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Study on Radiation Interception and Use in Some Mustard Varieties

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Authors' contributions

This work was carried out in collaboration between both authors. Author MAA designed the study, performed the statistical analysis, wrote the protocol and draft of the manuscript. Author MOG helped to collect field data. Both authors read and approved the final manuscript.

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ABSTRACT

Aim: Solar radiation is the unique source of energy which drives the photosynthesis of green plants for producing biomass to living being. Use efficiency of solar radiation to produce biomass has been quantified for many crops in field condition but no study is undertaken for mustard although it is an important oil seed crop in the world as well as in Bangladesh. Therefore, the present study was undertaken to evaluate the radiation-use efficiency of mustard crop.
Study Design: The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replicates.
Place and Duration of Study: The experiment was conducted in the Crop Botany Field Laboratory, Bangladesh Agricultural University, Mymensingh during the winter season extended from November 2011 to March 2012.
Methodology: Treatments comprised six mustard varieties viz. BINAsarisha-3, BINAsarisha-4, BINAsarisha-5, BINAsarisha-6, BINAsarisha-7 and BINAsarisha-8 which were grown following standard cultivation techniques to optimize the growth and development. Radiation measurements along the growing season were carried out during solar noon on some sunny days with a Radiometer connected to a 1 m long Line Quantum Sensor.
Results: Mustard varieties showed wide variation in terms of plant height, branch number, leaf area index (LAI), dry matter (DM) accumulation, yield components and yield and radiation

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interception and use. BINAsarisha-6 showed better performance on the aforesaid traits followed by BINAsarisha-7 while lower performance was observed in BINAsarisha-3 and BINAsarisha-4. The higher seed yield (2.41 t ha^{-1}) was obtained in the BINAsarisha-6, the variety also showed higher radiation-use efficiency, RUE (3.75 g MJ^{-1} PAR) whereas the lower seed yield (about 2.1 t ha^{-1}) was observed in the BINAsarisha-3 or BINAsarisha-4, the varieties also showed the lower RUE (<3 g MJ^{-1} PAR) which indicate that the higher accumulation of DM in BINAsarisha-6 variety as influenced by higher utilization of solar radiation effectively constitute the seed yield. The temporal RUE showed much fluctuated pattern in all the varieties and higher RUEs were observed at the later part of the crop growth. The variety BINAsarisha-6 also showed the higher seasonal mean RUE whereas BINAsarisha-4 showed the lower.

Conclusion: Mustard varieties showed wide variation in growth, yield and radiation interception and use. Higher biomass production as well as higher seed yield is associated with higher utilization of solar radiation.

Keywords: Brassica spp.; dry matter; light utilization; PAR; RUE; yield.

1. INTRODUCTION

Mustard belongs to the family Cruciferae is an important oilseed crop in the world as well as in Bangladesh. Seed yield of mustard in Bangladesh is very poor (0.74 t ha^{-1}) in comparison to other countries like India, Japan, France, United Kingdom and Poland with recorded yield about 1.05, 1.73, 2.68, 3.26 and 2.04 t ha^{-1}, respectively [1]. During the last decade, both acreage and production of mustard have gradually been decreased in Bangladesh due to the competition with other crops and some technological reasons. To promote the mustard production, Bangladesh Institute of Nuclear Agriculture (BINA) has released a number of new high yielding varieties of mustard with yield potentialities ranged between 1.8 and 2.0 t ha^{-1} [2]. The yield of mustard has been increased obviously with the introduction of such high yielding varieties although the demand is not reached up to the mark. Moreover, information on response of those varieties in terms of utilizing solar energy is essential for further promotion of mustard.

Dry matter production is a function of the total light energy intercepted, which drives photosynthesis and of the total amount of CO_2 assimilated minus losses by respiration [3]. On the other hand crop biomass production and yield are reduced with reducing radiation interception and use [4-5]. The arrangement, shape and number of leaves as well as leaf area index (LAI) of plant canopy affect the penetration, interception, distribution and reflection of light [6]. Larger interception of light in crop canopy with smaller mutual shading produces higher harvest index [3,7]. Absorption of light by different row crops depends on row width, width of inter-row, row height and sun and row's geometry [8].

Variation in economic yield of a healthy, well watered and fertilized crop can be related to the interception of photosynthetically active radiation (PAR), the radiation-use efficiency (conversion of that PAR energy to dry matter), and the partitioning of that DM to economic part that constitutes the yield [9-10]. However, there is no research is reported yet on the radiation interception and use in mustard crops. So, attention is to be given for maximizing the utilization of solar radiation by the mustard crop. Considering the above facts, the present study was undertaken with a view (i) to evaluate the growth and yield of six varieties of BINA mustard, (ii) to determine the solar radiation interception and its use efficiency by crop canopies of those mustard varieties and (iii) to correlate the yield and radiation-use efficiency of said mustard varieties.

2. MATERIALS AND METHODS

2.1 Experimental Site

The experiment was conducted in the Crop Botany Field Laboratory, Bangladesh Agricultural University, Mymensingh during the winter season extended from November 2011 to March 2012. Geographically the experimental field is located at 24°75″ N latitude and 90°50″ E longitude at the elevation of 18m above the sea level.

There was a moderate cold air during the month of November to early February and somewhat high warm air during the rest of the months. The average air temperature during the experimental period was 16.5°C to 26.9°C. The average relative humidity was 68% to 97% and the duration of total sunshine varies from 70 hours/month to 345 hours/month from 30 November to 15 March. Daily climatic parameters like air temperature, solar radiation, relative humidity and rainfall are shown in Fig. 1.

2.2 Land Preparation and Fertilization

The land of the experimental plot was opened on 25 November 2011 with a power tiller and it was made ready for sowing on 30 November 2011 by ploughing with a country plough followed by laddering. The corner of the land was spaded and visible larger clods were hammered to break into small pieces. All weeds and stubbles were removed from the land. The land was fertilized with Urea, Triple super phosphate (TSP), Muriate of potash (MP), Gypsum, Zinc sulphate and Boric acid @ 200, 150, 120, 100, 5 and 7.5 kg/ha. One-third of urea and entire doses of other fertilizers were incorporated into the soil during final land preparation and finally the plots were made ready for sowing. The remaining amount of urea was top dressed with 2 equal installments on 20 and 40 days after sowing (DAS).

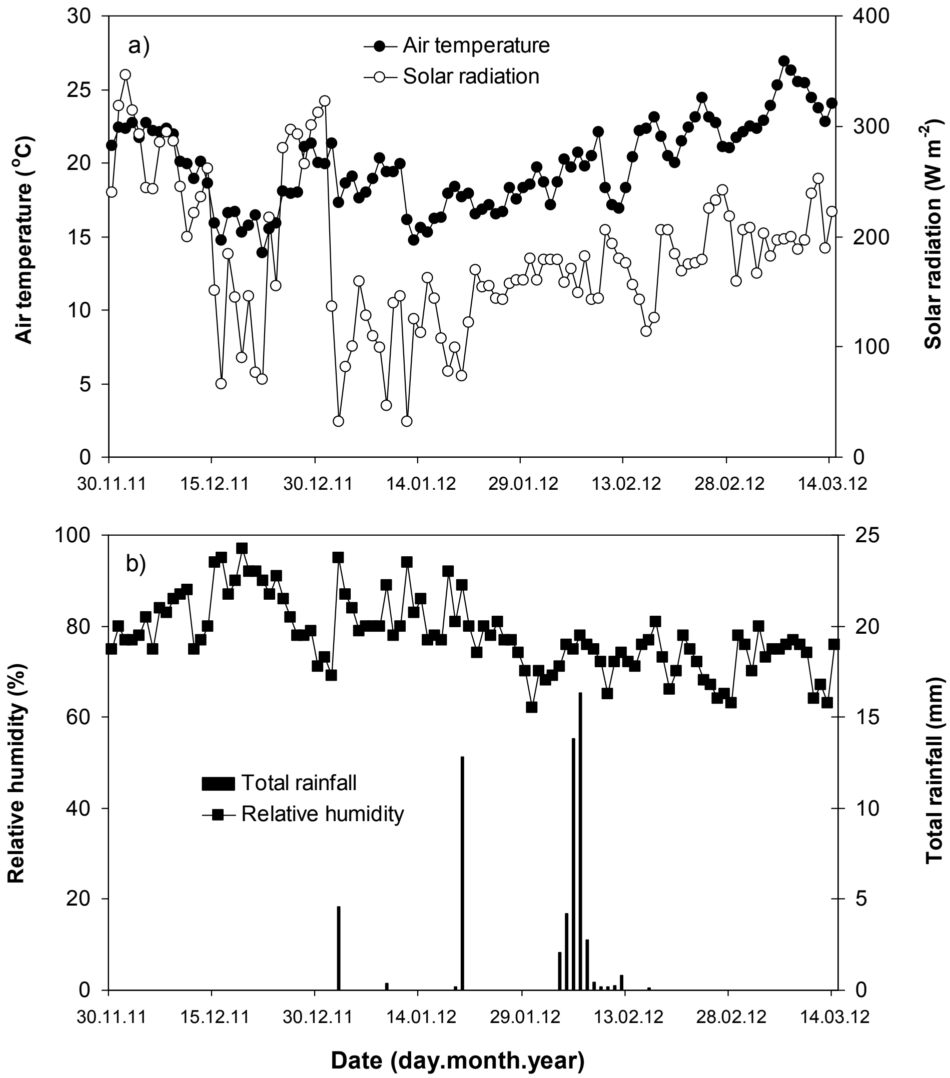

Fig. 1. Daly mean air temperatures, total incident solar radiation, mean relative humidity and total rainfall during the experimental period

2.3 Experimental Treatment and Design

The experimental treatments are six high yielding varieties of mustard viz. BINAsarisha-3, BINAsarisha-4, BINAsarisha-5, BINAsarisha-6, BINAsarisha-7 and BINAsarisha-8. The varieties were recently developed by the Bangladesh Institute of Nuclear Agriculture (BINA). The seeds of said varieties were collected from the Plant Breeding Division of Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh.

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The size of unit plot was 4m×4m. Distance between plots to plot was 1 m. The row to row and plant to plant distances within a row were 25 cm and 5 cm, respectively. Seeds were sown in plots on 30 November 2011. After sowing, the seeds were covered with the loose soil by hand. At least three seeds were shown in each sowing point and one healthy seedling was kept after emergence.

2.4 Intercultural Operations

First thinning operation was done on 12 DAS and the second thinning on 7 days after first thinning. Two irrigations were given. The first one was given at 25 DAS and second one at 45 DAS. Hand weeding was done two times at 15 DAS and 30 DAS to keep the plots weed free.

2.5 Light Measurements

Light characteristics like light reflection, light interception etc. of the growing mustard canopies were measured with a Radiometer or Light Meter (model LI-189, Li-Cor, Lincoln, NE, USA) connected to a 1m long Line Quantum Sensor (Sr. no. LQA 1401, Li-Cor, Lincoln, NE, USA) on some sunny days over the crop growing stages at 7-14 days intervals depending on the transparency of the atmosphere. So, the light measurement dates were 5, 15 and 27 January, 8 and 18 February, and 4 and 14 March of 2012. The measurements were made at noon time to avoid solar inclination angle. The measurements were done only under blue-sky conditions with no cloud cover. Each value was the average of six successive readings. Each set of measurements was taken during a period of constant incident solar radiation.

Light reflection data were taken by inverting the quantum sensor above the crop canopy [9]. Light reflection was calculated by dividing light reflection (I_r) by the light incident (I_o) measured above the crop canopy and then multiplied by 100.

i.e. $\%R = (I_r/I_o)\times100$

Light transmission (I_t) data were taken by placing the quantum sensor below the crop canopy oriented towards the sky. Light interception (I) was recorded by subtracting light transmission (I_t) from light incident (I_o) above the crop canopy which divided by light incident and then multiplied by 100.

i.e. $\%I = (I_o-I_t)/I_o\times100$

The quantitative amount of PAR interception between the two successive measurements was calculated using the following model [10]:

$$\sum I = \Omega\beta(I1+I2)/2$$

where Ω is the summation of the total daily incident short-wave solar radiation (R_s; 0.3–3.0 nm) between the first (1) and second (2) investigation periods, and β (= 0.45) is the conversion factor of R_s, to yield the PAR at 0.4–0.7 nm [3]. The daily incident R_s flux was recorded at the onsite Meteorological Observatory Station.

2.6 Computation of Radiation-use Efficiency (RUE)

The RUE of the seasonal changes (i.e., temporal) was calculated as the difference in the total crop dry weight between two consecutive measurements divided by the corresponding amount of PAR intercepted [10-11]. The seasonal mean RUE was computed as the slope of the linear regression of the cumulative biomass plotted against the corresponding amount of PAR intercepted [9].

2.7 Crops Sampling and Data Collection

The data on crop parameters were recorded on the same dates of light measurement. From each experimental plot 5 plants were uprooted. The sample plants were properly tagged and the data were collected on plant height, number of branches/plant, leaf area index (LAI) and total dry matter (TDM) accumulation.

On physiological maturity (when 70% siliquas became straw colored) the undisturbed crop stands of $1m^2$ from each plot was harvested and bundled separately with proper tags and brought to the clean threshing floor. The bundles were dried in open sunshine for four days, and then threshing, cleaning, winnowing and drying of seeds were done carefully. Straw was also dried properly in the sunshine. Then dry weight of seed and straw were recorded after keeping them in an oven for 72 hours at 80°C. The data on the yield components like number of siliqua per plant, number of seed/siliqua, seed weight per plant, 1000-seed weight etc. and seed yield were recorded. Harvest index was determined as seed yield over biological yield where biological yield means TDM accumulation.

2.8 Statistical Analysis

The collected data on different parameters were statistically analyzed to obtain the level of significance using MSTAT-C Package Programme. The mean differences were compared by Duncan's Multiple Range Test (DMRT) [12].

3. RESULTS AND DISCUSSION

3.1 Plant Height

Plant height increased gradually with the progress of growth stages (Fig. 2). The variation of plant height among the varieties was found significant in all the harvest dates. At maturity, the maximum plant height was obtained from BINAsarisha-4, BINAsarisha-5 or BINAsarisha-6 but at earlier growth stage, these varieties could not grow faster and obtained relatively shorter stature. The minimum plant height was recorded for the variety BINAsarisha-3 throughout the growing season. The observed variations in plant height for different mustard cultivars was due to the variation of inherent genotypic potentialities and the result is in agreement with that of Islam (2006) who found significant variation in plant height among the studied mustard genotypes or cultivars like MM02-02rb, MM02-02rb, MM09-02rb, MM03-05 etc. for *Brassica napus* and cvs. Agrani, Safal, Sonali etc. for *Brassica compestris*. Zhou et al. [13] carried out several experiments with the cultivars of *B. napus* and found significant variation in plant height ranged from 88 to 127cm. Mondal et al. [14] also observed the similar result.

3.2 Number of Branches per Plant

The number of branches increased gradually with season progressed. The effect of variety on the branch production was found significant (Fig. 3). The mustard crop grown with cv. BINAsarisha-8 produced the higher number of branches whereas cv. BINAsarisha-4 produced the lower number of branches throughout the growing season.

Branch number is largely influenced by genotypes and soil nutritional status but significant genotypic variation was observed in this character as found by many workers [13-15]. They reported that the branch number had ranged from 0.8 per plant to 10.5 per plant. Sharma and Kumar [16] conducted a field experiment to study the effect of irrigation on Indian mustard. They found an increase in the frequency of irrigation gave more branches/plant. Varieties among *Brassica* species showed a marked variation in the arrangement of the branches and their number/plant. Khaleque [17] observed 3.9 and 3.1 primary number of branches/plant produced in Kollania and Sonali sarisa (mustard), respectively. The results are also consistent with the results of Khaton [18] who reported that number of branches per plant differed significantly among the varieties of mustard like cvs. Agrani and Safal for *B. campestris* and cvs. MM49-98 and MM06-02rb for *B. napus* and cvs. MM04-04 and RAI5 for *B. juncea*.

3.3 Leaf Area Index (LAI)

Leaf area index quickly increased to attain a peak on 47 DAS (15 January 2012) followed by a decrease with growing season. However, there was almost no green leaf area at physiological maturity of the crop (Fig. 4). The higher LAI was obtained from the mustard canopy grown with BINAsarisha-5 or BINAsarisha-4 and the lower LAI was obtained from BINAsarisha-8 canopy in almost all the harvest dates.

It was observed that the effect of variety on the LAI was significant. The crop canopy grown with variety BINAsarisha-5 produced higher LAI whereas the BINAsarisha-8 canopy produced lower LAI throughout the crop growth stage. The results are in agreement with the results published by Prakash et al. [19] in mustard.

3.4 Light Reflection

Light reflection was recorded from 37 DAS (5 January 2012) to final harvest at 10-14 days interval. Light reflection increased up to 59 DAS (27 January 2012) followed by a decrease with progress of crop age (Fig. 5). The higher percentage of light was reflected from the crop

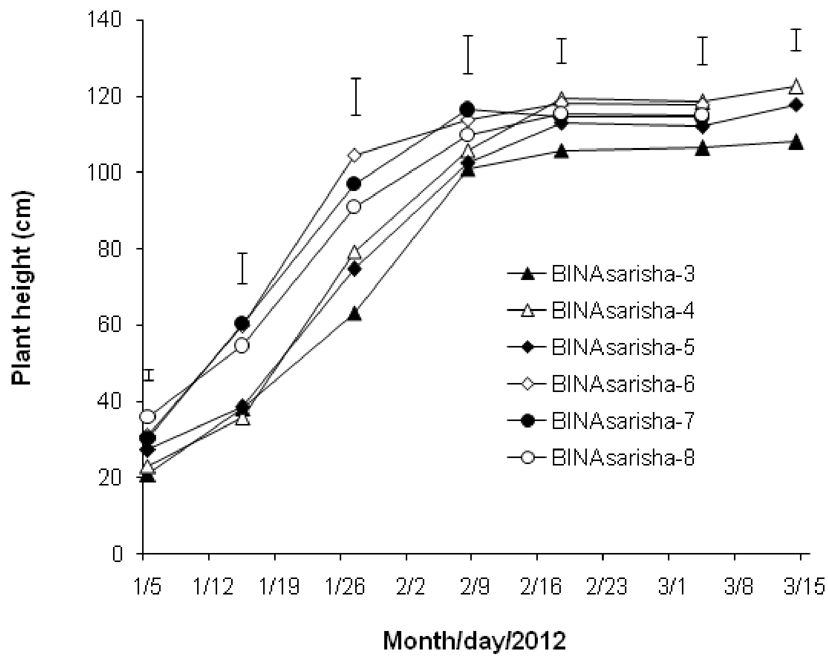

Fig. 2. Plant height of six mustard varieties at different dates. Vertical bars represent the Least Significant Difference (LSD) at *P*<0.05

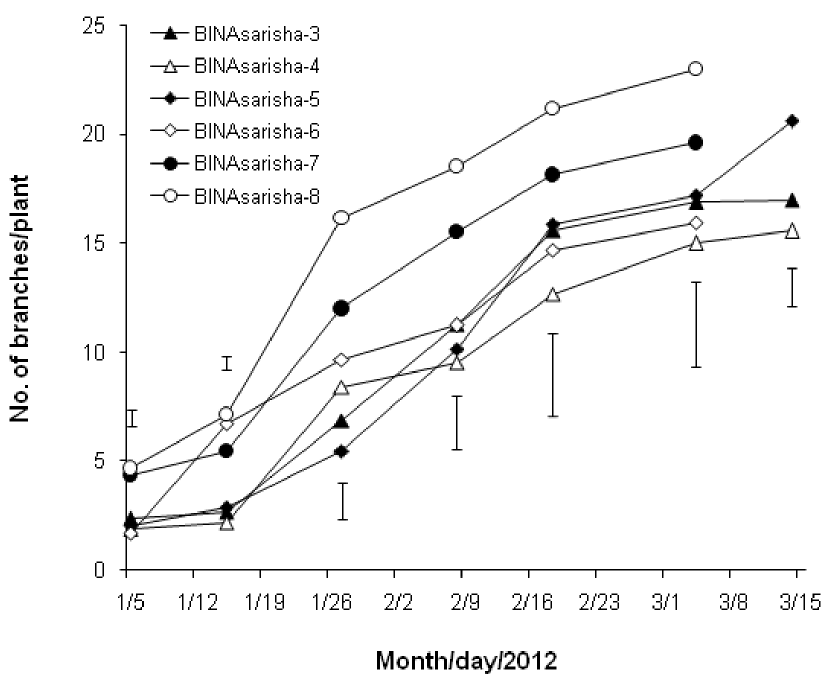

Fig. 3. Number of branches per plant of six mustard varieties at different dates. Vertical bars represent the Least Significant Difference (LSD) at *P*<0.05

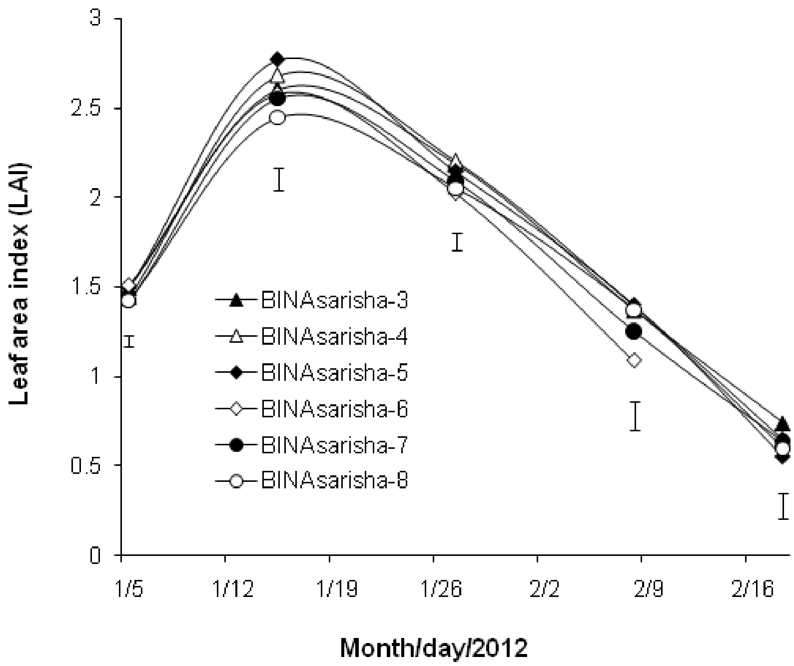

Fig. 4. Leaf area index (LAI) of six mustard varieties at different dates. Vertical bars represent the Least Significant Difference (LSD) at *P*<0.05

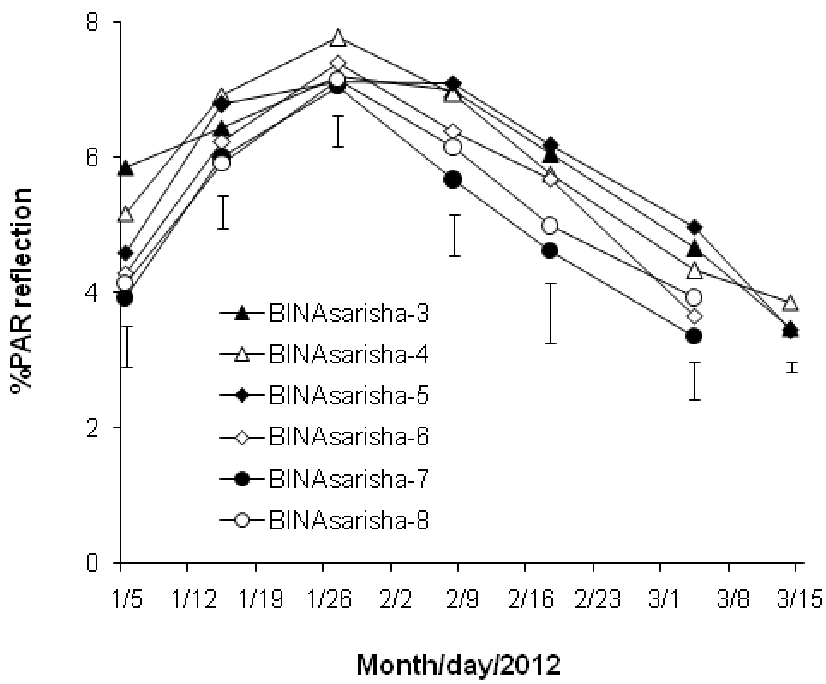

Fig. 5. Percent reflection of Photosynthetically Active Radiation (PAR) by the canopies of six mustard varieties at different dates. Vertical bars represent the Least Significant Difference (LSD) at *P*<0.05

canopies at 59 DAS (27 January 2012) and the lower percentage of light reflected at 37 DAS (5 January 2012) and 106 DAS (14 March 2012). The variation in light reflection percentage among the varieties was found significant. The higher percentage of light reflection was recorded from the crop canopy of mustard variety BINAsarisha-3 and the lower percentage of light reflection was observed from the crop canopy of variety BINAsarisha-7 throughout the growing season. Yellow flower at canopy apex increased the light reflection in mustard crop as compared to the other crops like peanut [9].

3.5 Light Interception

Light interception through the growing crop canopy increased up to 71 DAS followed by a decrease with growth progress (Fig. 6). The minimum light interception was recorded through the mustard crop raised from the variety BINAsarisha-6 throughout the growing season. Maximum light interception was recorded from the crop canopy raised from the mustard variety BINAsarisha-8. The seasonal time course of light interception of mustard varieties in this study is similar to that of other field crops reported else [9-10,20].

3.6 Total Plant Dry Matter Accumulation

Total dry matter (TDM) is the sum of dry weight of roots, stem, leaves, and branches and fruits (i.e. siliqua). Initial slow accumulation of TDM increased rapidly till 96 DAS followed by a slower increase. Fig. 7 showed that the higher TDM accumulation was observed from the crop raised with BINAsarisha-8 whereas the slower increase of TDM accumulation was found in the crop grown with BINAsarisha-5 in almost all the harvest dates throughout the growing season.

Radiation interception had significant effect on total plant dry matter accumulation. At 47-90 DAS, higher light interception was recorded when TDM accumulation was also found higher than other days of harvests. The amount of dry matter produced by a crop, growing under non-limiting conditions, is almost related to the amount of photosynthetically active solar radiation (i.e. PAR) intercepted or absorbed by its green leaf area [3].

Total plant dry matter accumulation was increased gradually with the increase of growing season. It was observed that the effect of variety on the total plant dry matter accumulation was found significant. The crop grown with variety BINAsarisha-8 produced the higher TDM and the crop grown with BINAsarisha-5 produced the lower total plant dry matter across the growth phases (Fig. 5). Similar results were found by Mondal et al. [14] and Islam [21] who observed a wide range of TDM accumulation in mustard varieties like cvs. MM02-02rb, MM09-02rb, MM03-05 etc. for *B. napus* and cvs. Agrani, Safal, Sonali etc. for *B. campestris*.

3.7 Temporal and Seasonal RUE

Temporal RUE showed irregular pattern in all the varieties which gradually increased with the progress of season (Fig. 8). Higher RUE of mustard crops was observed during the last month of crop growth. The higher temporal RUE was recorded from the crop grown with variety BINAsarisha-3 at 106 DAS (14 March 2012) and the lower temporal RUE was recorded from variety BINAsarisha-5 at 37 DAS (5 January 2012). The maximum temporal radiation-use efficiency was found in variety BINAsarisha-7 than other varieties of mustard studied on 18 February 2012. While the minimum temporal RUE was found in variety BINAsarisha-5.

Variation in seasonal mean RUE for the different mustard varieties was found significant (Fig. 9). The higher seasonal mean RUE was recorded from the crop grown with variety BINAsarisha-6 and the lower seasonal RUE was recorded from BINAsarisha-4. Seasonal mean RUEs of BINAsarisha-5 and BINAsarisha-7 were statistically same. Awal and Ikeda [9] and Awal et al. [10] measured the RUEs in peanut and maize stands ranges from 1.07 to 1.53 g MJ^{-1} for peanut and from 3.03 to 3.27 g MJ^{-1} for maize which are similar to those of the RUE data obtained for mustard crops in this experiment.

3.8 Yield Components, Yield and Harvest Index

The mustard varieties had shown significant variation on the data of yield components (Table 1). The mustard varieties BINAsarisha-7 and BINAsarisha-8 showed significantly higher values in all the yield components except for the number of seed per siliqua where BINAsarisha-5 variety had higher number of seed per siliqua. The sink characters i.e. thousand grain weight has direct effect on grain yield. If thousand grain weights increase the ultimate total yield may increase if the total number of seed is unchanged. A wide range of variation for thousand grain weight was

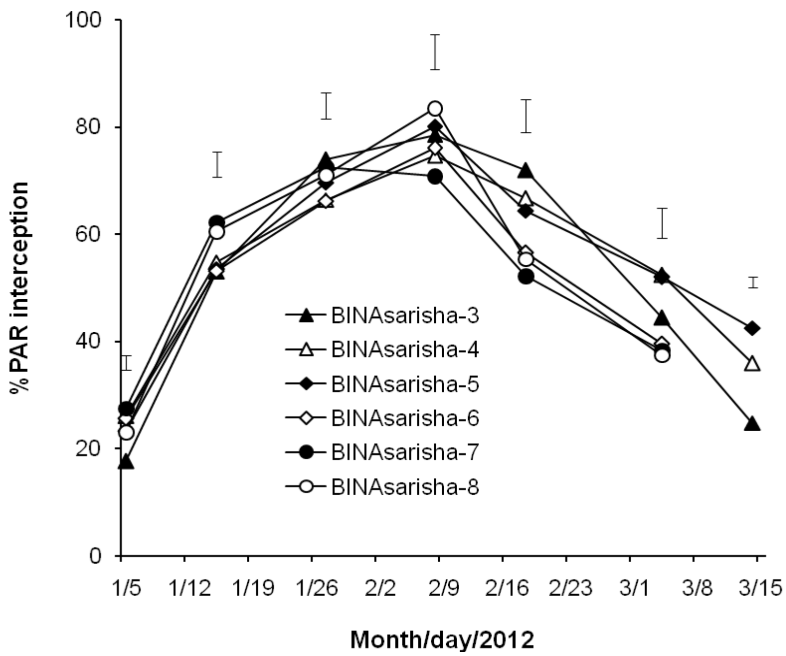

Fig. 6. Percent interception of photosynthetically active radiation (PAR) through the canopies of six mustard varieties at different dates. Vertical bars represent the Least Significant Difference (LSD) at *P*<0.05

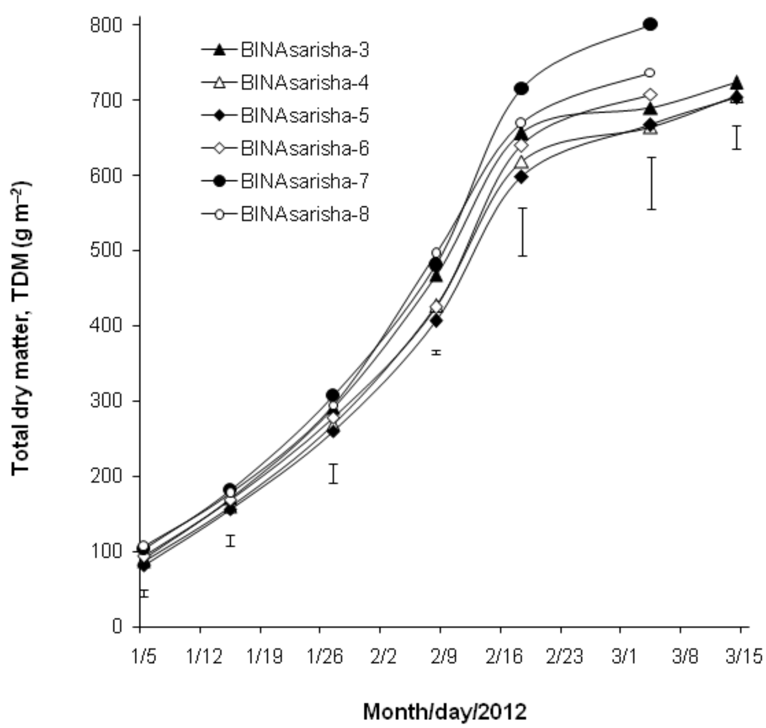

Fig. 7. Total Dry Matter (TDM) accumulation of six mustard varieties at different dates. Vertical bars represent the Least Significant Difference (LSD) at *P*<0.05

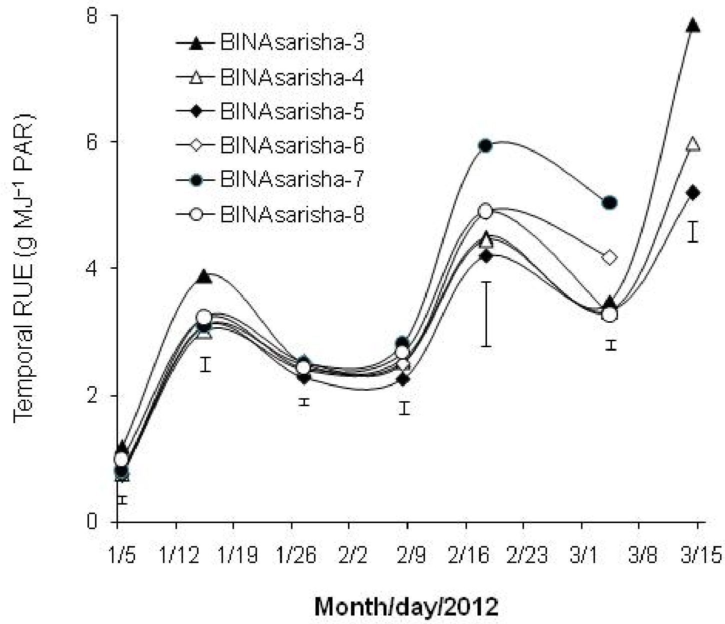

Fig. 8. Seasonal fluctuation in radiation-use efficiency (RUE) of six mustard varieties at different dates. Vertical bars represent the Least Significant Difference (LSD) at *P*<0.05

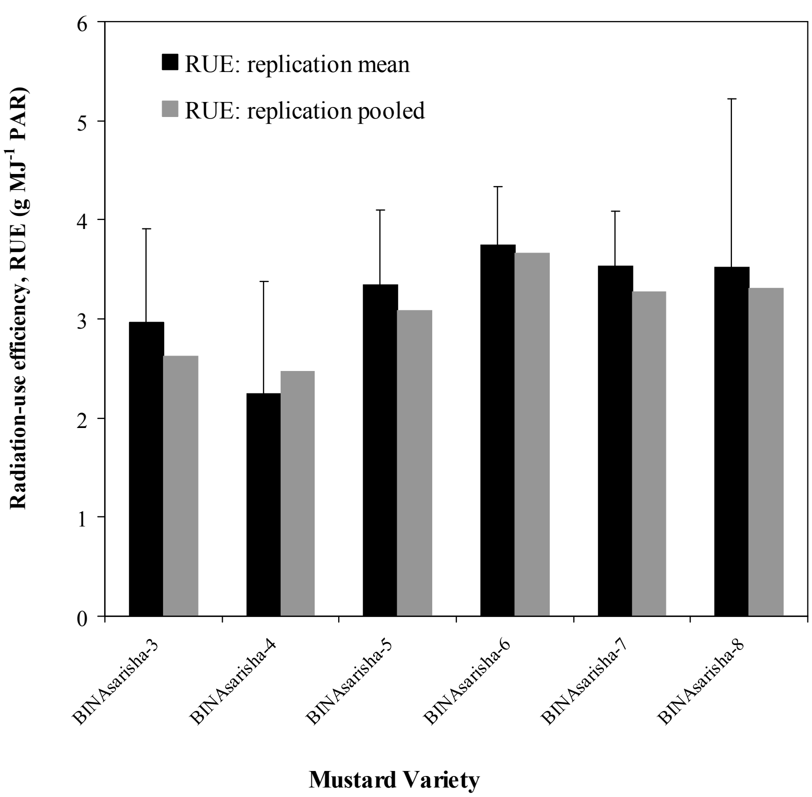

Fig. 9. Seasonal mean radiation use-efficiency (RUE) of six BINA mustard varieties. Vertical bars represent the standard deviation (*n = 3*) of means

Table 1. Yield components and yield of six mustard varieties

Mustard variety	No. of siliqua plant^{-1}	No. of seed siliqua^{-1}	1000 Seed wt. (g) [a]	Seed wt. (g plant^{-1}) [a]	Seed yield (t ha^{-1}) [a]	Biological yield (t ha^{-1})[a]	Harvest index (%)[b]
BINA sarisha-3	54.67c	18.00b	2.683b	2.643d	2.113b	7.210b	24.37c
BINA sarisha-4	55.67c	18.00b	2.677b	2.677cd	2.143b	6.950b	25.60bc
BINA sarisha-5	55.67c	19.67a	2.650b	2.903ab	2.323ab	6.807b	28.67ab
BINA sarisha-6	65.33b	18.00b	2.56c	3.013a	2.410a	7.067b	31.37a
BINA sarisha-7	76.33a	14.00c	2.777a	2.970ab	2.373a	8.003a	29.73ab
BINA sarisha-8	74.00a	14.00c	2.713ab	2.813bc	2.250ab	7.363ab	27.07bc
$LSD_{0.05}$	5.75	0.954	0.081	0.163	0.199	0.656	3.97

[a & b] stand for sundry weight and oven dry weight basis, respectively. Values with similar smaller letters within a column are not significantly differed at 5% level of probability

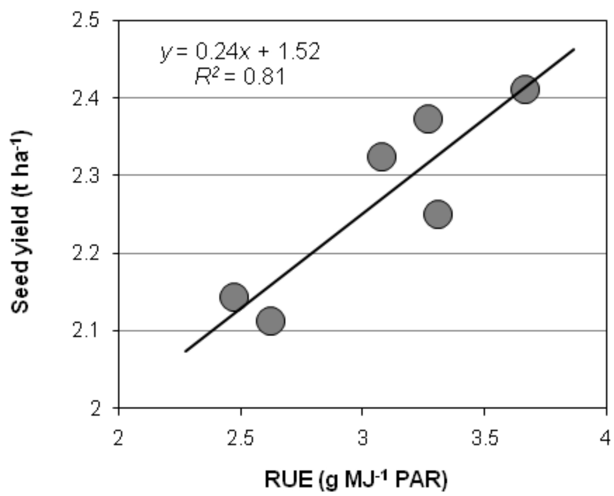

Fig. 10. Relationship between RUE and seed yield across six varieties of mustard

observed by Singh et al. [22], varying from 3.8-5.7 g in locally selected varieties of *Brassica napus*. The genetic potentiality is different for different varieties, and accordingly, yield components are differed and the results are also supported by Mondal et al. [14], Khaton [18], Prakash et al. [19], Singh et al. [22], and Ahmed and Kashem [23] for a wide range of mustard genotypes.

The mustard crops grown with varieties BINAsarisha-6 and BINAsarisha-7 produced the higher seed yield while the lower seed yield was obtained from the crops raised with varieties BINAsarisha-3 and BINAsarisha-4 (Table 1). Overall, the seed yield of mustard varieties was found either similar or higher as that reported earlier [23-30]. Seed yield of rapes and mustard may differ widely from variety to variety within the same species. The results are consistent with that of Khaton [18] who observed a wide variation of seed yield among the mustard genotypes like cvs. MM 49-3-98, MM 48-19, MM 04-04 etc. for *Brassica napus* and cvs. Agrani, Safal, Sonali etc. for *Brassica campestris*.

The higher biological yield was obtained from the variety BINAsarisha-7 with the higher RUE and the lower biological yield was found from the BINAsarisha-4 with lower RUE (Table 1). Similar results were found by Mondal et al. [14] and Islam [21]. They observed a wide range of variability of biological yield in mustard varieties like cvs. MM 02-02rb, MM 09-02rb, MM 03-05 etc. for *Brassica napus* and cvs. Agrani, Safal, Sonali etc. for *Brassica campestris*.

The variation of harvest index of six BINA mustard varieties was found significant (Table 1). The higher harvest index was obtained from the variety BINAsarisha-6 and the lower harvest index was found in the variety BINAsarisha-3 or BINAsarisha-4. Since seed yield and biological yield are different for different mustard varieties hence harvest index also exhibited with different result. Harvest index is an important physiological yield determining character and it measures the partitioning of photosynthates to economic yield i.e. seed yield. Sharma and Kumer [16] reported higher variation for harvest index in mustard crops varying from 12.2% to 32.3%. Moderately higher genotypic variation for harvest index was also reported by Singh et al. [22].

3.9 Relationship between RUE and Yield

A close correlation was observed in between the RUE and yield (Fig. 10). That is the seed yield increases with RUE except for crops grown with varieties BINAsarisha-3 or BINAsarisha-8 because these mustard varieties could not synthesized higher seed yield due to their lower harvest index.

4. CONCLUSION

Six BINA mustard varieties showed wide variation in radiation interception and use, and crop growth in terms of plant height, branch and leaf area development, dry matter accumulation, and seed yield. Crops grown with BINAsarisha-6 or BINAsarisha-8 varieties showed higher seasonal mean radiation-use efficiency (RUE) followed by BINAsarisha-7 or BINAsarisha-5. Similarly, crops grown with the varieties BINAsarisha-6 or BINAsarisha-7 showed higher seed yield followed by BINAsarisha-8 or BINAsarisha-5 which indicate that higher dry matter is produced due to higher RUE. Similarly, higher seed yield is ensured for successful partitioning of biomass to the economic part (i.e., seed) of the mustard plant. A close correlation is found between the radiation-use efficiency and seed yield of mustard varieties except for BINAsarisha-3 or BINAsarisha-8 varieties.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. FAO. Production year book. Food and Agricultural Organization (FAO) of the United Nations, Rome, Italy; 2005.
2. BINA. Annual Report for Development of Crops. Bangladesh Institute of Nuclear Agriculture, Mymensingh; 2010.
3. Monteith JL. Climate and efficiency of crop production in Britain. Philosophical Transactions of the Royal Society B. 1977; 281:277-297.
4. Monteith JL. Solar radiation and productivity in tropical ecosystems. Journal of Applied Ecology. 1972;9:747-766.
5. Monteith JL, Scott RK. Weather and yield variation of crops. In: Food, Nutrition and Climate. (Blaxter K, Fowden L, eds.). (Applied Science Publishing: Englewood, NJ). 1982;127-149.
6. Blad BL, Lemeur R. Miscellaneous techniques for alleviation heat and moisture stress. Modification of the Aerial Environment and Plants (Barfield BJ, Gerber, eds.). American Society of Agricultural and Biological Engineers Monograph. 1979;2:409-425.
7. Donald CM, Hamblin J. The biological yield and harvest index of cereals as agronomic and plant breeding criteria. Advances in Agronomy. 1976;28:361-405.
8. Mutsaers HWJ. The effect of row orientation, date and latitude on light absorption by row crops. The Journal of Agricultural Science Camb. 1980;95:211-225.
9. Awal MA, Ikeda T. Effect of elevated soil temperature on radiation-use efficiency in peanut stands. Agricultural and Forest Meteorology. 2003;118:63-74.
10. Awal MA, Koshi H, Ikeda T. Radiation interception and use by maize/peanut intercrop canopy. Agricultural and Forest Meteorology. 2006;139:74-83.
11. Pradhan S, Sehgal VK, Bandyopadhyay KK, Panigrahi P, Parihar CM, Jat SL. Radiation interception, extinction coefficient and use efficiency of wheat crop at various irrigation and nitrogen levels in a semi-arid location. Indian Journal of Plant Physiology. 2018;23:416-425.
12. Gomez KA, Gomez AA. Statistical Procedures for AGRICULTURAL research. International Rice Research Institute. John Wiley & Sons, New York. 1984;139-240.
13. Zhou YM, Tan Y, Li, Liu M, Wei ZL, Yao L, Shi SW. Studies on irradiation induced mutating in rapeseed (*Brassica napus* L.). Chinese Journal of Oil Crops Science. 1998;20(4):1-5.
14. Mondal MMA, Das ML, Malek MA, Khalil MI. Performance of advanced generation rapeseed mutants under high and low input conditions. Bangladesh Journal of Agricultural Science. 2003;30:115-118.

15. Mondal MMA, Islam MM, Hamid MA, Dutta RK. Performance of rapeseed and mustard varieties/ mutants in Rangpur region under farmers, management practices. Bangladesh Journal Nuclear Agriculture. 2002;18:97-102.
16. Sharma DK, Kumar A. Effect of water stress on plant water relations and yield of varieties of Indian mustard (*Brassica juncea* sub sp. *juncea*). Indian Journal of Agriculture Science. 1989;59(5):281-285.
17. Khaleque MA. A guide book on the production of oilseeds in Bangladesh. Directorate of Agriculture Extension, Dhaka. 1989;24-26.
18. Khaton M. Study of canopy structure and flower production in mustard. M.S. Thesis. Department of Crop Botany, Bangladesh Agricultural University, Mymensingh; 2004.
19. Prakash N, Chauhan YS, Kumar K. Genetics of harvest index, seed and biological yield in Indian mustard. Narendra Deva Journal of Agricultural Research. 1987;2:198-201.
20. Awal MA, Amin MR, Rhaman MS, Shelley IJ, Rahman MS. Canopy characters and light-use efficiency of some modern wheat varieties in Bangladesh. Journal of Agriculture and Ecology Research International. 2017;11(1):1-16.
21. Islam A. Study of some morphological characters and reproductive efficiency in mustard. M.S. Thesis. Department of Crop Botany, Bangladesh Agricultural University, Mymensingh; 2006.
22. Singh P, Khera MK, Gupta KP. Variability and correlation studies for oil seed rape in Rabi season. Crop Improvement. 1991; 18:99-102.
23. Ahmed Z, Kashem MA. Performance of mustard varieties in *Haor* area of Bangladesh. Bangladesh Agronomy Journal. 2017;20(1):1-5.
24. Awal MA, Pramanik MHR, Hoque MA. Compatibility analysis of mustard and soybean stands in intercrop association. Journal of Agroforestry and Environment. 2007;1(2):53-57.
25. Rahman MM, Awal MA, Amin A, Parvej MR. Compatibility, growth and production potentials of mustard/lentil intercrops. International Journal Botany. 2009;5(1): 100-106.
26. Awal MA, Sultana F. Microclimatic alteration and productivity of mustard crop as induced by indigenous mulches. International Journal of Agricultural Research. 2011;6(12):819-829.
27. Awal MA, Fardous T. Effect of a single weeding on growth and yield of two *Brassica* species. American Journal of Biology and Life Science. 2014;2(6):166-172.
28. Rhaman MS, Awal MA, Shelley IJ. Interception and use of solar radiation in mustard/grass pea intercropping. Journal of Agriculture and Ecology Research International. 2016;12(6):1-13.
29. Singh AK, Singh BK, Thakral SK, Irfan M. Effect of sowing dates and varieties for higher productivity of Indian mustard (*Brassica juncea* L.) – A review. Advances in Bioresearch. 2018;9(4):1-8.
30. Jankowski KJ, Załuski D, Mateusz Sokólski M. Canola-quality white mustard: Agronomic management and seed yield. Industrial Crops & Products. 2020;145: 112-138.

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