent variable (PAR interception) and X is the dependent variable (Dry matter accumulation). The results revealed that there is a high degree of relationship between PAR interception and leaf area index, with R^2 values of 0.85 and 0.90 during 2019-20 and 2020-21, respectively. Likewise, the PAR interception mainly depends on the variety of factors such as leaf area index, canopy architecture and the physiological capacity to intercept radiation and convert it into biomass (Tripathi *et al.,* 2018). A linear relationship between leaf area index and PAR interception was also reported (Dhaliwal and Hundal, 2004). Scientists also reported the highest PAR interception at flowering stage (85.9%), radiation use efficiency (2.87%) in variety PBR 357 as compared to variety PC6 and GSC7(Singh *et al.,* 2018).

Effect of different varieties and row direction on total dry matter accumulation

Dry matter represents the extent of plant infrastructural buildup and, consequently, the yield-bearing base capacity. Periodic monitoring of dry matter is a good index of plant growth rate. Timely accumulation of dry matter by the crop is important for adequate transfer of assimilates to the sink and ultimately higher yield.

In the present study, dry matter accumulation was recorded at 15 days interval and the pooled results for dry matter accumulation are presented in Table 2. The results revealed that the dry matter accumulation was very low at 30 days after sowing and subsequently increased as the crop moved towards maturity. However, among the varieties, dry matter accumulation ranged from 37.48 q/ha to

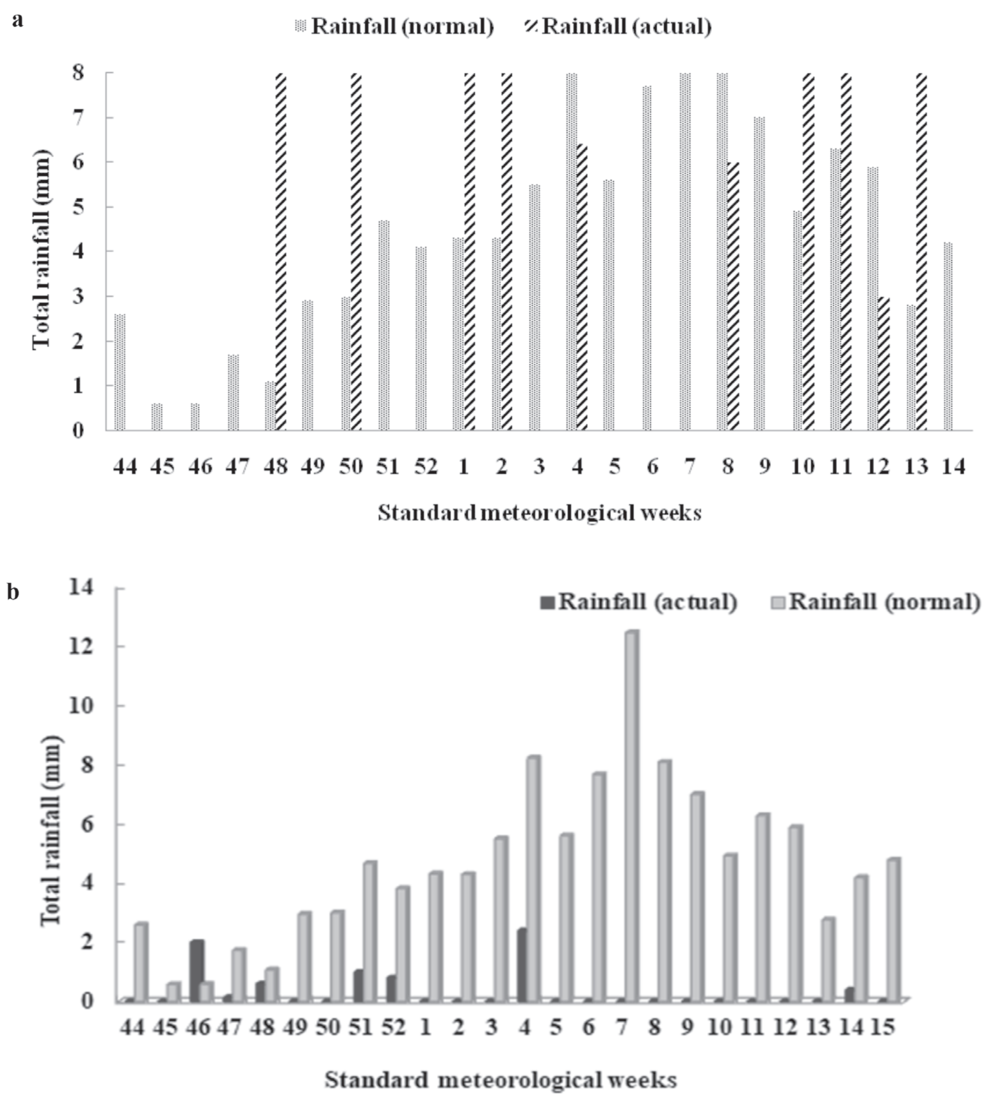

Fig. 3. Total rainfall 2019-20 (a) and 2020-21 (b)

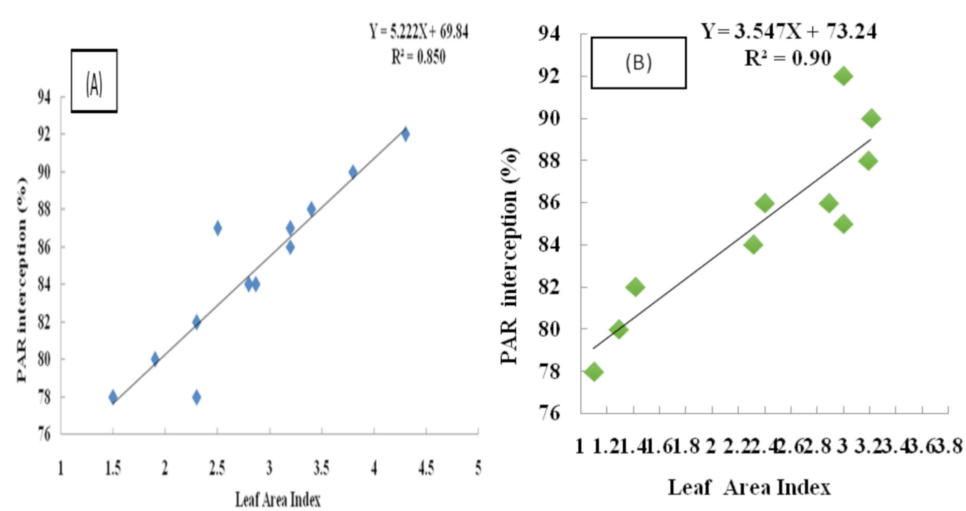

Fig. 4. Relationship between Leaf area index and PAR interception for 2019-20 (A) 2020-21 (B)

145.26 q/ha in variety PBR 91 whereas, in variety PBR 37 it ranged between 37.96 q/ha to 147.35 q/ha. This clearly indicated that variety PBR 357 produced better results in terms of dry matter accumulation than variety PBR 91. The literature reported that the maximum dry matter value was recorded at physiological maturity (Koca *et al.,* 2016). Similarly, dry matter accumulation increased with crop age until harvest (Tripathi *et al.,* 2021). Likewise, the highest dry matter at 100 DAS in mustard was observed (Barimavandi *et al.,* 2010). Varieties also significantly affected dry matter accumulation, with the highest value (53.4 g/g/plant) in variety PBR 357 (Manhas *et al.,* 2022).

Row direction also significantly affected dry matter accumulation (Table 2). Dry matter accumulation continues to increase with the age of the crop. At 150 DAS, the N-S row direction indicated the higher dry matter accumulation (146.61 q/ha) as compared to the E-W row direction, which had a dry matter accumulation of 144.81 q/ha. The maximum dry matter accumulation in the N-S direction is basically because of more interception of solar radiation and more leaf area index in this direction as compared to the E-W direction. Maximum values for biomass under N-S sown mustard (927 g/m^2) and compared to E-W direction (942 g/m^2), and highly significant variations at 1% level among different varieties were observed (Jha *et al.,* 2015).

Relationship between total dry matter accumulation and PAR interception

The photosynthetic efficiency of a crop increases with greater interception of solar radiation. The total dry matter yield of the crop is definitely determined or affected by net photosynthesis. Therefore, the relationship between PAR interception and total dry matter accumulation in *raya* under different treatments was computed. A linear and statistically significant relationship between PAR interception and dry matter accumulation was observed during both years (Fig.5). The regression equations were obtained as: Y=-27.01+0.727X with (R^2= 0.84) and Y= 74.300+148x with (R^2= 0.96) during 2019-20 and 2021-22, respectively. Total of 96 % variation in dry matter accumulation due to PAR interception was depicted by linear regression analysis during 2020-21 (Fig. 3B). On the other hand, for 2019-20, the linear regression equation explained the 84 % variation in dry matter due to PAR interception (Fig. 5A). The results are well supported in past studies in which a regression equation and showed that PAR interception accounted for 85 per cent variation in dry matter (Adak *et al.,* 2011). Also, increasing biomass values were associated with an increasing trend in IPAR (Saikia *et al.,* 2014). The correlation between PAR interception and total dry matter accumulation yielded similar results (Keerthi *et al.,* 2017).

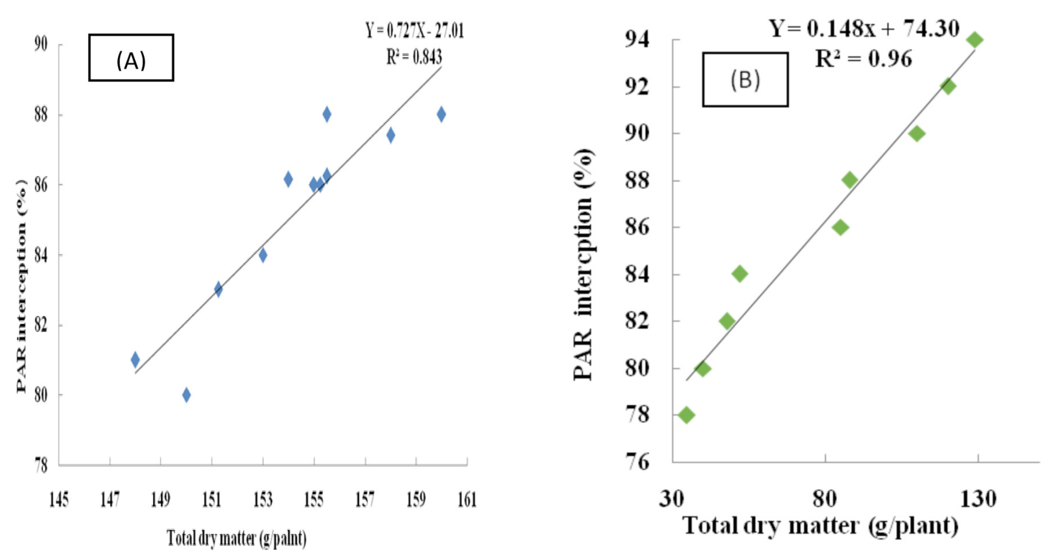

Fig. 5. Relationship between total dry matter and PAR interception of *raya* during *rabi* 2019-20 (A) 2020-21 (B)

Table 2. Periodic total dry matter accumulation of *raya* varieties in different row directions (Pooled data for 2019-20 and 2020-21)

Treatments	Days after sowing					
	30	45	60	75	90	105
Varieties						
PBR 91	37.48	51.01	67.61	104.21	130.91	145.26
PBR 357	37.96	52.81	71.61	107.62	135.06	147.35
CD (p=0.05)	0.04	1.00	1.83	1.31	2.00	0.87
Row Direction						
E-W	37.70	51.81	67.66	103.61	133.72	144.81
N-S	38.21	52.06	70.10	107.75	135.41	146.61
CD (p=0.05)	0.05	NS	2.11	4.61	0.93	0.75

Effect of different varieties and row direction on yield attributes

Different varieties of mustard may have varying characteristics and row direction, which, on the other hand, also affect the yield attributes of mustard by influencing sunlight exposure, airflow and nutrient availability for plants. It is always important to consider the effects of different varieties and row directions on yield attributes.

The yield attributes, viz., number of primary branches/plant, number of secondary branches/plant, number of siliqua/plant, number of seeds/siliqua and 1000-seed weight, were recorded at harvesting. The pooled results for yield attributes are presented in Table 3. All yield attributes except the number of primary branches/plant were significantly affected by two varieties. However, the maximum number of primary branches/plant (3.89), number of secondary branches/plant (13.50), number of siliquae/ plant (260.48), number of seeds/siliqua (11.69) and 1000-seed weight (7.89) were observed in variety PBR 357 as compared to variety PBR 91. The variety PBR 357 performed better with the highest number of siliqua per plant (234.99), number of seed per siliqua (11.61), 1000- seed weight (6.74 g), biomass yield (89.09 q/ha) and seed yield (15.08 q/ha) as compared to variety RLC3 (Jain *et al.,* 2019). Also, more yield contributing characters were observed in variety PBR 357 than the other treatments (Singh *et al.,* 2017)

Likewise, row direction has also shown significant effects on all the yield attributes of *raya*. The crop sown in the E-W row direction observed fewer primary branches/plant, fewer secondary branches/plant, fewer siliquae/plant, fewer seeds/ siliqua and 1000-seed weight (4.21, 12.25, 238.15,

Table 3. Effect of different varieties and row directions on yield and yield attributes of *raya* (Pooled data for 2019-20 and 2020-21)

Treatments	No of primary branches/ plant	No of secondary branches/ plant	No of siliqua/ plant	No of seed/ siliqua	1000-seed weight (g)	Seed yield (q/ha)	Biological yield (q/ha)	Straw yield (q/ha)
Varieties								
PBR 91	3.76	11.98	241.36	10.90	7.64	19.00	84.71	65.86
PBR 357	3.89	13.50	260.48	11.69	7.89	20.46	87.14	66.83
CD (p=0.05)	NS	0.59	5.87	0.36	0.31	0.58	0.85	0.37
Row direction								
E-W	4.21	12.25	238.15	11.09	7.96	18.70	84.55	65.90
N-S	4.48	13.75	263.98	11.71	8.26	20.91	87.10	66.79
CD (p=0.05)	0.10	0.59	6.11	0.28	0.30	0.59	0.89	0.40

11.09 and 7.96) as compared to the N-S direction. This may be owing to low radiation falling on the E-W side as compared to the N-S direction. Similarly, the North-South direction caused more light to penetrate the canopy than the East-West direction, which showed profound effects on the yield attributes of *raya* (Robinson, 1975). Likewise, the highest number of siliquae/plants was more in the N-S row direction due to more light interception (Ismail *et al.,* 1997). The mustard performed better under N-S than under E-W direction (Singh *et al.,* 2018).

Effect of different varieties and row direction on yield (biological yield, seed yield, straw yield)

The biological yield refers to the total dry matter accumulation of a plant system. Straw is an agricultural byproduct consisting of dry stalks of cereal plants after the grain yield chaff has been removed. Seed yield of the crop also has great economic importance. An improved harvest index represents increased physiological capacity to mobilise photosynthates and translocate them into organs that contribute to economic yield. Different varieties and row direction posed significant effects, and the pooled results are presented in Table 3. The data revealed that the biological yield was the highest (87.14 q/ha) in variety PBR 357, compared with variety PBR 91 (84.71 q/ha). Likewise, variety PBR 357 recorded higher seed and straw yields of 20.46 q/ha and 66.83 q/ha, respectively, than variety PBR 91, which had seed and straw yields of 19.00 q/ha and 65.86 q/ha, respectively. This clearly demonstrated the potential of variety PBR 357 to outperform variety PBR 91. Also, in other studies, the highest values of biological yield (86.8 q/ha) and grain yield (19.1 q/ha) were observed under the PBR 357 variety, compared to other cultivars [23]. A significant effect of different varieties on mustard yield was reported, and the highest yield (2770 kg/ha) was recorded under variety PBR 357, compared with other Indian mustard varieties (Manhas *et al.,* 2022). Overall, significant differences in yield and biological yield were observed. Apart from this, N-S reported the highest values compared to the E-W sown crop.

Conclusion

The present study concluded that variety PBR 357 exerted higher number of primary branches/plant, number of secondary branches/plant, number of siliquae/ plant, number of seed/siliqua and 1000-seed weight which contributed to the highest seed yield (20.64 q/ha), biological yield (87.14 q/ha) and straw yield (66.83 q/ha) as compared to variety PBR 91. Among the row direction, owing to the improved PAR interception under crop sown in N-S direction, it recorded the highest number of primary branches/plant, number of secondary branches, number of siliqua/plant, number of seeds/siliqua, 1000- seed weight, leaf area index, dry matter accumulation, seed yield, biological yield and straw yield as compared to crop sown in E-W direction. So, by changing the row direction to the N-S direction, a comparatively higher yield can be obtained without any extra cost.

References

Adak, T., Chakravarty, N.V. K., Kumar, M., Deshmukh, P.S., Joshi, H.C. and Katiyar, R.K. 2011. Evaluation of biomass and thermal energy utilization efficiency of oilseed Brassica (*Brassica juncea*) under altered micro-environments. *Biomass Bioenergy* **35**: 2254-267.

Ainsworth, E.A. and Long, S.P. 2005. What have we learned from 15 years of free-air CO enrichment (FACE)? A meta-analytic review of the responses of photosynthesis, canopy. *New Phytol.* **165**: 351-71.

Anonymous (2023-24) *Package of Practices for Crops of Punjab (Rabi)*. Punjab Agricultural University, Ludhiana, pp. 22-32.

Awal, M.A. and Gani, M.O. 2020. Study on radiation interception and use in some mustard varieties. *Asian J. Adv. Res*. **9**: 11-23.

Barimavandi, A.R., Sedaghathoor, S. and Ansari, R. 2010. Effect of defoliation treatments on yield and yield components in maize. *Aust. J. Crop Sci.* **4**: 9-15.

Dalirie, M.S., Sharifi, R.S. and Farzaneh, S. 2010. Evaluation of yield, dry matter accumulation and leaf area index in wheat genotypes as affected by terminal drought stress. *Not. Bot. Horti. Agrobo*. **38**: 182-86

Dhaliwal, L.K. and Hundal S.S. 2004. Growth dynamics and radiation interception in Indian mustard (*Brassica juncea*). *Asian J. Agric. Sci*. **74**: 321-23.

Goyal, A., Vashisth, A., Sehgal, V.K., Pradhan, S., Mukherjee, J., Das, D.K. and Singh, J. 2018. Effect of row direction and cultivar on micrometeorological and biophysical parameters of oil seed Brassica. *J. Agric. Meteorol*. **20**: 85-91.

Huang, J.Z., Shreshta, A., Tollenaar, M., Deen, W., Rajcan, I., Rahimian, H. andSwantona, C.J. 2001. Effect of temperature and photoperiod on the phenological development of wild mustard. *Field Crops Res*. **70**: 75-86.

Iraddi, V.S. 2008. Response of mustard (*Brassica juncea* L. Czernj and Cosson) Varieties to date of sowing and row spacing in Northern transition zone of Karnataka. Thesis: University of Agricultural Sciences, Dharwad.

Ismail, M.A. 1997. Effect of some agronomic practices on maize. M.Sc. Thesis, Zagazig University, Zagazig, Egypt.

Jain, G. and Sandhu, S.K. 2019. Agroclimatic indices and yield of mustard under different thermal regimes. *J. Agric. Phys.* **8**: 232-39.

Jha, S., Sehgal, V.K. and Rao, Y.V.S. 2015. Effect of sowing direction and crop geometry on water use efficiency and productivity of Indian mustard (*Brassica juncea.* L.) in semi-arid region of India. *J. Oilseeds Res*. **6**: 257-64.

Keerthi, P., Pannu, R.K., Dhaka, A.K. and Reddy, Y.A. 2017. Yield attributes, yield and quality of Indian mustard (*Brassica juncea* L.) as influenced by dates of sowing and nitrogen levels in Western Haryana. *Int. J. Chem. Stud*. **5**: 1890-93.

Koca, Y.O. andErekul, O. 2016. Change of dry matter, biomass and relative growth rate with different phenological stages of corn. *J. Agric. Sci*. **10**: 67-75.

Lunagaria, M.M. and Shekh, A.M. 2006. Radiation interception, light extinction coefficient and leaf area index of wheat (*Triticum aestivum* L.) crop as influenced by row orientation and row spacing. *J. Agric. Sci.* **2**: 43-54.

Manhas, S.S. and Singh, H. 2022. Effect of sowing dates on growth, yield and economics of different varieties of Indian mustard (*Brassica juncea* L.) DOI: 10.15740/HAS/IJAS/18-CIABASSD/28-32.

Robinson, R.G. 1975. Effect of row direction on sunflower. *J. Agron*. **67**: 93-4.

Saikia, B., Banerjee, S. and Sarkar, S. 2014. Crop weather relationships in *Brassica campestris* variety yellow sarson grown in gangetic West Bengal. *J. Agrometerol*. **11**: 67-9.

Sandhu, S.K. and Dhaliwal, L.K. 2018. Effect of row orientation on radiation interception and growth dynamics of wheat. *Int. J. Agric. Sci*. **14**: 186-91.

Shekhawat, K., Rathore, S.S., Premi, O.P., Kandpal, B.K. and Chauhan, J.S. 2012. Advances in agronomic management of Indian Mustard (*Brassica juncea* (L.): An Overview. *Int. J. Agron*. https://doi.org/10.1155/2012/408284

Singh, A.K., Singh, H., Rai, O.P., Singh, G., Singh, V.P., Singh, N.P. and Singh, R. 2017. Effect of sowing dates and varieties for higher productivity of Indian mustard (*Brassica juncea* L.). *J. Appl. Nat. Sci.* **9**: 883-87.

Singh, J., Singh, S. and Kingra, P.K. 2018. Dynamic growth pattern of biophysical parameters of rapeseed-mustard cultivars under different thermal environments and row-orientation. *Int. J. Curr. Microbiol. Appl. Sci*. **7**: 435-48.

Singh, J., Singh, S. and Kingra, P.K. 2018. Influence of sowing time and planting geometry on yield and radiation use efficiency of various rapeseed - mustard cultivars. *J. Agric.Meteorol*. **20**: 246-48.

Singh, J. 2016. Microclimate modifications to improve input use efficiency of mustard genotypes. M.Sc. Thesis, Punjab Agricultural University, Ludhiana, India.

Tripathi, M., Gaur, T., Pandey, L., Singh, A., Tiwari, A., Prakash, V., Rathore, U.S. and Singh, R.K. 2021. Effect of sowing dates on growth and yield of Indian mustard (*Brassica juncea* L.) *Int. J. Curr. Microbiol. Appl. Sci.* **10**: 3046-57.

Tripathi, M., Rao, V.U.M. and Singh, D. 2018. Effect of sowing time and season growth manipulations on phenology of Indian mustard (*Brassica juncea*). *Indian J. Agric. Sci*. **77**: 153-57.

Yadav, M.S. and Brar, K.S. 2003. Relationship between meteorological factors and incidence of alternaria blight and white rust of Indian mustard in south-western Punjab. *Plant Dis. Res.* 1**8**: 80-82.

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