Responses of Water and Pigments Status, Dry Matter Partitioning, Seed Production, and Traits of Yield and Quality to Foliar Application of GA$_3$ in Mungbean (Vigna radiata L.)

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This study evaluated the role of gibberellic acid [GA$_3$; (0, 100, 200, and 300 ppm)] in modulation of the growth, physiology, yield, and quality traits in two varieties (BARI Mung-6 and BARI Mung-8) of mungbean (Vigna radiata L.). Irrespective of the two varieties (BARI Mung-6 and BARI Mung-8), 100, 200, and 300 ppm of GA$_3$ differentially modulated the tested parameters (relative water content, RWC; photosynthetic pigments: chlorophyll a, chlorophyll b, and carotenoids; growth parameters: fresh and dry weights of leaves, petioles, stems, and roots; yield contributing traits such as plant height, number of pods plant$^{-1}$, number of grains pod$^{-1}$, pod length, and 100-grain weight; quality traits such as grain nitrogen and protein). However, compared to the lowest GA$_3$ (100 ppm) and the highest GA$_3$ (300 ppm), the moderate concentration of GA$_3$ (200 ppm) led to highest values of leaf-RWC, where this parameter exhibited 16.1 and 13.4% increase in BARI Mung-8 and BARI Mung-6, respectively. Similarly, the tested herein growth parameters and the yield traits significantly increased up to the foliar application of the moderate GA$_3$ concentration (200 ppm), and thereafter these traits decreased with 300 ppm GA$_3$. The 200 ppm-led changes in the growth and yield traits were significantly higher in BARI Mung-8 when compared to BARI Mung-6. Considering the quality traits, GA$_3$ positively influenced the nitrogen and protein content in grains, where 200 ppm of GA$_3$ led to increases of 25.2% in N, and 17.7% in protein over control. Overall, BARI Mung-8 significantly responded to the foliar supply of 200 ppm GA$_3$ when compared to BARI Mung-6. Hence, in order to high
INTRODUCTION

Pulses are rich in protein, and contain more than three times higher quality protein than cereals. In addition, pulse crops preserve, and improve soil fertility through biological nitrogen fixation (BNF) in soil and hence, contribute a significant role in sustainable agriculture. Pulses are popularly known as the “poor man’s meat” in most of the developing countries due to cheaper and availability than animal protein. Mungbean [Vigna radiata (L.) R. Wilczek] is an important pulse crop all over the world with an admirable economic importance. The grains of mungbean contain 25.67% protein, 1–3% fat, 5.4% carbohydrates, 3.5–4.5% fibers, and 4.5–5.5% ash with very low amount of flatulence effects (Frauque et al., 2000; Ahmad et al., 2008), and rich in folate and iron (Noble et al., 2018). It is an antique crop in Bangladesh with dietary and nutritional value (Islam et al., 2017c). It is a vital crop to the small land-holdings Asian farmers, and is consumed as a soup of split seeds and spices called Dal or Dhal. It is easily digestible, and does not have any adverse effect on human bodies. It ranks 3rd position next to lentil and grasspea both in acreage and production importance in Bangladesh [Agriculture Information Service (AIS), 2019]. The area and production of mungbean is gradually decreasing regrettably [Agriculture Information Service (AIS), 2019], and it is indispensable to produce extra food from decreasing agricultural land area for mitigating the appropriate food requirements (Islam et al., 2017a,b). The crop fits well in multi-cropping systems, because of its rapid growth and early maturity. Since, the crop is widely grown in marginal and abiotically stressed agro-ecosystems (Raina et al., 2016), but it experiences a considerable yield losses. Total pulses production must be increased urgently to meet the consumption and protein demand. Due to lack of high yielding variety and proper production technology, the yield of mungbean is very low in Bangladesh as compared to other mungbean producing countries. BARI Mung-6 and BARI Mung-8 are the high yielding varieties but the yield in the farmers’ field is very low as compared to their yield potential. Various management practices may help to achieve the desired yield potential of mungbean, and plant growth regulators (PGRs) application in different techniques seem to be the most significant one in view of cost and labor efficacy.

Gibberellic acid (GA3) is an important PGR which enhances the growth, development, and yield of different crops. GA3 is a phyto-hormone, and terpenoid compounds containing 19–20 carbon atoms, naturally produced in new leaves and germinated seed embryos, and more than 136 species have been identified (Sponsel and Hedden, 2004). Very small amount of GA3 enhances stem elongation (Abd El-Fattah, 1997; Hoque and Haque, 2002; Abdel and Al-Rawi, 2011; Keykha et al., 2014) by increasing cell divisions and cell size (Taiz and Zeiger, 2006, 2010), improves plant growth and development (Kundu et al., 2017; Rahman et al., 2018) by inducing metabolic activities (Kumar et al., 2014; Singh et al., 2015), many key enzymes like carbonic anhydrase (CA), nitrate reductase (NR) (Afroz et al., 2005; Aftab et al., 2010; Ahmad Dar et al., 2015), ribulose-1, 5-biphosphate carboxylase/oxygenase (RuBPCO) (Yuan and Xu, 2001), and regulating nitrogen utilization (Siddiqui et al., 2008; Khan et al., 2010; Sure et al., 2012; Zhang et al., 2017; Miceli et al., 2019), consequently increases dry weight and yield (Asahina et al., 2002; Tasmim et al., 2020). It also induces growth and development by enhancing water uptake in plant tissues (Al-Whaibi et al., 2010; Maggio et al., 2010; Renu, 2019), photosynthetic pigments (El Karamany et al., 2019), photosynthesis (Khan et al., 2002; Aftab et al., 2010), sex determination (Fleet and Sun, 2005), flower formation and fruit set in legumes (Deotale et al., 1998; Chauhan et al., 2010), and hence amplifies yield of many crops (Bhadra, 2004; Bora and Sharma, 2006; Abdel-Mouty and El-Gready, 2008; Faizanullah et al., 2010; Rastogi et al., 2013; Keykha et al., 2014). It has also been evidenced that GA3 assists to maintain water status in plants under salinity/drought mediated water deficit stress (Hossain et al., 2015; Nehal et al., 2018), enhances stress tolerance and pathogenic defense (Maggio et al., 2010; Soliman, 2020).

However, exogenous application of GA3 on several other crops has been previously studied but no updated and precise information is available regarding the effects GA3 on the morpho-physiology and quality traits of Vigna radiata in home and abroad. Now, the challenge is to find the ways and means for increasing productivity of Vigna radiata genotypes. Our study concerning responses of water and photosynthetic pigments status, dry matter partitioning, seed production, and traits of yield and quality to foliar application of GA3 in Vigna radiata varieties may lead to provide useful information for increasing productivity worldwide. In view of the above back ground, the present investigation was undertaken to assess the effects of GA3 by different concentrations on the water status, photosynthetic pigments, dry matter partitioning, yield and quality of Vigna radiata, and to find out the optimum concentration of GA3 and suitable variety for higher yield.

MATERIALS AND METHODS

Location and Duration

The study was designed and conducted at the Crop Museum, Department of Agronomy, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh. The geographical position of the area is between 25° 44.574” N and 88° 40.344” E, and 40 m above sea level. The Agro Ecological Zone (AEZ) of the area is the Old Himalayan Piedmont

Keywords: physiology, growth, yield, protein content, gibberellic acid, mungbean
Plain (AEZ-1) [Fertilizer Recommendation Guide (FRG), 2012]. The experiment was completed within the period of February–May 2018.

**Weather Conditions**

Weather data on weekly average temperature, humidity, and rainfall during the research period were recorded regularly by the HOBO U12 Family of Data Loggers (MicroDAQ.com) at the meteorological station of HSTU, Dinajpur. The data regarding average temperature (maximum, minimum, and mean), humidity, and rainfall during the experimentation are presented in Figure 1.

**Soil Properties**

The soil of the experiment was analyzed before sowing of *V. radiata*, and it was sandy loam having very poor nutrients status. The total soil N was 0.08%, indicating a deficiency in soil N. The available K was 0.10 meq 100 g\(^{-1}\) soil, and available P, S, B, Zn, were 11.2, 7.29, 0.13, and 0.90 ppm, respectively. Based on the critical value, the content of N, S, and B were low; but P, K, and Zn were high in the experimental soil. The organic matter content and soil pH values were 1.48% and 5.41, respectively. The morphological, physical and chemical properties of the soil are presented in the Table 1.

**Plant Materials**

BARI Mung-6 (V\(_1\)) and BARI Mung-8 (V\(_2\)) were used in this study. The seeds of high yielding *V. radiata* varieties were obtained from Pulse Research Center, Regional Agricultural Research Station (Bangladesh Agricultural Research Institute, BARI), Ishurdi, Pabna, Bangladesh. Both varieties are very popular due to their unique properties like they can be grown in the year round (Rabi, Kharif-1, and Kharif-2 seasons). The comparative properties of *V. radiata* varieties are presented in Table 2.

**Gibberellic Acid**

Gibberellic acid (GA\(_3\)) was used as PGR, and it is a plant hormone stimulating plant growth and development, which has a tetra cyclic di-terpenoid compound, shown in Figure 2.

**Treatments and Experimental Design**

The research work was comprised as two factors naming four levels of GA\(_3\) (0, 100, 200, and 300 ppm), and two *V. radiata* varieties naming BARI Mung-6 and BARI Mung-8. The research area was divided into 3 blocks, each block was subdivided into eight plots, and size of each plot was 3 m \(\times\) 2 m (6.0 m\(^2\)). The study was laid out in Randomized Complete Block Design (RCBD) with three replications.

**Experimentation**

In experimental site, the land was first plowed thoroughly, fertilized with the recommendation of [Bangladesh Agricultural Research Institute (BARI), 2019] and prepared the land ready for seed sowing. The seeds were sown at mid-February with a spacing of 30 cm \(\times\) 5 cm maintaining required moisture conditions. All intercultural operations are done properly equally for better growth and development. Treatments of GA\(_3\) were prepared according to the treatments specification (100, 200, and 300 ppm concentration), and applied on the plant foliage twice at 25 days after sowing (DAS) i.e., before flowering stage and at 35 DAS i.e., at flowering stage.

![Figure 1](image1.png)
TABLE 1 | Morphology, physical and chemical properties of the soil of the research field, HSTU, Dinajpur, with the critical value and extraction method.

| Parameter | Properties |
|-----------|------------|
| **Morphological soil properties** | |
| AEZ | AEZ-1: Old Himalayan Piedmont Plain |
| Land type | Highland |
| General soil type | Non-calcareous, brown floodplain soil |
| Soil series | Ranisankil |
| Topography | Leveled |
| Drainage | Good drainage system |
| Flood level | Above flood level |
| Geographic position | 25.44° North Latitude, 88.40° East Longitude, 37.35 m above sea level |
| **Physical soil properties** | Value (%) | Critical value | Extraction method |
| Sand | 58 | – | – |
| Silt | 28 | – | – |
| Clay | 14 | – | – |
| Textural class | Sandy loam | – | Hydrometer method (Black, 1965). Determined by Marshall’s triangular coordinates by USDA system |
| **Chemical soil parameters** | Value | Critical value | Extraction method |
| Soil pH (1:1.25, Soil:H₂O) | 5.41 | – | Glass-electrode pH meter with 1:1.25 soil-water ratios (Page et al., 1982). |
| Organic matter | 1.48 | – | Wet oxidation method (Black, 1965). Calculated by Van Bemmelen factor 1.73 (Piper, 1966). |
| N (%) | 0.08 | 0.10 | Micro-Kjeldahl method (Bremner and Mulvaney, 1982). |
| Available P (ppm) | 11.20 | 8.00 | Molybdate blue ascorbic acid (Bray and Kurtz, 1945). |
| Exchangeable K (meq %) | 0.10 | 0.08 | Determined by flame photometer |
| Available K (ppm) | 7.29 | 8.00 | Turbidity method using BaCl₂ (Fox et al., 1964). |
| Available B (ppm) | 0.13 | 0.16 | Atomic absorption spectrophotometer (Lindsay and Norvell, 1978). |
| Available Zn (ppm) | 0.90 | 0.50 | |

TABLE 2 | Properties of existing V. radiata varieties used in the present experiment [Bangladesh Agricultural Research Institute (BARI), 2019].

| Varieties | Year of release | Life span (days) | Plant height (cm) | 1,000-grain weight (g) | Yield (tha⁻¹) | Major diseases and pests |
|-----------|----------------|-----------------|-----------------|-------------------|--------------|-------------------------|
| BARI Mung-6 | 2003 | 55–58 | 40–45 | 51–52 | 1.5–1.6 | Highly tolerant to leaf spot and yellow mosaic virus |
| BARI Mung-8 | 2015 | 60–62 | 55–60 | 30–32 | 1.6–1.7 | Highly tolerant to leaf spot and yellow mosaic virus |

Data Collection

Growth, Plant Biomass, Yield Traits, and Yield

The first sampling was done at 40 DAS for measuring fresh and dry weight of leaves, petioles, stems, and roots. The final data was taken at the harvesting time. The following parameters e.g., plant height (cm), number of pods plant⁻¹, number of grain pod⁻¹, pod length (cm), thousand grain weight (g), grain yield (tha⁻¹), stover yield (tha⁻¹), and harvest index (%) were taken. Harvest index was calculated by dividing the economic yield (seed) from the net plot by the total biological yield (seed yield + stover yield) from the same area and multiplying by 100 according to Donald (1963).

Harvest index(%) = (Grain yield/Biological yield) × 100.

Relative Water Content

The relative water content (RWC) was measured at 40 DAS by fresh weight basis. Fully expanded third trifoliate leaves from top were taken. The leaves were kept immersed in distilled water for 24 h at room temperature in the dark. The turgid weights of those plant parts were measured, and afterwards all the materials were oven-dried at 80°C for 72 h to take dry weight. The values of the fresh, turgid and dry weights of the leaves were used to calculate RWC according to the following formulae used by Barr and Weatherley (1962). The RWC expresses as percentage.

Relative Water Content (RWC) = \[
\frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \times 100.
\]
Determination of Photosynthetic Pigments
Photosynthetic pigments (chlorophyll a and b, and carotenoids) contents in fresh leaves were estimated at 45 DAS on fresh weight basis extracting the leaf samples with 80% acetone using a spectrophotometer (Spectronic UV-1700, Shimadzu, Japan). The reading of the solution (optical density) was recorded at 645 and 662 nm for chlorophylls, and at 470 nm for carotenoids, and calculated using the method of Lichtenthaler and Buschmann (2001). The values of photosynthetic pigments were expressed in mg g⁻¹ FW.

Determination of Nitrogen and Protein Content of Mungbean Seeds
Nitrogen content in grains was determined by Micro-Kjeldahl method (Bremner and Mulvaney, 1982). The actual nitrogen values in the sample were calculated from the standard curve and expressed as percentage. The protein content of seed samples was determined by using method of Thaltooth et al. (2006) and Yagoob and Yagoob (2014), and expressed as percentage.

Seed protein content (%) = Total nitrogen (%) × 6.25

Data Analysis
To analyze the collected data and all parameters MSTAT-C program (One-way ANOVA) was used in computer and presented as mean ± SE (n = 3). Data were adjusted by Duncan’s Multiple Range Test (DMRT) at 5% level of probability (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION
Physiological Traits
Relative Water Content (%)
Exogenous application of GA₃ significantly and positively influenced the RWC in the leaves of V. radiata varieties in this study (Table 3). However, GA₃ application increased the RWC as compared to control, and the highest RWC (85.52 and 88.35%) was recorded with the 200 ppm of GA₃ in BARI Mung-6 and BARI Mung-8, respectively. BARI Mung-8 contained higher RWC than BARI Mung-6 under all GA₃ levels. The increment rates due to foliar application of 100, 200, and 300 ppm GA₃ were 7.9, 13.4, and 7.1% in BARI Mung-6, and 9.2, 16.1, and 10.6% in BARI Mung-8, respectively. The results of our study were strongly supported by Renu (2019), who reported that 200 ppm of GA₃ maintained the highest value of RWC in V. radiata leaves. Several studies showed that exogenous application of GA₃ remarkably increased the RWC in many crops such as faba bean (Al-Whaibi et al., 2010), chickpea (Hossain et al., 2015), wheat (Aldesuquy and Ibrahim, 2001; Hammad and Ali, 2014), maize (Kaya et al., 2006), sweet potato (El-Tohamy et al., 2015), cut flowers (Emongor, 2004), and Thymus vulgaris (Pazoki et al., 2012). Application of GA₃ improved the root growth in our study (Tables 5, 6) which might help to uptake more water in plants. The increased water use efficiency due to GA₃ might be revealed the encouraging effect of GA₃ on both stomatal conductance and leaf area development (Miceli et al., 2019). Leaf stomatal conductance estimates the transpiration rates and gas exchange capacity through leaf stomata. Maggio et al. (2010) concluded that the stomatal resistance is decreased, and water use efficiency is increased in tomato plants due to exogenous application of GA₃. It is also noted in previous studies that GA₃ promotes to synthesize enzymes (invertase) that hydrolyze sucrose into glucose and fructose, thereby making water potential more negative in cells, which in turn results in increased water uptake by the cells (Salisbury and Ross, 1990; Jane, 2001).

Photosynthetic Pigments
Photosynthesis is the essential for plant growth, development, and yield of crops, and chlorophyll is one of the basic inputs for functioning photosynthesis. GA₃ treatments caused a significant increase of the constituent of photosynthetic pigments (chlorophyll a, chlorophyll b, and carotenoids) as compared to control in both varieties, and BARI Mung-8 showed higher values than in BARI Mung-6 (Table 4). However, foliar application of GA₃ at 200 ppm produced the highest amount of chlorophyll a, chlorophyll b, and carotenoids which were statistically similar to 300 ppm of GA₃. These results are supported by several studies reporting that GA₃ enhanced the photosynthetic pigments in V. radiata (Mubeen et al., 2014; Baliah et al., 2018; El Karamany et al., 2019) as well as other crops like wheat (Pazuki et al., 2013), cotton (Onanuga et al., 2012; Firmino da Costa et al., 2017), Euphorbia lathyris (Garg and Kumar, 2012), Aloe barbadensis
TABLE 4 | Effect of GA3 on the photosynthetic pigments (mg g⁻¹ fresh weight) in the leaves of V. radiata varieties.

| GA3 (ppm) | Chlorophyll a | Chlorophyll b | Carotenoids |
|-----------|---------------|---------------|-------------|
|           | BARI Mung-6   | BARI Mung-8   | BARI Mung-6 | BARI Mung-8 |
| 0         | 1.31d (0.06)  | 1.67c (0.12)  | 0.73c (0.06) | 0.81c (0.06) | 0.44c (0.03) | 0.52c (0.01) |
| 100       | 1.93c (0.02)  | 2.23b (0.06)  | 0.89bc (0.03) | 0.98b (0.03) | 0.52bc (0.05) | 0.61b (0.05) |
| 200       | 2.17b (0.06)  | 2.56a (0.06)  | 1.11ab (0.06) | 1.34a (0.06) | 0.69ab (0.03) | 0.86a (0.02) |
| 300       | 2.10b (0.06)  | 2.37ab (0.06) | 1.03b (0.06)  | 1.21a (0.06) | 0.67ab (0.03) | 0.89a (0.03) |
| CV (%)    | 5.32          | 2.36          | 7.85         |

Data are presented as mean ± SE (n = 3). Data followed by same letter are not significantly different by DMRT test at p < 0.05. CV, Co-efficient of variation.

(Sardoei, 2014), broccoli leaves (Hameed et al., 2015), and *Simmondsia chinensis* (Atteya et al., 2018). It has also been reported that exogenous application of GA3 modifies the specific constitution of plastids which is responsible for retention of chlorophyll (Ashour et al., 1973). Among all photosynthetic organisms, the carotenoids act as protecting “antenna pigments” for photosynthesis, gathering wavelengths of light that are not absorbed by chlorophylls (Vichnevetskaia and Roy, 1999). In fact, our results are consistent with previously reported findings that the GA3 enhanced the carotenoids contents in *V. radiata* (El Karamany et al., 2019), *Artemisia annua* (Aftab et al., 2010), rice (Ghodrat et al., 2013), corn (Al-Shaheen et al., 2014), *Trigonella foenum-graecum* (Ahmad Dar et al., 2015). It is suggested that the increase in carotenoid content by GA3 may be due to development of ultrastructural morphogenesis of plastids (Arteca, 1996). The increased contents of photosynthetic pigments (chlorophylls and carotenoids) owing to GA3 are responsible to increase the number and size of chloroplasts, enhance the activity of plastids (Arteca, 1996), Rubisco and photosynthetic CO2 assimilation rate (Taiz and Zeiger, 2006).

**Plant Growth Traits**

**Leaf Fresh Weight**

Fresh weight of *V. radiata* leaves progressively increased with the application of GA3. In case of BARI Mung-8, significantly the highest leaf fresh weight (6.17 g plant⁻¹) was obtained by using 200 ppm of GA3 and the lowest weight (1.51 g plant⁻¹) was reported from control treatment i.e., 0 ppm of GA3 (Table 5). The enhancement of leaf area as well as leaf fresh weight has been demonstrated by Rahman et al. (2018) in *V. radiata*, and they concluded that 100 ppm GA3 as foliar application had produced highly significant values for obtaining the more leaf area comparatively than that of other foliar treatments. A similar conclusion was drawn from a very recent study by Renu (2019) who stated that GA3 at 200 ppm increased the fresh weight of leaves plant⁻¹ in *V. radiata*. Our results are also supported by Keykha et al. (2014) who noted that less concentration of GA3 (75 ppm) produced the highest forage yield of *V. radiata*. Area and number of leaves plant⁻¹ was significantly increased with the application of GA3, and hence, GA3 of 33.3 ppm produced the highest leaf area plant⁻¹ in cow pea (Nabi et al., 2014), 50 ppm produced the highest number of leaves and thereafter decreased in *V. radiata* (Hoque and Haque, 2002) which were indirectly related in our result. GA3 apparently proved to increase the growth of leaves and reproductive organs through intermingling with other growth promoting hormones. In tobacco internodes, GA20-oxidase is the major target for auxin from the shoot apex (Wolbang and Ross, 2001), and it has been suggested that these increases in GA1 and GA4 are necessary for promoting inflorescence development.

**Petiole Fresh Weight**

The fresh weight of petiole in *V. radiata* was also observed as significant increase owing to GA3, and the highest (0.44 g plant⁻¹) and lowest (0.31 g plant⁻¹) values were found at BARI Mung-8 and BARI Mung-6 by the application of GA3 at 200 and 0 ppm, respectively (Table 5). These results are consistent with previously reported information for *V. radiata* (Baliah et al., 2018; Renu, 2019), where GA3 remarkably increased the petiole fresh weight.

**Stem Fresh Weight**

Plant growth and development is considered as an index of yield. As a beginning of physiological process, adequate water absorption is required for plant fresh weight. The stem fresh weight of *V. radiata* varieties were significantly influenced by the application of GA3. Nonetheless, applying of GA3 at 200 ppm gave the highest value of stem fresh weight (1.83 g plant⁻¹) in BARI Mung-8, while 0 ppm (control) gave the lowest value of stem fresh weight (0.72 g plant⁻¹) in BARI Mung-6 (Table 5). BARI Mung-8 was more responsive to GA3 than BARI Mung-6 in this study. Significant variation due to varieties was also obtained in respect of plant growth including stem fresh weight plant⁻¹. Rahman et al. (2018) noticed that foliar application of 100 ppm GA3 produced the highest plant growth (total biomass) in two *V. radiata* varieties of BARI Mung-6 and BARI Mung-5, and the previous variety produced higher biomass than the later. In previous studies (Hedden and Phillips, 2000; Sevik and Guney, 2013), GA3 showed greater influence on many growth
and developmental processes in plants which was confirmatory to the present report, that was particularly important in regulating the stem elongation (Zhang et al., 2007). Seed priming with GA3 (15 ppm) in V. radiata increased the shoot fresh weight up to 6.88% over control (Kundu et al., 2017). Miceli et al. (2019) reported that exogenous application of GA3 showed an increase of total fresh biomass by 41.1 and 40.2% as compared to controls in lettuce and rocket plants, respectively. GA3 increases plant fresh weight due to enhancing water retention in plant cells (Salisbury and Ross, 1990).

### Root Fresh Weight

Foliar spray of GA3 had stimulatory effect on the root fresh weight plant\(^{-1}\). Spraying of 200 ppm GA3 gave the highest root fresh weight (0.62 g plant\(^{-1}\)) from BARI Mung-8, and the lowest fresh weight (0.40 g plant\(^{-1}\)) was obtained from BARI Mung-6 at control treatment (Table 5). However, we observed genotypic variability between the varieties under GA3 treated and non-treated conditions. Application of GA3 produced the highest fresh weight in V. radiata (Baliah et al., 2018), pea (Lazlo, 1974), and Ixora coccinea (Gad et al., 2016). Most favorable effect on the characteristic of root length was highlighted by respective treatments of 10 ppm GA3 as seed priming of V. radiata, and treating of V. radiata seeds with GA3 caused an increase of the root length up to 2.60% (5 ppm of GA3) and the root fresh weight up to 4.35% (10 ppm of GA3) was evidenced over control (Kundu et al., 2017).

### Leaf Dry Weight

Leaf dry matter was significantly influenced by the application of different concentrations of GA3. The higher dry weight of leaf (0.98 g plant\(^{-1}\)) was obtained from BARI Mung-8 as compared to BARI Mung-6 at 200 ppm of GA3 (Table 6). In case of control treatment, both varieties (BARI Mung-6 and BARI Mung-8) gave the lowest values (0.60 and 0.69 g plant\(^{-1}\)), respectively. The present findings are in agreement with the effect of GA3 at its optimum dose of 150–200 ppm for obtaining the highest leaves dry weight plant\(^{-1}\) as indicated by previous workers in V. radiata (Renu, 2019), and in rice (Zhu et al., 1998; Thirthalingapa et al., 1999), although the highest dry weight was recorded at 125 ppm GA3 by Akand et al. (2015) in tomato, and Saini et al. (2017) in mustard. GA3 plays a significant role in leaf expansion, resulting increased leaf dry weight of cabbage (Roy and Nasiruddin, 2011). GA3 acts as messengers for triggering metabolic activities, and accelerates plant growth and development. The significant increase of the leaf dry weight could be explained by the positive effect of photosynthetic pigments due to GA3 (Table 4) that might increase the photosynthesis and dry matter production. Nabi et al. (2014) reported that leaf area, leaf area index as well as leaf dry weight significantly increased with the application GA3 in cowpea. Foliar application of GA3 at the pre-flowering stage causes 35.5% increase in leaf area, which apparently enhances trapping of sunlight and dry matter of mustard plants (Khan et al., 1998), stimulate flowering and can cause fruit set by initiation of fruit growth, followed by pollination (Gupta and Gupta, 2005), involves in the regulation of cell division in meristematic tissues, which results in the formation of new cells (Emongor, 2007) resulting in increased plant growth (Abel and Theologis, 2010).

### Petiole Dry Weight

Both varieties showed significant results at 200 ppm concentration of the foliar application of GA3. But when the varieties are compared with one another then and there BARI Mung-8 showed higher values than BARI Mung-6 in every cases. The highest (0.27 g plant\(^{-1}\)) and lowest (0.14 g plant\(^{-1}\)) petiole dry weight were observed in BARI Mung-8 and BARI Mung-6 at 200 and 0 ppm concentrations, respectively (Table 6). The outcome is identical with Renu (2019), who stated that GA3 of 200 ppm significantly increased the petiole dry weight.

### Stem Dry Weight

Stem dry weight was increased gradually by the application of GA3 from 0 to 200 ppm concentration. The highest value (0.38 g plant\(^{-1}\)) was obtained from BARI Mung-8 at 200 ppm GA3. In case of stem dry weight, BARI Mung-6 gave lower values compared to BARI Mung-8 (Table 6). Our results regarding GA3 are in agreement with the previous results of Renu (2019) who found the highest stem dry weight plant\(^{-1}\) in V. radiata treated with 200 ppm GA3 as compare to untreated control.

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**TABLE 5 | Effect of GA3 on the fresh weight in different plant parts of V. radiata varieties.**

| GA3 (ppm) | BARI Mung-6 | BARI Mung-8 | BARI Mung-6 | BARI Mung-8 | BARI Mung-6 | BARI Mung-8 | BARI Mung-6 | BARI Mung-8 |
|-----------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| 0         | 1.51g (0.06) | 1.80f (0.12) | 0.31h (0.03) | 0.38f (0.02) | 0.72d (0.07) | 1.35b (0.06) | 0.40h (0.02) | 0.47f (0.06) |
| 100       | 2.26e (0.03) | 3.25d (0.12) | 0.33g (0.02) | 0.39d (0.03) | 0.89cd (0.02) | 1.48ab (0.05) | 0.46g (0.02) | 0.53d (0.02) |
| 200       | 5.21b (0.17) | 6.17a (0.18) | 0.41c (0.05) | 0.44a (0.03) | 1.55ab (0.03) | 1.83a (0.04) | 0.53c (0.02) | 0.62a (0.06) |
| 300       | 3.11d (0.25) | 4.11c (0.12) | 0.38e (0.01) | 0.42b (0.01) | 1.43ab (0.06) | 1.23bc (0.06) | 0.50e (0.03) | 0.56b (0.02) |

**CV (%)** | 2.83 | 8.03 | 12.14 | 7.82

Data are presented as mean ± SE (n = 3). Data followed by same letter are not significantly different by DMRT test at p < 0.05, CV, Co-efficient of variation.
TABLE 6 | Effect of GA3 on the dry matter in different plant parts of V. radiata varieties.

| GA3 (ppm) | Leaf dry weight (g plant⁻¹) | Petiole dry weight (g plant⁻¹) | Stem dry weight (g plant⁻¹) | Root dry weight (g plant⁻¹) |
|-----------|-----------------------------|-------------------------------|-----------------------------|-----------------------------|
|           | BARI Mung-6 | BARI Mung-8 | BARI Mung-6 | BARI Mung-8 | BARI Mung-6 | BARI Mung-8 | BARI Mung-6 | BARI Mung-8 |
| 0         | 0.60h       | 0.69f           | 0.14h       | 0.19f           | 0.25h       | 0.29g           | 0.05h       | 0.09f           |
| (0.06)    | (0.06)      | (0.02)         | (0.02)     | (0.02)         | (0.01)     | (0.01)         | (0.01)     | (0.02)         |
| 100       | 0.90f       | 0.92d           | 0.16g       | 0.22d           | 0.30f       | 0.32e           | 0.08g       | 0.11d           |
| (0.03)    | (0.01)      | (0.02)         | (0.02)     | (0.02)         | (0.01)     | (0.01)         | (0.01)     | (0.01)         |
| 200       | 0.97c       | 0.98a           | 0.24c       | 0.27a           | 0.36b       | 0.38a           | 0.12c       | 0.15a           |
| (0.03)    | (0.05)      | (0.02)         | (0.01)     | (0.02)         | (0.02)     | (0.01)         | (0.01)     | (0.01)         |
| 300       | 0.91e       | 0.95b           | 0.21e       | 0.25b           | 0.33d       | 0.35c           | 0.10e       | 0.13b           |
| (0.03)    | (0.01)      | (0.02)         | (0.01)     | (0.01)         | (0.03)     | (0.01)         | (0.01)     | (0.02)         |
| CV (%)    | 5.09         | 7.09           | 5.43         | 7.01           |

Data are presented as mean ± SE (n = 3). Data followed by same letter are not significantly different by DMRT test at p < 0.05, CV, Co-efficient of variation.

Mukhtar and Singh (2006) reported that GA3 stimulated an increase in growth, and grain yield of cowpea. GA3 increased the total dry biomass plant⁻¹ at all stages of growth, and the maximum total dry biomass plant⁻¹ was recorded with foliar spraying of GA3 at 125 ppm in mustard (Saini et al., 2017) and tomato (Akand et al., 2015). GA3 had significant effect on the plant dry weight where it increased the dry weight, while the highest dry weight was recorded with 33.3 ppm GA3 which was statistically close to 50 ppm GA3 (Nabi et al., 2014). Doijode (1977) also found the highest plant dry weight in garden pea at flowering stage with foliar spraying of 30 ppm GA3. GA3 is responsible for prompting growth activities, increasing stem elongation and dry weight and yield (Abdel et al., 1996; Deotale et al., 1998). It may be due to greater cell division and stem elongation (longer plant), higher RWC, photosynthetic pigments, and plant biomass (fresh weights of leaves, stems, and roots) and N content in grains. Similar trends of better plant growth due to cell division and expansion (Roy and Nasiruddin, 2011), higher photosynthesis (Kumar et al., 2014), more total chlorophyll, carotenoid, total carbohydrates (Singh et al., 2015), higher crop growth rate (CGR), relative growth rate (RGR) (Rahman et al., 2018) was recorded in many studies. On the other hand, our study contradicts the earlier findings as non-significant improvement of shoot dry weight in V. radiata was observed by exogenous application of GA3 (Kundu et al., 2017). As compare to control, the total dry biomass of lettuce and rocket plants increased due to exogenous application of GA3 (10⁻⁶ M) by 59.9 and 59.0%, respectively (Miceli et al., 2019). From different literature it can be said that the concentration of GA3 varied for obtaining the maximum dry weight might be differential plant species and contiguous environment. Hedden and Thomas (2012) also concluded the similar statement on their study.

### Root Dry Weight

GA3 caused a significant increase of root dry weight plant⁻¹ as like the previous parameter in both varieties. However, foliar application of 200 ppm concentration GA3 recorded the highest value of root dry weight plant⁻¹ (0.12 and 0.15 g plant⁻¹) in BARI Mung-6 and BARI Mung-8, respectively. While, the lowest root dry weight (0.05 and 0.09 g plant⁻¹) was obtained at control condition from BARI Mung-6 and BARI Mung-8, respectively (Table 6). These results are consistent with previously reported data where the highest root dry weight plant⁻¹ was obtained with 200 ppm GA3 in V. radiata (Renu, 2019), and with 125 ppm GA3 in tomato (Akand et al., 2015). The root dry weight was always higher in BARI Mung-8 than in BARI Mung-6 in this study. It has been reported that GA3 increases the root dry weight in beans (Jaques et al., 2019), Trigonella foenum-graeeum (Ahmad Dar et al., 2015), the dry weight of pods in French bean (Gabal et al., 1990), and bulbs in onion (Hore et al., 1988). However, exogenous application of GA3 through seed priming in V. radiata did not influence the root dry weight as reported by Kundu et al. (2017), which contradicts in our findings.

The results demonstrated an increased dry matter accumulation (leaves, petioles, stems, and roots) due to GA3 treatment may be potentially attributed to the better water balance (demonstrated by higher RWC) in photosynthetic organs (Table 3), and higher photosynthetic pigments (Table 4) thus helped to maintain higher photosynthetic rate and growth. Sun (2004) reported that GA3 stimulates the production of mRNA molecules in cells which activates hydrolytic enzymes, and consequently promotes speedy growth. It is well-established that greater dry matter production and distribution significantly contributes to the yield potential of crop plants and would appear to largely account for the increased crop yields. A clear correlation between phytohormone content and the rate of dry matter accretion by the sink is recorded in many recent studies (Rahman et al., 2018; Miceli et al., 2019; Renu, 2019). PGRs have a potential role to influence the movement of photo-assimilates through their action on either sink activity and/or sink size. The rate of photo-assimilates transfer from the phloem could be adjusted by PGRs influencing phloem unloading and/or sink uptake processes (Patrick and Wareing, 1981). GA3 enhances hydrolysis of starch, fructans and sucrose into glucose and fructose molecules which provide energy via respiration, and also contribute to cell wall formation, thereby promoting cell and plant growth (Salisbury and Ross, 1990).
Plant Height

We evaluated the effect of GA$_3$ on the plant height which was recorded at final harvesting stage. Genetically, BARI Mung-8 was the longer plant as well as more responsive to GA$_3$ as compare to BARI Mung-6. GA$_3$ had a positive effect on the plant height of both varieties, and the rate of increment was higher in BARI Mung-8 than BARI Mung-6. BARI Mung-8 treated by GA$_3$ at 200 ppm substantially increased the plant height (24.17%), while the increment was only 19.75% in case of BARI Mung-6 (Table 7). Application of GA$_3$ at 200 ppm increased the plant height of 59.42% in V. radiata (Renu, 2019), 100.98% in garden pea (Singh et al., 2015), and 11.72% in tobacco plants (Wolbang and Ross, 2001). The possible reason of increased plant height could be ascribed to the favorable effects of GA$_3$ on the physiological processes inducing cell division, increasing cell elongation, and enlargement or both due to higher RWC (Table 3) and photosynthetic pigments (Table 4). Our result is also in agreement with the findings of Hoque and Haque (2002), Abdel and Al-Rawi (2011), Keykha et al. (2014) and Raina et al. (2018) in V. radiata, Iqbal et al. (2001) in chickpea, Emongor (2007) in cowpea, Pandey et al. (2004) in pea, Deotale et al. (1998) in soybean, and Kumar et al. (2014) in tomato. The increase in plant height due to GA$_3$ application might be had an effect on the elongation of internodes (Krishnamoorthy, 1981). If the concentration of GA$_3$ is increased, the plant height also increased in faba bean (Omar et al., 1998). Application of GA$_3$ resulted in increase plant height was evidenced by Chauhan et al. (2009) in black gram and horse gram, Noor et al. (2017) in French bean, Sarkar et al. (2002) in soybean. Seed priming with GA$_3$ also increased the seedling length of many crops like V. radiata (Kundu et al., 2017), Pennisetum typhoides (Sevik and Guney, 2013), carrot, lettuce, onion, and Welsh onion (Jeong et al., 2000), and Pennisetum typhoides (Gupta and Mukherjee, 1982). During priming GA$_3$ may be influence seed germination, and growth and developmental processes of plumules and radicles regulating increase stem and root elongation. This may be attributed to the capacity of GA$_3$ to induce mRNA synthesis pertaining to hydrolytic enzymes and to the increased cell enlargement eventually leading to increased length of internodes. Exogenous PGR enhanced plant growth by overcoming any harmful effect that may be due to changing (Yoshida and Hirasawa, 1996; Ahmad Dar et al., 2015) and functioning endogenous plant hormones.

Number of Pods per Plant

The application of GA$_3$ showed a significant effect on the increasing number of total pods. According to inherent characteristics, the varieties differed significantly, and BARI Mung-8 produced higher number of pods (9.84) than BARI Mung-6 (6.07) under control condition. The maximum number of pods plant$^{-1}$ by applying 200 ppm of GA$_3$ was obtained (13.81 and 9.04) from BARI Mung-8 and BARI Mung-6, respectively (Table 8). GA$_3$ controls the pod development in pea (Santes and Garcia-Martinez, 1995). Application of GA$_3$ at 80 DAS increased the number of pods plant$^{-1}$ in Brassica juncea (Khan et al., 1998; Saini et al., 2017). The effective rate of application on the number of pods plant$^{-1}$ varied with the varieties and crop species. Abdel and Al-Rawi (2011) reported that application of GA$_3$ at 100 ppm in V. radiata plant produced the highest pods plant$^{-1}$ (8.49% increment over control), whereas Singh et al. (2015) obtained the highest number pods plant$^{-1}$ in pea with 200 ppm GA$_3$. This is might be due to the genetic variability of the crops. Application of GA$_3$ increased the vegetative growth by enhancing other growth promoting hormones resulting increased the number of pods plant$^{-1}$ in V. radiata (Abdel and Al-Rawi, 2011), and soybean (Sarkar et al., 2002). GA$_3$ facilitates increasing the fruit bearing nodes which eventually develop into pods reducing abscission of flowers and pods in bean (Abdel-Fattah et al., 1995), increasing the number of flowers plant$^{-1}$ in fenugreek and pea (Shahine et al., 1992), and hence increasing number of pods that reach maturity (Jane, 2001).

Pod Length

Pod length was significantly influenced by the application of GA$_3$. The pod length ranges from 7.29–8.91 cm with different GA$_3$ levels. In between varieties, application of 200 ppm GA$_3$ produced the longest pod (7.98 and 8.91 cm) in BARI Mung-6 and BARI Mung-8, respectively. Exogenous application of GA$_3$
increased the pod length more in BARI Mung-8 than in BARI Mung-6 (Table 7). The pod length is increased due to application of GA$_3$ as reported by Bhadra (2004), Renu (2019) in V. radiata, Emongor (2007) in cowpea, and Singh et al. (2015) in pea, although the effect of GA$_3$ depends on the particular species and surrounding factors (Hedden and Thomas, 2012). Such as, 125 ppm GA$_3$ produced the longest siliqua plant$^{-1}$ of mustard (Saini et al., 2017), maximum fruit length of tomato (Akand et al., 2015). Pod development is the resultant effect of active cell division (Inglese et al., 2005), more plasticity of cell walls (Stoddart, 1981; Salisbury and Ross, 1990) which is induced by the GA$_3$. The enhanced water uptake by the leaves (Table 3) possibly led to enhanced leaves expansion (exhibited by fresh and dry weights of leaves), hence the increased pod length observed in this study.

**Number of Grains per Pod**

Various concentrations of GA$_3$ have a significant effect on the number of grains pod$^{-1}$. The number of grains pod$^{-1}$ increased with the application of GA$_3$ up to 200 ppm, and thereafter decreased in both the varieties. Plants treated with 200 ppm of GA$_3$ produced the highest number of grains pod$^{-1}$ (9.10 and 10.81), and the lowest values (7.00 and 8.01) were found with untreated control plants from BARI Mung-6 and BARI Mung-8, respectively (Table 7). The increment rate due to GA$_3$ was higher in BARI Mung-8. The result is accordance with the findings of Abdel and Al-Rawi (2011) and Renu (2019) in V. radiata, Emongor (2007) in cowpea, and Singh et al. (2015) in pea, who reported that application of GA$_3$ at 200 ppm produced the highest number of grains pod$^{-1}$. GA$_3$ stimulates flowering which enhances fruit setting positively (Gupta and Gupta, 2005). The number of grains pod$^{-1}$ significantly increased with various concentration of GA$_3$ on soybean (Rahman et al., 2004), okra (Kumer et al., 1996), and linseed (Rastogi et al., 2013).

**100-Grain Weight**

The effect of GA$_3$ on the 100-grain weight was insignificant in both the varieties, although the 100-grains weight gradually increased with the increasing concentration of GA$_3$. However, the highest 100-grain weight (4.17 g) was obtained with the GA$_3$ of 300 ppm in BARI Mung-6. On the other hand, the lowest (2.99 g) 100-grain weight was obtained in BARI Mung-8 under control condition. BARI Mung-6 always produced bolder grain than BARI Mung-8 among all the treatments (Table 8). Similar results were also reported by Bhadra (2004), Renu (2019) in V. radiata, and Emongor (2007) in cowpea. Exogenous application of GA$_3$ progressively increased the grain weight in different crops in previous studies (Groot et al., 1987; Lee, 1990; Emongor, 2007; Tiwari et al., 2011). Bora and Sharma (2006) obtained the highest 100-grain weight at 250 ppm GA$_3$ in pea. The result of this study is approximately similar to the above reports.

### Yield

#### Grain Yield

Grain yield is an important parameter, and application of suitable concentration of GA$_3$ influenced grain yield of V. radiata significantly. The varietal difference in case of grain yield was significant, and BARI Mung-8 produced higher grain yield plant$^{-1}$. The highest grain yield (1.85 tha$^{-1}$) was obtained by applying 200 ppm of GA$_3$, and the lowest grain yield (0.92 tha$^{-1}$) was obtained from control treatments (Table 8). The highest grain is obtained with foliar spraying of 200 ppm GA$_3$ which may be due to higher values of RWC (Table 3), higher contents of photosynthetic pigments (Table 4) better translocation of photosynthates and metabolites (fresh and dry weights; Tables 5, 6), more N uptake (demonstrated by higher N content in grain; Table 9) and yield contributing traits. The results of our investigation are in line with the findings obtained by Renu (2019) who found that plants treated with 200 ppm GA$_3$ produced the highest yield among the GA$_3$ treated plants in V. radiata. Foliar application of 100 ppm of GA$_3$ increased the grain yield per plant in rice (Awan and Alizai, 1989), okra (Kumer et al., 1996), mustard (Saini et al., 2017), and tomato (Groot et al., 1987; Jong et al., 2009; Akand et al., 2015). In the present study, the best treatment was 200 ppm of GA$_3$, where treated plants tended to increase grain yield by 54.35 and 52.89% in BARI Mung-6 and BARI Mung-8, respectively. In very recent study, Tasnime et al. (2020) concluded that 100 ppm GA$_3$ increased the grain yield of 41.25% in BARI Mung-8 variety. However, GA$_3$ causes a substantial increase of grain yield in different crops.
has also been reported by Bhadra (2004), Abdel and Al-Rawi (2011), Keykha et al. (2014), and Rahman et al. (2018) in V. radiata, Noor et al. (2017) in French bean, Swain et al. (1997), and Sharma et al. (2006) in pea, Emongor (2007) in cowpea, Sarkar et al. (2002) in soybean, Tomar and Ramgiry (1997), and Khan et al. (2006) in tomato. Exogenous application of GA3 may help to redistribute assimilates toward the shoot apex and young leaves, aiding in the utilization of nitrogen, and thus resulting in increased yield of mustard (Khan et al., 2002). The effective partitioning and translocation of assimilates from source to sink in the field crops are promoted by PGRs (Solaimalai et al., 2001; Senthil et al., 2003). GA3 also increased the yield of beans might be attributed through increase of pod length and number, water content in pod, fresh weight, and reduce wilting of pods in French beans (Jane, 2001), increase leaf number, leaf area index, and leaf area duration in faba beans (Harb, 1992), more dry matter accumulation in peach fruit (Patrick and Wareing, 1981). Hence, application of GA3 as foliar may be a valuable approach for boosting the plant growth and yield of V. radiata.

Stover Yield

The present study clearly indicated that different levels of GA3 have the potentiality to influence the stover yield of V. radiata in both varieties. The highest stover yield of 0.88 tha−1 was recorded at 200 ppm of GA3 from BARI Mung-8, and the lowest stover yield as 0.50 tha−1 at 0 ppm of GA3 from BARI Mung-6 (Table 8). It might be due to more efficient diversion of energy from source to sink. This result is in agreement with the findings of Hoque (2001), Gadi et al. (2017), Rahman et al. (2018), Renu (2019), Tasnim et al. (2020) who concluded that the straw yield of V. radiata was significantly increased with increasing levels of growth regulator GA3. GA3 increased the vegetative growth (increased fresh and dry weights), and reproductive growth (higher number of pods and pod lengths) which might be enhanced the elevated stover weight per plant. In this background, GA3 increased TDM, LAI, RGR, and NAR which tended to increase plant biomass (Sarkar et al., 2002; Rahman et al., 2004; Azizi et al., 2012; Noor et al., 2017).

Harvest Index

Significant influence in harvest index is occurred by application of GA3. There is a significant variation occur in both varieties with using GA3. The highest harvest index (74.63 %) was found from BARI Mung-8 by applying GA3 at 300 ppm. In contrary, BARI Mung-6 gave the lowest harvest index (61.11%) from control treatment (Table 8). These results were adhered to the results of Uddin (1999), Rahman et al. (2018), Renu (2019), and Tasnim et al. (2020) in V. radiata, Noor et al. (2017) in French bean, Emongor (2007) in cow pea, Khan (1997) in mustard, Ahmad Dar et al. (2015) in Trigonella foenum-graecum, who concluded that application of GA3 increased the harvest index, though its concentration was varied for different crops. In this experiment, GA3 increased the harvest index statistically. Nabi et al. (2014) reported that foliar spraying GA3 at 33.3 ppm increased the harvest index (22.45 %) in cowpea that was identical to 50 ppm GA3 (22.07%), and the lowest harvest index (18.76%) was noticed in control treatment.

Correlation of Grain Yield With Growth and Yield Attributes

Association between two traits represents the performance of the treatments under such situations for which the data was recorded. In the study, the PH showed non-significant relationship with LDW, significant negative relationship with GPP and HGW, whereas other traits exhibited significant positive correlation (Figure 3). Likewise, NPPP showed non-significant relationship with LDW, significant negative relationship with HGW, but other traits exhibited significant positive correlation. The results clearly indicated that the HGW decrease with increasing NPPP. The PL showed positive significant correlation with almost all the traits except GPP, whereas HGW and LDW showed negative and positive non-significant effect, respectively. The GPP showed significant negative correlation with almost all the study traits except NPPP but exhibited non-significant effect with HGW and LDW. The HGW showed non-significant negative correlation with almost all the study traits except PH and NPPP which showed significant negative relationship. The LDW exhibited a significant positive correlation only with SDW, RDW, and GY, whereas others parameters showed non-significant relation. The SDW showed significant positive correlation with almost all the study traits except GPP and HGW where exposed significant negative and non-significant relationship, respectively. Similar results were observed in case of RDW. The SDY demonstrated non-significant negative association with HGW and LDW, whereas significant negative association found with GPP, and others traits were associated positive significantly. HGW showed significant positive correlation with all traits except GPP and HGW which nowed negative but significant and non-significant correlation, respectively. Positive correlation among yield parameters like NPPP, HSW, SWPP, and GY were reported by Ullah (2006) in cowpea, and Azizi et al. (2012) in soybean. A positive correlation among PH, number of branches plant−1, NPPP, HSW, and GY of chickpea was also reported by Hasanuzzaman et al. (2007). Noor (2014) found strong positive correlation among the leaf area index, total dry matter, CGR, NAR, fresh pod yield plant−1, and fresh fodder yield plant−1 of French bean. In another study, Emongor (2007) observed linear regression with significant positive correlation between GA3 levels and grain yield in cowpea.

Quality Traits

Nitrogen Content (%)

Gibberelic acid induced the metabolic activities, and regulated nitrogen utilization that reflected plant growth and development (Sure et al., 2012). V. radiata plants treated with foliar GA3 significantly increased the N content in grains in our study (Table 9). However, the highest amount of N (4.57 and 4.76 %) was obtained in grains with the foliar spraying of GA3 at 200 ppm level in BARI Mung-6 and BARI Mung-8, and increment rates were 25.2 and 28.3% over control, respectively. Grains of BARI Mung-8 contained higher N content as well as higher increment due to GA3 than BARI Mung-6. This might be due to genetic makeup of the variety of V. radiata. The results of our study were strongly supported by Renu (2019), who concluded...


| GA₃ (ppm) | N (%) | Increase over control (%) | Protein (%) | Increase over control (%) |
|-----------|-------|---------------------------|-------------|--------------------------|
|           | BARI Mung-6 | BARI Mung-8 | BARI Mung-6 | BARI Mung-8 | BARI Mung-6 | BARI Mung-8 |
| 0         | 3.65c (0.23) | 3.71c (0.12) | –           | –           | 23.52c (0.58) | 24.23c (0.02) |
| 100       | 3.91b (0.17) | 3.98b (0.12) | 7.1         | 7.3         | 25.55b (0.58) | 26.41b (0.08) |
| 200       | 4.57a (0.04) | 4.76a (0.46) | 25.2        | 28.3        | 27.69a (0.58) | 28.66a (1.15) |
| 300       | 3.96b (0.06) | 4.08ab (0.06) | 8.5         | 10.0        | 26.13ab (0.58) | 27.73ab (0.58) |
| CV (%)    | 7.22               | –                  | 10.01       | –                  |

Data are presented as mean ± SE (n = 3). Data followed by same letter are not significantly different by DMRT test at p < 0.05, CV, Co-efficient of variation.

that foliar application of 200 ppm GA₃ produced the highest amount of N content in V. radiata grain. These finding were also closer to the finding of Kumar et al. (2018), who reported that 150 ppm GA₃ generated the highest N content in V. radiata leaves. It might be due to fact that GA₃ increases N use efficiency through nitrogen metabolism and nitrogen redistribution (Khan et al., 2002). The enhancement of N, P and K contents due to application of GA₃ has earlier been reported by Sayed (2001), Soad (2005), and Sure et al. (2012). Miceli et al. (2019) reported that GA₃ (10⁻⁶ M) significantly increased the N use efficiency in lettuce and rocket over control by 27.1 and 30.7%, respectively. Exogenous GA₃ enhanced the plant growth which increases the nitrogen requirements of the plant, and increases the N content in grains. It is reported that GA₃ enhances the nitrate reductase activity that leads to increase nitrogen utilization (Ahmad Dar et al., 2015; Zhang et al., 2017, Miceli et al., 2019). Foliar application of GA₃ enhanced the enzyme activity in crop plants (Broughton, 1968; Crozier and Turnbull, 1984), and increased the membrane permeability (Wood and Paleg, 1972, 1974) that might facilitate uptake and use of mineral...
Protein Content

The protein content in grain is an important quality parameter in legumes, and plant hormones have a significant role on the protein content in *V. radiata* grains. The results revealed that the protein content increased significantly over control with increasing GA3 concentration, and the highest values (27.69 and 28.66%) were recorded with spraying 200 ppm of GA3 in BARI Mung-6 and BARI Mung-8, respectively (Table 9). These results are supported by several studies reporting that GA3 markedly increased the protein content in the grains of *V. radiata* (Chen et al., 1987; Mubeen et al., 2014; Balia et al., 2018; Kumar et al., 2018; Renu, 2019), blackgram (Dheeba et al., 2015), chickpea (Mazid, 2014), garden pea (Mishrinky et al., 1990; Singh et al., 2015), and soybean (Khaafagy, 1995; Khatun et al., 2016).

Exogenous application of GA3 has been shown to promote the synthesis of protein in many crops (Johri and Varner, 1968; Pain and Dutta, 1977; Mozer, 1980), and consequently increased the vigorous plant growth. GA3 may induce the development of xylem and phloem, and consequently increase the flow and deposition of assimilation products in seeds (Secer, 1989).

CONCLUSIONS

GA3 has a potential role for escalating RWC, photosynthetic pigments, dry matter production, yield contributing characteristics, yield and quality (N and protein content) of *V. radiata* varieties. Plants treated with 200 ppm GA3 as foliar spraying maintained the highest RWC and photosynthetic pigments, and showed the highest dry matter in different plant parts, and thereby fabricated the highest values of yield contributing characteristics and yield of *V. radiata* varieties. Similar trends were also observed in case of nitrogen and protein content in grains with GA3 treatments. Grain yield indicated a significant positive correlation with all traits except GPP and TGW. Considering all morpho-physiology and quality traits, BARI Mung-8 performed better than BARI Mung-6, and the previous one is more responsive to GA3 than the later one. Based on the findings, it is recommended, therefore, to use 200 ppm GA3 for obtaining the maximum yield of *V. radiata* varieties.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

MSI conceived and designed research, coordinated for publication, and wrote the manuscript. MKH, BI, and NR conducted the experiment. MKH contributed to analyze the data and drafting of the manuscript. MRI, MAH, MC, AU, HS, MA, SF, CB, FC, and ME reviewed and editing the manuscript. AE coordinated manuscript submission and processing. All authors read and approved the manuscript.

FUNDING

This work was supported by University Grants Commission (UGC), Bangladesh (Grant # 4829), through Institute of Research and Training (IRT), HSTU, Dinajpur, Bangladesh.

ACKNOWLEDGMENTS

The authors are grateful to Dr. Shafiqual Islam Sikdar, Chairman and Professor, Department of Agronomy, HSTU for providing research materials and assistance. The authors also acknowledge to Amena, Anas, Anik, Asraf, Bilkas, Choyon, Foysal, Keya, Mosabbirul, Nupur, Parvin, Rafi, Rafia, Ratul, Rajju, Sanchita, Sazedul, Shariful, Sumona, Tartila, and Tonusree, the students of L4SII/2017, Faculty of Agriculture, HSTU, Dinajpur for their supports as a part of practical class (Project).

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