EFFECT OF GA_3 ON VEGETATIVE GROWTH, MORPHOLOGICAL ATTRIBUTES AND SEED YIELD OF BLACK CUMIN (*Nigella sativa* L.)

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CERTIFICATE

*This is to certify that the thesis titled, " **EFFECT OF GA$_3$ ON VEGETATIVE GROWTH, MORPHOLOGICAL ATTRIBUTES AND SEED YIELD OF BLACK CUMIN (Nigella sativa L.)"** submitted to the **DEPARTMENT OF AGRICULTURAL BOTANY, Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka** in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (MS)** in **AGRICULTURAL BOTANY** embodies the result of a piece of bona fide research work carried out by **MD. ALI REAZ, Reg. No. 09-03478** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged by the Author.

____

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Dated:
Place: Dhaka, Bangladesh

Dedicated to

"My Beloved Parents and well wisher's"

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The Author

EFFECT OF GA_3 ON VEGETATIVE GROWTH, MORPHOLOGICAL ATTRIBUTES AND SEED YIELD OF BLACK CUMIN (*Nigella sativa* L.)

ABSTRACT

A field experiment was conducted at the research field of Sher-e- Bangla Agricultural University, Dhaka during the period from November 1, 2016 to April 30, 2017 to investigate the effects of GA_3 on vegetative growth, morphological attributes and seed yield of black cumin (*Nigella sativa* L.). The experimental treatments were consisted of eight different doses of GA_3 *viz*., 0 ppm (distilled water spray), 20 ppm, 40 ppm, 60 ppm, 80 ppm, 100 ppm, 120 ppm and 140 ppm. The variety BARI kalojira-1 was used as planting material and different doses of GA_3 were applied on the plants at 40 days after sowing. The experiment was laid out in Randomized Complete Block Design with 3 replications. GA_3 had significant effect on vegetative growth, morphology, yield and yield contributing characters of black cumin. Plant height at 50 % flowering stage, number of leaves at 50 % flowering, number of primary branches plant^{-1}, dry weight plant^{-1}, days to 1st and 50 % flowering, number of capsules plant^{-1}, number of seeds capsule^{-1}, weight of seeds plant^{-1}, 1000-seed weight were found maximum from the application of GA_3 at 120 ppm which was closely followed by 100 ppm GA_3. A strong positive correlation of seed yield was observed with capsules plant^{-1}, seeds capsule^{-1}, weight of seeds plant^{-1} and 1000-seed weight. Application of GA_3 at 120 ppm gave the maximum seed yield (2.95 t ha^{-1}) which was statistically identical with GA_3 at 100 ppm (2.85 t ha^{-1}) and the worst seed yield was recorded from control (distilled water) (1.38 t ha^{-1}). Application of GA_3 @ 120 ppm and @ 100 ppm increased seed yield over control by 53.32 % and 51.61 %, respectively. The highest stover yield was also recorded from GA_3 at 120 ppm closely followed by 100 ppm GA_3. Finally, it may be said that; the foliar application may be a better option for improving the seed yield of black cumin under prevailing climatic condition of Bangladesh.

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LIST OF ACCRONYMS AND ABBREVIATIONS

AEZ	Agro-Ecological Zone
Agric.	Agriculture
Agril.	Agricultural
Agron.	Agronomy
Annu.	Annual
Appl.	Applied
Biol.	Biology
Chem.	Chemistry
cm	Centi-meter
CV	Coefficient of Variation
DAS	Days after Sowing
Ecol.	Ecology
Environ.	Environmental
et al	et alii, And Others
Exptl.	Experimental
g	Gram
Hortc.	Hotriculture
i.e.	id est (L), that is
J.	Journal
kg	Kilogram
LSD	Least Significant Difference
M.S.	Master of Science
m^2	Meter square
mg	Milligram
Nutr.	Nutrition
Physiol.	Physiological
Progress.	Progressive
Res.	Research
RCBD	Randomized Complete Block Design
SAU	Sher-e-Bangla Agricultural University
Sci.	Science
Soc.	Society
t/ha	Ton per hectare
viz	videlicet (L.), Namely
%	Percentage
@	At the rate of

CHAPTER I

INTRODUCTION

Black cumin (*Nigella sativa* L.) belonging to the family Ranunculaceae is one of the important seed spices in Bangladesh. In Bengali it is called ‘kalojira’. Spice crop is widely cultivated in South Europe, Syria, Egypt, Saudi Arabia, Iran, Pakistan, India and Turkey (Meena *et al.,* 2014; Nadeem *et al.,* 2013 and Rana *et al.*, 2012). In Bangladesh, it is grown well in Faridpur, Sariatpur, Madaripur, Pabna, Sirajganj, Jessore, Kushtia and Natore districts. The seed is believed to be carminative, diuretic, jactagogue and vermifuge due to presence of volatile oil. In the external use of black seed have been found to give relief when applied on pityriasis, leucoderma, ringworm, eczema, alopecia, freckles and pimples. Besides, the seed oil also alleviates asthma, chronic headache, migraine, chest congestion, rheumatism and paralysis (Riaz, 1996 and Saeed, 1996). It is reported that just two grams daily intake of black cumin seed could result in reduced blood sugar levels, along with decreased insulin resistance and increased beta-cell function in the pancreas. It also prevents heart attack, colon and breast cancer (Anon., 2013).

Black cumin cultivation is increasing day by day in Bangladesh on account of its medicinal value. Now-a-days peoples are conscious about their health and as a result this type of medicinal spice has the great demand to the farmers. But the proper growth and development of black cumin is hindered by some factors *viz.,* climatic, varietal and nutritional management. Among these factors the nutritional management, more emphasized to growth regulating hormone is the most important that can improve the yield performance of black cumin in prevailing climatic condition of Bangladesh. The application of gibberellic acid (GA_3) may be the best hormone for increasing the growth and development of black cumin. Gibberellic acid is a plant growth hormone actively involved in various physiological activities such as, growth, flowering and ion transport (Wareing and Philips, 1981; Khan, 2003).

Besides stimulating leaf area expansion (Brock, 1993) and inducing elongation and osmoregulation in internodes (Azuma *et al.*, 1997), in addition to increasing the dry matter content of plant (Bhaskar *et al.*, 1997) are characterized by GA_3. Plants subjected to exogenous application of GA_3 have been found to exhibit increased activities of carbonic anhydrase, nitrate reductase CO_2 fixation, stomatal conductance resulted in higher amount of photosynthate for better yield (Hayat *et al*., 2001 and Afroz *et al*., 2005). Use of growth regulators specially the GA_3 involved in promoting flowers and seed yield of black cumin (Shah and Samiullah, 2006). The use of GA_3 is thought to be trendsetting as it addresses the improper source-sink relationship and internal hormonal imbalance occurring during the plant growth.

The growth regulator GA enhances the plant growth, flower induction, nutrient uptake and photosynthesis (Hayat and Ahmad, 2007). Ouzounidou and Ilias (2005) reported that, the GA exerts a pleiotropic effect on plant developmental processes, such as seed germination, endosperm mobilization, stem elongation, leaf expansion, flower, fruit set and assimilate translocation. Pariari *et al*. (2012) pointed out that, GA_3 100 ppm increased plant height as compared to control and 50 ppm and 75 ppm of doses. The lower concentration (100 ppm) of GA_3 resulted in increased number of pods plant^{-1}, seeds plant^{-1}, 100-seed weight and seed yield plant^{-1} of soybean more efficiently than the higher concentration (200 ppm) and the control (Sarkar *et al.*, 2002). Foliar application of plant growth regulators (Kinetin and GA_3 each at 10^{-5} M) on yield of black cumin revealed that plants treated with GA_3 at 10^{-5} M showed more number of capsules per plant as compared to control (Shah, 2007; Shah and Samiullah, 2006). Akter *et al*. (2007) reported that, there was a positive response of of Gibberellic acid (GA_3 0, 25, 50 and 75 ppm) on yield of mustard and revealed that the spraying of GA_3 at 50 ppm resulted in maximum number of seeds per siliqua as compared to control. The spraying of GA_3 at 100 ppm produced more number of seeds per pod as compared to control in fenugreek (Vasudevan *et al*., 2008).

Panda *et al*. (2007) observed that, foliar application of GA_3 at 100 ppm significantly increased seed yield per plant over control in coriander. Vasudevan *et al*. (2008) also said that, the spray of GA_3 at 100 ppm increased the seed yield per plant compared to control in Fenugreek. Shah and Samiullah (2006) observed that application of GA_3 at 10^{-5} M increased the seed yield per plant as compared to control in black cumin as an effect of phytohormone. The information about the response of plant growth regulators especially the effects of gibberellic acid on the performance of black cumin in Bangladesh aspect is not well evaluated. Keeping the above facts in view the present experiment was undertaken for the following objectives:

i) to assess the response of GA_3 on vegetative growth,

ii) to evaluate the effect of GA_3 on morphological characteristics and

iii) to find out the suitable dose of GA_3 on seed yield of black cumin (BARI kalojira-1).

CHAPTER II

REVIEW OF LITERATURE

Black cumin is an important oil seed crop in Bangladesh. For the improvement of growth and yield attributes of black cumin the application of plant growth regulator is much important. The production of black cumin in Bangladesh is much lower than other developed countries. But, the yield potential of black cumin is changeable by growth hormone and nutritional management. The research on black cumin with the application of PGRs is not adequate in Bangladesh. Some of the important research findings regarding vegetative growth, morphology and yield of black cumin had been reviewed in this chapter.

Response of GA_3 and other plant growth regulators on different characteristics of black cumin and other crops

Meena *et al.* (2015) carried out a study to the effect of plant growth regulators and sulfur on productivity of coriander. Results showed that application of thiourea @ 500 ppm as foliar spray being at par with triacontanol @ 1000 ppm and brassinolide @1.0 ppm significantly increased chlorophyll content in leaves over water spray. Whereas, dry matter accumulation per plant, seed, straw, biological yields, N and S content in both seed and straw increased significantly with 500 ppm thiourea spray as compared to water spray and brassinolide but remained at par with 1000 ppm triacontanol. Application of sulfur in increasing levels up to 40 kg ha^{-1} significantly increased the dry matter accumulation per plant, chlorophyll content in leaves seed, straw, biological yield, N and S concentration of coriander over control and 20 kg S ha^{-1}.

Mura *et al*. (2015) conducted a field experiment during the *pre-kharif* season of 2008 on a clay to investigate the effect of pre-sowing treatment of growth regulators and agrochemicals on germination, dry matter accumulation, chlorophyll content and yield of sesame (*Sesamum indicum* L.) cv. Rama. Before sowing, the seeds of sesame were soaked overnight with different concentrations of growth regulators and agrochemicals like GA_3, KH_2PO_4 and Na_2HPO_4. Dry seeds were sown in the control plot. The growth regulators and agrochemicals were used in different concentrations (100 ppm GA_3, 200 ppm GA_3, 200 ppm KH_2PO_4, 500 ppm KH_2PO_4, 200 ppm Na_2HPO_4, 500 ppm Na_2HPO_4) for pre-sowing soaking of seeds. It was found that pre-sowing treatments of growth regulators and agrochemicals had a significant effect on the germination, dry matter accumulation, seed yield, oil yield and test weight. The highest yield in terms of both seed (749.4 kg ha^{-1}) and oil yield were recorded from the seed treatment with 200 ppm GA_3 treatment where as the lowest data was recorded from the dry seed. 200 ppm GA_3 treatment also recorded the highest germination percentage (90.0), vigour index, dry matter accumulation, test weight and oil yield. The chlorophyll content of leaves in terms chlorophyll a, chlorophyll b and total chlorophyll was also found to be higher in plants grown from GA_3 treated seeds.

Siddik *et al*. (2015) undertook an experiment to examine the response of different levels of foliar application of 1-napthaleneaciticacid (NAA) on morpho-physiology, yield contributing attributes and seed yield of sesame. The treatments of this experiment consisted of four different levels of NAA *viz*., A_0 = 0 ppm, A_1 = 25 ppm, A_2 = 50 ppm and A_3 = 75 ppm. The research was laid out in single factors Randomized Complete Block Design (RCBD) with four replications. In this study, NAA significantly increased morphological characters- plant height, leaf number $plant^{-1}$, branch number $plant^{-1}$, fresh and dry weight of shoot and root other than leaf and branch number $plant^{-1}$ of at 30 and 40 DAS. As morphological parameters NAA also significantly improves yield contributing characters of sesame-the number of pod $plant^{-1}$, diameter and length of pod, seed weight $plant^{-1}$ and $plot^{-1}$, thousand seed weight compared to without NAA. The foliar application of 50 ppm NAA increased seed yield of sesame (1.22 t ha^{-1}) which is consistent with the results of morph-physiological and yield contributing characters of this study.

Separately, the higher dose of NAA, 75 ppm failed to produce better results of this experiment including seed yield. These results suggest that NAA shows a positive consequence to increase the seed yield of sesame by changing the plant architecture and biomass production. Based on the present results, it can be suggested that the 50 ppm NAA is appropriate for higher yield of sesame.

Vaidehi *et al*. (2015) conducted a field experiment to study the effect of NAA (1-Napthalan Acetic Acid), Chlormequat (2-Chloroethyl trimethyl Ammonium Chloride), Ethrel (2-Chloroethyl Phosphonic Acid) and 2, 4-D (2, 4 Dichloro Phenoxy Acetic Acid) on growth and yield of coriander (*Coriandrum sativum*) at Horticultural College and Research Institute, Coimbatore with three concentrations and with water spray as control were applied as foliar spray after 25, 40 and 55 days after sowing. The results obtained from experiments suggested that the treatment of NAA@ 20 ppm improved all the growth and yield parameters.

Heidari and Sadeghi (2014) conducted an experiment to investigate the effectiveness of GA_3 and temperature regimes as seed priming strategies on the seed germination parameters of cumin (*Cuminum cyminum* L.). Cumin seeds treated with different GA_3 concentrations (0, 100, 200 and 400 ppm) and then were placed in growth chamber at 20, 25, 30 and 35°C. Some seed germination and seedling growth characters were performed for 10 days. The results showed that the percentage of germination, average duration of germination, germination speed, seedling fresh and dry weights significantly increased along with increasing in GA_3 concentration as the highest amount was found in 400 ppm. These parameters slightly increased with increasing temperature from 20 to 25 °C and then slightly decreased. Overall, the results suggested that the 400 ppm of GA_3 in combination with 25°C, which showed the better seed germination and seedling growth characters, could be more appropriate to use as a priming strategy in cumin seed.

Meena *et al*. (2014) conducted a study aims to examine the effect of Plant growth regulators and sulphur on productivity of coriander. The experiment consisting of four PGRs (1000 ppm Triacontanol, 1.0 ppm Brassinolide, 500 ppm Thiourea and water spray) and four levels of sulphur (0, 20, 40 and 60 kg/ha) making 16treatment combinations under randomized block design (RBD) with three replications. Results showed that significantly higher plant height, dry matter accumulation per plant, chlorophyll content, number of branches per plant, number of umbels per plant, umbellets per umbel, seeds per umbellet, seed, straw and biological yields were obtained with 500 ppm thiourea spray as compared to water spray and brassinolide but remained at par with 1000 ppm triacontanol. Application of sulphur up to 40 kg/ha significantly increased all above mentioned growth, yield attributes and yield of coriander over control and 20 kg S ha^{-1}. In terms of net returns and B: C ratio, the treatment 500 ppm thiourea and 40 kg S ha^{-1} fetched significantly higher net returns and B: C ratio over rest of the treatment. It was concluded that independent application of 500 ppm thiourea as foliar spray twice at 45 and 80 days after sowing and soil applied sulphur at 40 kg ha^{-1} is recommended as these treatments fetched significantly higher economic net returns from coriander.

Yugandhar (2014) conducted a field experiment to know the effect of growth regulators on growth, seed yield and quality of Coriander *(Coriandrum sativum* L.) cv. “Sudha” during *rabi* 2013-2014. The experiment consists of 6 levels of plant growth regulators *viz*., GA_3 (50 and 75 ppm), NAA (10 and 25 ppm) and Cycocel (100 and 250 ppm) as presoaking, foliar spray at 30 and 60 DAS. An absolute control was also maintained. The experiment consists of 7 treatments replicated thrice in a randomized block design. The results indicated that application of 75 ppm GA_3 resulted in maximum plant height (78.09 cm). However, maximum number of primary branches per plant (7.13), number of secondary branches per plant (16.13), number of umbels per plant (28), number of umbellets per umbel (6.33), number of seeds per umbel (34.73), seed yield per plant (9.02 g) and seed yield per hectare (18.46 q) was maximum with 250 ppm Cycocel. However GA_3 75 ppm followed by GA_3 50 ppm recorded minimum number days to 50 per cent flowering (40.33) and maturity (85.00). Among the quality parameters, maximum carbohydrate content (23.09 %), protein content (16.12 %) was noticed with GA_3 75 ppm. Similarly lowest moisture content (9.19 %) in seeds was also observed with 75 ppm GA_3. While, the essential oil content (0.43 %) in seeds was maximum with GA_3 50 ppm. Economics study showed that maximum net returns and B: C ratio (Rs.1, 38,947 ha^{-1} and 3.91: 1) was recorded with Cycocel 250 ppm followed by GA_3 75 ppm and Cycocel 100 ppm.

Rastogi *et al.* (2013) reported that, the commercial importance of linseed (*Linum usitatissimum* L.) has attracted breeders to increase its seed yield using various breeding approaches. Plant growth regulators (PGRs) have a significant role in enhancing yield and its related traits in linseed. In the present study, two plant growth hormones, auxin and gibberellic acid, were applied individually, as well as in combinations, in order to study their effect on yield and its components in "Neelam", which is a high yielding variety of linseed. A comparative study was done under pot and field condition. A combined dose of auxin (1.0 mg L^{-1}) and gibberellin (200 mg L^{-1}) is recommended for the enhancement of seed yield, whereas a 0.5 mg L^{-1} dose of auxin is recommended for the enhancement of vegetative growth. It was concluded that the plant growth regulators can be successfully employed to enhance the yield in this economically important oil seed crop.

Pariari *et al*. (2012) conducted a field study to determine the effect of gibberellic acid (GA_3) and NAA on the growth and yield of black cumin. The treatments comprised 25 (T_1), 50 (T_2), 75 (T_3), 100 ppm GA_3 (T_4), 25 (T_5), 50 (T_6), 75 (T_7), 100 ppm NAA (T_8) and control (T_9). Data were recorded on the plant height, branches per plant, pods per plant, fruit length, fruit diameter, 1000 seed weight, seed yield and volatile oil content of black cumin.

Results showed that GA_3 had a significant function on cell division in the apical meristem, whereas, NAA at higher concentrations induced the reproductive phase. Hence, the vegetative parameters showed better results with increased concentration of GA_3, however, seed yield and other yield attributes showed significant increase with the application of NAA at higher concentrations. NAA at 100 ppm was the best treatment and recorded the maximum seed yield of black cumin.

Shah (2011) conducted an experiment on black cumin with PGRs. The leaves of 40-day old plants of black cumin were sprayed with 10–7, 10–6, 10–5 M 4-Cl-IAA, and 10–6, 10–5 and 10–4 M kinetin. Both the hormones improved vegetative growth, photosynthetic efficiency and seed yield of the test plants as compared to deionized water (control). However, 10–6 M 4-Cl-IAA was most prominent in its effect, generating 42, 30, 40, 41 and 51% higher values for carbonic anhydrase, nitrate reductase, net photosynthetic rate, leaf protein content and dry mass respectively, over control in 70-day old plants. Similarly, capsule number and seed yield per plant were elevated by 41 and 43% over the untreated control at harvest (130 days after sowing) following the same treatment. Overall, the auxin showed a higher efficiency than kinetin in all treatment concentrations.

Faizanullah *et al*. (2010) conducted a field experiment to compare the effect of plant growth regulators (PGRs) *viz*., kinetin (K), chlorocholine chloride (CCC) and salicylic acid (SA) on seed yield, oil content and oil quality of Linseed (*Linum usitatissimum* L) cv. Chandni with a new perspective to biodiesel production. The growth regulators (10-6M) were applied as seed soaking for 10 h prior to cultivation. Kinetin significantly increased the number of capsules/plant, seed number/capsule, 1000 seed weight and total seed yield (kg/h). The growth regulators increased the seed oil content maximum being in kinetin and CCC treatments. Kinetin and CCC significantly decreased the oil acid value, free fatty acid content (% oleic acid) and increased the pH of oil.

Nevertheless, SA significantly decreased the oil specific gravity and did not alter the pH. Only kinetin significantly increased the oil iodine value. The oil extracted from seeds of kinetin and CCC treated plants showed maximum conversion (% w/w) to methyl esters/biodiesel after transesterification. It can be inferred that PGRs can be utilized successfully for improving the biodiesel yield of linseed.

Kumar *et al.* (2008) conducted an experiment to study the effect of different concentration of ethrel in comparison with the commercial form of growth promoter ace in promoting growth and yield of black cumin during 2006 and 2007. The experiment was laid out in a Randomized Block Design having 6 treatments replicated thrice. In this experiment growth regulators were ethrel (50 ppm, 75 ppm, 100 ppm and 125 ppm) along with ace (a commercial bioregulator @ 0.5 ml lit^{-1}). Further to get a comparison one untreated control treatment was included to have a clear picture of controlled plants as compared to growth regulator treatment. The results clearly indicated that there was increase in seed yield with all the treatments except the control (untreated) plot. Among all the treatments, ethrel @ 75 ppm proved to be most effective in promoting growth and gave highest seed yield(6.03 q ha^{-1}), followed by ethrel @ 100 ppm (5.59 q ha^{-1}) which was statistically at par.

Verma and Sen (2008) suggested that, GA_3 at 50 ppm applied through pre-plant soaking + spraying 20 DAS significantly improve the vegetative growth of coriander herb.

Akter *et al*. (2007) conducted an experiment in pot house to evaluate the effects of Gibberellic Acid (GA_3) on growth, and yield of mustard var. Binasarisha-3. Four concentrations *viz*., 0, 25, 50 and 75 ppm of GA_3 were sprayed on canopy at 30 days after sowing. The results showed that different levels of GA_3 significantly influenced the plant height, number of fertile siliqua $plant^{-1}$, number of seeds $siliqua^{-1}$, number of flowers $plant^{-1}$, setting of siliqua $plant^{-1}$ (%), and harvest index.

Results revealed that GA_3 at 50 ppm significantly increased plant height, number of fertile siliqua plant^{-1}, number of flowers plant^{-1}, siliqua plant^{-1} (%), dry matter yield, number of seeds siliqaua^{-1}, and harvest index, while the number of flowers plant^{-1} was significantly increased with the application of 75 ppm GA_3. The highest seed yield plant^{-1} was recorded from the application of 50 ppm GA_3 at optimum harvest date. The seed yield plan^{-1} was positively correlated with plant height, number of seeds siliqua^{-1}, number of fertile siliqua plant^{-1} and % of setting siliqua plant^{-1}.

Shah and Ahmad (2007) conducted an experiment to study the combined effects of foliar sprays of water or 1, 10 and 100 µM aqueous solutions of gibberellic acid (GA_3) or kinetin (KIN) to 40 days old plants of *Nigella sativa* (L.) on net photosynthetic rate, nitrogen metabolism, and the seed yield. The 10 µM solutions of both the hormones, especially GA_3, appreciably increased the activities of nitrate reductase and carbonic anhydrase, chlorophyll and total protein contents and net photosynthetic rate in the leaves, along with capsule number and seed yield plant^{-1}, at harvest.

Shah (2007) reported that, a pre-sowing treatment was applied to black cumin (*Nigella sativa* L.) seeds, which were surface-sterilized and soaked for 5, 10 or 15 h in 10–6, 10–5, or 10–4 M aqueous solution of gibberellic acid (GA). The potted plants were then analysed at 50, 70 and 90 days after sowing for leaf chlorophyll (Chl.) content, stomatal conductance (gs), carbonic anhydrase (CA) activity, nitrate reductase (NR) activity, total protein content, net photosynthetic rate (PN), capsule number and seed yield at harvest (130 days after sowing). All these parameters were found to be appreciably enhanced by the hormone treatment. The most prominent results were obtained with 10–5 M GA following a pre-sowing treatment for 10 h, in which case the values for P N, CA and NR activity, and seed yield were elevated by 44, 40, 30 and 40% respectively over the control at the 70 day stage.

Shah and Ahmad (2006) conducted a field trial on black cumin (*Nigella sativa* L.), sprayed with either deionized water (control) or 10⁻⁵ M GA₃ at 40 (vegetative stage) or 60 (flowering stage) days after Sowing (DAS) to characterize the effects of hormone treatment on the mentioned parameters and select the suitable growth stage for spray in order to achieve desired results. Capsule number plant^{-1}, seeds /capsule, 1000 seed weight, seed yield q ha^{-1}, harvest index and Seed Yield Merit (SYM) were analyzed at harvest (130 DAS). It was noted that growth, NPK accumulation and seed yield were maximal when spraying of GA₃ was carried out at 40 DAS. However, spraying at 60 DAS was not much effective in terms of the parameters studied. Moreover, there was a significant difference in spray treatments at various growth stages only when GA₃ was sprayed and not when water was sprayed.

Shah (2006) conducted a pot trial to study the effect of foliar spray of 0 (de-ionized water), 10^{-6}, 10^{-5} and 10^{-4} M each of gibberellic acid (GA_3) or Kinetin (KIN) at 40 days after sowing (vegetative stage) on growth and yield of black cumin (*Nigella sativa* L.). Application of 10^{-5} M GA_3 was found to be more effective than KIN in promoting shoot length, plant dry weight, leaf number, leaf area and branch number observed 70 days after sowing (DAS). Application of 10^{-5} M GA_3 resulted in more capsule number, seed yield and seed yield merit, which was found increased by 43.33, 43.85 and 53.62% respectively.

El-Greedly *et al*. (2005) carried out a pot experiment to investigate the influence of different concentrations of stigmasterol (0, 100, 150 and 200 ppm) on growth, yield and endogenous hormones of two sesame cultivars. In general, increasing stigmasterol concentration up to 200 ppm significantly increased the growth, seed yield and number of capsules plant^{-1} as well as 1000-seed weight was also increased due to increasing stigmmasterol concentrations. Plants treated by 100 or 150 ppm showed approximately the same values of seeds plant^{-1}, while when it sprayed by high concentration (200 ppm), seed yield was increased.

Seed oil (%) was gradually increased at the same high concentration. However, the plants that sprayed by 100 or 150 ppm showed the same oil (%), whereas the plants received 200 ppm recorded the highest seed oil percentage (59.96) and the lowest (55.99) was untreated plants. Shandweel - 3 cultivars showed the highest oil content (64.53%) at 200 ppm followed by the same cultivar when sprayed by 150 ppm of stigmasterol. Concerning, the endogenous hormones, Giza - 32 had more GA_3, IAA and lower ABA than Shandweel - 3 cultivar, however, in both cultivars application of 150 or 200 ppm of stigmasterol had the highest GA_3, IAA and lowest ABA compared to the treatments sprayed by 100 ppm and/or to untreated plants.

Leite *et al.* (2003) conducted a pot experiment to study effects of GA_3 and cytokinin on the vegetative growth of the soybean. GA_3 (50 mg L^{-1}) was applied as seed treatment, leaving plants with water application as control. GA_3 (100 mg L^{-1}) and cytokinin (30 mg L^{-1}) were sprayed on leaves at the physiological stage V_3/V_4, and 15 days after, cytokinin (30 mg L^{-1}), also as foliar spray. Seed treatment decreased plant emergence and initial soybean root growth, but as the season progressed, differences in root growth disappeared; plants were shorter, and presented a decrease in the number of nodes, in stem diameter, in leaf area and in dry matter yield. Conversely, foliar application of GA_3 led to an increase in plant height, first node height and stem diameter. Leaf area and dry matter production also increased as a result of GA_3 foliar application. There was no effect of exogenous gibberellin and cytokinin on the number of soybean leaves, number of stem branches and root dry matter. Joint application of gibberellin and cytokinin tended to inhibit gibberellin effects. Cytokinin applied to leaves during soybean vegetative growth was not effective in modifying any of the evaluated plant growth variables.

Khan *et al*. (2002) examined a field trial on the effect of foliar spray of 0 (de-ionized water), 10^{-6}, 10^{-5} and 10^{-4}M of indole acetic acid (IAA), gibberellic acid (GA_3) and kinetin (KN) at 40 days after sowing (pre-flowering stage) on growth and yield characteristics of mustard (*Brassica juncea* L.).

Application of GA_3 at 10^{-5}M concentration was found to be more effective than IAA and KN in promoting shoot length, leaf number, leaf area and plant dry weight at 60 and 80 days after sowing (DAS), net assimilation rate (NAR) at 60-80 d interval and yield at harvest. Application of 10^{-5} M GA_3 increased seed yield, oil yield and seed yield merit by 33.3, 31.2 and 50.3% respectively compared to water sprayed control.

Sarkar *et al*. (2002) investigated a study to know the effect of plant growth regulators on yield of soybean. Plants of soybean cv. BS-3 were sprayed at three different times with two concentrations (100 and 200 ppm) of gibberellic acid (GA_3) and indole acetic acid (IAA). GA_3 at 100 ppm had regulatory effect to enhance the plant height, number of branches, number of leaves, leaf area per plant, number of flowers, number of pods, percentage of fruit set, number of seed per plant, seed yield per plant, 100-seeds weight and seed yield (tha^{-1}). On the other hand, 100 ppm IAA produced the highest plant height, number of flowers, number of pods, percentage of fruit set, number of seed per plant, seed yield per plant and seed yield (tha^{-1}), as compared to other plant growth regulators and control. IAA at 200 ppm increased number of branches, number of leaves, leaf area per plant, 100-seeds weight and net assimilation rate.

Nagel *et al*. (2001) carried out an experiment on exogenous application of cytokinin to raceme tissues of soybean (*Glycine max* L.). Which has been shown to stimulate flower production and to prevent flower abortion? Soybeans were grown hydroponically or in pots in the greenhouse, and 6-benzylaminopurine (BA) was introduced into the xylem stream through a cotton wick for 2 weeks during anthesis. After the plants had matured, the number of pods, seeds per pod, and the total seed weight per plant were measured. In the greenhouse, application of 3.4×10^{-7} moles of BA resulted in a 79% increase in seed yield compared with controls. Data suggest that cytokinin levels play a significant role in determining total yield in soybeans, and that increasing cytokinin concentrations in certain environments may result in increased total seed production.

Baydar (2000) studied an experiment to determine the effects of gibberellic acid (GA_3) on male and female sterility, seed yield, oil and fatty acid syntheses, growth and development properties in safflower (*Carthamus tinctorius* var. Yenice). GA_3 was applied in five different doses at three different stages, and induced male sterility at a rate of up to 93.0%. This finding has important implications for the practical use of GA_3 in hybrid seed production. GA_3 applications significantly decreased the seed yield per plant both in isolation and non–isolation. Although fatty acid syntheses did not change with any application, oil synthesis increased significantly from 33.8% to 38.8% with the application of 300 ppm GA_3 at the budding stage.

Khan and Ansari (1998) carried out a field trial during 1993–1994, on mustard with either deionised water or 10^{-5} M GA_3 at 40 (vegetative stage), 60 (flowering stage) or 80 (pod fill stage) days after sowing (DAS) to select the suitable growth stage for spray for augmenting productivity of the crop. Shoot length per plant, leaf number per plant, leaf area per plant, dry weight per plant and leaf area index and accumulation of N, P and K were recorded at 100 DAS. Pods per plant, seeds per pod, 1000 seed weight, seed yield, biological yield, harvest index and seed yield merit were computed at harvest. Growth, NPK accumulation and yield were maximal when spraying was done at 40 DAS. However, spraying at 40 and 60 DAS gave at par values for most of the growth and yield parameters. It was also noted that there was a significant difference in spray treatment at different growth stages only when G A, was sprayed and not when water was sprayed.

Ghosh *et al*. (1991) conducted a series of field experiments were conducted at the Viswavidyalaya Research Farm during 1984–85 to 1986–87 to study the effects of five growth regulators *viz.,* Miraculan (a triacontanol based growth stimulant), Nutron (1-triacontanol growth stimulant), Planofix (α-napthylacetic acid), Paras or Mixtalol (Higher alcoholic carbon compounds) and N-triacontanol on productivity of five different major oilseed crops *viz.,* rapeseed, mustard, sesame, linseed and safflower. Results showed the positive influence of growth regulators on the productivity of crops (10–40 % increase in yield); however the influence was not consistent over the years. N-triacontanol when tried on mustard only improved the grain yield significantly, more so when applied with paras or planofix, sesame was most influenced by spraying planofix and paras. Nutron favourably influenced safflower and linseed. The test weight of grains followed by the number of pods/plant was influenced most by the application of growth regulators.

Lee (1990) carried out an experiment on gibberellic acid and IAA application of growth and yield of groundnut. Groundnut seeds were soaked in solutions of 0, 50 and 100 ppm gibberellic acid or 50, 100 and 200 ppm indole acetic acid prior to sowing produced plants with longer main stems, more branches, higher chlorophyll content, greater numbers of flowers, internodes and pods, and greater grain wt/plant than in the control. Seedling emergence and time to flowering were also improved by growth regulator seed treatment.

By reviewing the different sources of information regarding the present experiment it was found and taken that, the application of different plant growth regulators has the capacity to improve the performance of oil seed crops among the PGRs the Gibberellic acid (GA) may the most important growth promoting substance for black cumin. So, different doses of gibberellic acid were taken for the present study on vegetative growth, morphology and yield of black cumin.

CHAPTER III

MATERIALS AND METHODS

A brief description about experimental period, site, climatic condition, crop or planting materials, treatments, experimental design and layout, crop growing procedure, intercultural operations, data collection and statistical analysis was described in this chapter. The details of experimental materials and methods are described below:

3.1 Experimental period

The experiment was conducted at the research field of Sher-e-Bangla Agricultural University, Dhaka-1207 during the period from November 1, 2016 to April 30, 2017 in *rabi* season.

3.2 Site of study

The experimental area was belonged to $23^{0}7$'N latitude and $90^{0}3$'E longitude at an altitude of 8.6 meter above the sea level (Anon., 2004). The experimental site belongs to the agro-ecological zone of “Madhupur Tract”, AEZ-28. The experimental site is shown in the map of AEZ of Bangladesh in (Appendix-I).

3.3 Climate and soil of the experimental site

A sub-tropical monsoon climatic zone was prevailed around experimental site, most provably characterized by winter during the months from November 01, 2016 to April 30, 2017 (*rabi* season). The weather data during the study period at the experimental site including maximum and minimum temperature, total rainfall and relative humidity were shown in (Appendix-II). Silty clay in texture, olive-gray with common fine to medium distinct dark yellowish brown mottles was the main traits of top soil. The soil was also characterized by pH-5.6 and organic carbon-0.45%. The irrigation and drainage system was available with the flat type of experimental area and topography was medium high land.

3.4 Details of the experiment

Treatments

The experiment was consisted of eight treatments (8 different doses of GA_3) were as follows:

G_1= GA_3 0 ppm (distilled water spray)	**G_5=** GA_3 80 ppm
G_2= GA_3 20 ppm	**G_6=** GA_3 100 ppm
G_3= GA_3 40 ppm	**G_7=** GA_3 120 ppm
G_4= GA_3 60 ppm	**G_8=** GA_3 140 ppm

The solution was made at the rate of 20, 40, 60, 80, 100, 120 and 140 mg of GA_3 solute dissolved in 1000 mL of water for the concentration of 20, 40, 60, 80, 100, 120 and 140 ppm solution. All the doses of gibberellic acid were applied on the standing crops at 40 days after sowing (DAS).

3.5 Planting material

A most promising black cumin variety (**BARI kalojira-1**) was used as planting material.

3.6 Experimental design and layout

Experiment was set in a single factor randomized complete block design (RCBD) with 3 replications. Distance between lines to line was 25 cm and a plant to plant distance was 10 cm. Distance between plots to plot was 50 cm and 1.0 m in between two replications. The size of the unit plot was 3.0 m× 1.0 m.

3.7 Crop management

3.7.1 Collection of seed

The seed of black cumin (BARI kalojira-1) was collected from Regional Spices Research Centre, BARI, Joydevpur, Gazipur.

3.7.2 Land preparation

The experimental site was first opened with power tiller with successive cross-ploughed three times followed by laddering up to the desirable tilth. The stubbles, weeds and crops residues of last crop were removed from the field. Proper drainage channels were made in order to avoid water logging due to rainfall during the study period.

3.7.3 Manure and fertilizer application

Manure/Fertilizers	Dose (kg/ha)
Cowdung	5 tons
Nitrogen (N)	58 kg
Phosphorus (P)	20 kg
Potassium (K)	37 kg
Sulphur (S)	10 kg
Zinc (Zn)	4 kg
Boron (B)	2 kg

Source: (Mondal *et al.*, 2011)

The entire amount of cowdung, phosphorus from TSP, potassium from MoP, sulphur from gypsum, zinc from zinc sulphate and boron fron boric acid (medicated), with one half of nitrogen from urea was applied at basal doses during final land preparation. The remaining 50% nitrogen from urea was top dressed at 40 days after sowing (DAS) followed by irrigation.

3.7.4 Sowing of seed

To enhance germination, the seeds were soaked in water for 12 hours before seed sowing. Seeds were also treated with Thirum @ 2 g per kg of seeds before sowing. The soil was also treated with Furadan 5G @15 kg ha^{-1} when the plot was finally ploughed to protect the young plant from the attack of cut worm. The seeds were sown @ 10 kg ha^{-1} on 1 November, 2016 in rows continuously by hand. The seeds were mixed with loose soil to maintain the uniform sowing in rows.

A light application of water was applied in rows before the sowing to maintain the proper moisture for better emergence of seeds. With good pulverized soil the seeds were covered just after sowing and gently pressed by hands. After 20 days of seed sowing, the seedlings were thinned to maintain 10 cm in between plants.

3.7.5 Intercultural operations

3.7.5.1 Irrigation and drainage

Irrigation was applied at an interval of 12 days up to completion of flowering and after the flowering two irrigations were applied in the field. The proper drainage system was developed to avoid the flooding of water in field.

3.7.5.2 Weeding

The serve a weed free field condition for proper growth of black cumin the allocated plots were weeded at 25, 40 and 60 DAS, respectively.

3.7.5.3 Plant protection measures

As a preventive measure for controlling fungal infection, Dithane M-45 was applied at 12 days intervals @ 2g/litre of water. Sometimes of chewing type insects were found in some plots. So, Admire 200 SL was applied @ 1mL/litre of water.

3.8 Harvesting of plant

Due to the different doses of GA_3, the plants were matured on different times for their differences of senescence's. The plant of each plot were separately harvested, bagged and tagged and brought to the laboratory. Harvesting was done manually by hand with khurpi. The plant was well dried and beated to take the seed. The different yield contributing traits of were taken after harvesting of crop.

3.9 Recording of data

Just after sowing of seeds different experimental data were recorded and continued until harvest and the yield and yield contributing traits were counted and calculated after harvest on threshing floor. The following data were collected during the experimentation.

3.9.1 Vegetative growth parameters

1. **Days to first emergence:** The days required for first emergence of seeds from the soil was calculated by deduction of first seeing of emergence from the days of seed sowing.

2. **Days to 50% emergence:** All the plants were observed keenly to take the days of 50 % emergence of seeds by deducting the seeing days from the days of seed sowing from each plot.

3. **Plant height at 50% flowering:** The plant is much important trait for all crops as black cumin. So, by using a measuring tape the height of plant was taken from the base of plant up to the tip in centimeter unit. The means of five randomly selected plants were taken.

4. **Leaves at 50% flowering:** The total number of leaves was counted visually from respective plots as per treatment.

5. **Primary branches plant^{-1} at harvest:** The total number of primary branches was counted after harvesting of crop and only the main stems were considered as primary branch of black cumin.
6. **Secondary branches plant^{-1} at harvest:** The side branches of primary branch were considered as secondary branches and its total number was counted after harvest.

7. **Tertiary branches plant^{-1} at harvest:** The branching of secondary branches was considered as tertiary branch and its number was counted after harvest.

8. **Dry weight per plant at 1st flowering stage:** Five plants were taken from each plot to take the dry weight and finally means of five plants were considered as final dry weight of plant at first flowering stage.
9. **Chlorophyll content of leaf at first flowering stage:** The SPAD value offers the relative content chlorophyll content of leaves. So, SPAD-502 electrical device was used under present study which was manufactured by Minolta Camera Co., Ltd, Osaka, Japan. (1989). Five randomly selected plants were taken to take the SPAD values and in all time the third number leaf from the top of plants were selected from each plant.

3.9.2 Morphological parameters

In all cases of morphological parameters five plants were taken to take the mean values.

1. **Days to first flowering:** All the plants were keenly observed and the days of first flowering were counted by deducting the days of observe from the days of seed sowing.
2. **Days to 50% flowering:** All the plants were keenly observed and the days of 50 % flowering were counted by deducting the days of observe from the days of seed sowing.
3. **Capsule development period:** After the initiation of capsule on plant the days for capsule development was counted by deducting the days of consideration of physiological maturity from the days of seed sowing.
4. **Duration of reproductive stage:** The duration of total reproductive stage was considered from the flowering to capsule maturity. The duration was counted in respect of days by deducting the days from seed sowing.
5. **Date of harvesting:** The date of harvesting was considered to give total information of life span of BARI kalojira-1 by the application of GA_3. The total number of days needed for final harvest from each treatment was counted from deducting the days of seed sowing.

3.9.3 Yield and yield contributing parameters

1. **Capsules plant^{-1}:** After the harvest of black cumin plant the total number of capsules was counted from five plants of each plot and the means were taken.
2. **Seeds capsule^{-1}:** After harvest of crop the capsules were placed for drying and the well dried capsule was beaten to take the number of seeds from each capsule. Five plants of each plot were selected to count the seed number and means were taken.
3. **Weight of seeds capsule^{-1} (g):** Five plants were selected from each plot, the weight of all seeds of each capsule was taken with the help of electric balance and the mean value was considered for weight of seed per capsule in gram unit.
4. **Weight of seeds plant^{-1} (g):** After harvest the total number of capsule were counted and then the total weight of total number of seeds from the five plants of each plot in gram unit was taken with the help of electric balance.
5. **1000-seed weight (g):** One thousand seeds were weighed from each plot in of gram unit with the help of electric balance.
6. **Seed yield plot^{-1}:** Total weight of seeds from each plot was considered as seed yield per plot in respect of gram unit.
7. **Stover yield plot^{-1}:** The husk and dry plant parts other than seed were considered as stover and the total weight of stover per plot was measured in gram unit.
8. **Seed yield:** Total weight of seed from each plot was considered as seed yield per plot in respect of gram unit and then seed yield of per plot was converted to tons per hectare.
9. **Stover yield:** The husk and dry plant parts other than seed were considered as stover and the total weight of stover per plot was measured in gram unit and then plot yield was converted to stover yield tons per hectare.

10. **Harvest Index:** Harvest index was calculated by dividing the seed yield by biological yield (seed yield + stover yield) and then multiplied by hundred.
11. **Seed yield increase over control:** The seed yield merit is calculated by the percent yield increased by the application of different doses of GA_3 over control treatment to evaluate the best doses of treatment.

3.10 Statistical package used

The collected data were analyzed through using the WASP-Web Agri Stat Package (Version-1) computer software following the ANOVA technique. The means were compared by Least Significant Difference (LSD) at 5% level of probability (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS AND DISCUSSION

The present study was aimed to observe the response of gibberellic acid on different vegetative growth, morphology and yield characteristics of black cumin. In this chapter figures, tables and appendices have been used to present, discuss and compare the findings obtained from the present study. The ANOVA (analysis of variance) of data in aspects of all the visual and measurable characteristics have been presented in Appendix (IV-XI). The all possible reveals and interpretations were given under the following headings:

4.1 Plant height

In respect of the plant height at 50% flowering stage of black cumin to the effect of GA_3 was found significant ($p \leq 0.05$) (Table 1 and Appendix IV). The height of plant was increased with the increasing of GA_3 application. Results revealed that, the tallest plant was found by the treatment G_7 (62.747 cm) closely followed by G_6 (62.257 cm), G_5 and G_4 whereas the smallest height was found by the plant treated with G_1 (49.617 cm). Shah *et al*. (2006) found that, plant height 41.12 to 46.51 cm of black cumin. BARI (2007) also reported that, plant height lies between 55 to 60 cm. But, the application of optimum doses of GA_3 increased the internode elongation of stem. So, the height of plant was increased under present study with significantly varied on different levels of doses.

4.2 Leaves plant^{-1}

Significant ($p \leq 0.05$) variation was observed in respect of number of leaves at 50% flowering stage of black cumin due to the effect of GA_3 (Table 1 and Appendix IV). The number of leaves was increased with the increasing of GA_3 doses. Results revealed that, the maximum number of leaves was found from the plant treated with G_7 (43.407) which was statistically similar to G_6 (42.447) and G_4 (37.307) whereas the minimum was found from G_1 (32.597).

The application of GA_3 at the rate of optimum levels may increase plant turgor pressure as a result, the vegetative growth may increase including number of leaves as a part of photosynthesis.

Table 1. Effect of GA_3 on emergence, plant height and number of leaves plant^{-1} of black cumin

Doses of GA_3 (ppm)	Days to first emergence	Days to 50% emergence	Plant height at 50% flowering (cm)	Number of leaves at 50% flowering
0 ppm	10.047	12.707	49.617 b	32.597 c
20 ppm	10.051	11.667	55.707 ab	36.517 bc
40 ppm	10.117	11.543	55.747 ab	36.997 bc
60 ppm	10.082	12.054	57.467 a	37.307 a-c
80 ppm	10.072	11.982	58.147 a	37.117 bc
100 ppm	10.053	11.885	62.257 a	42.447 ab
120 ppm	10.043	12.467	62.747 a	43.407 a
140 ppm	10.112	12.545	56.117 ab	36.447 bc
CV (%)	---	---	7.36	9.45
LSD (0.05)	---	---	7.37	6.26
Level of significance	NS	NS	*	*

Numbers in columns followed by the same letter are not statistically different at $P_{0.05}$.
*= Significant at 5% level of probability, NS= non-Significant

4.3 Primary branches plant^{-1}

Significant ($p \leq 0.01$) variation was observed in respect number of primary branches plant^{-1} of black cumin due to the effect of GA_3 (Table 2 and Appendix V). The number of primary branches plant^{-1} was increased with the increasing of GA_3 doses. Results revealed that, the maximum number of primary branches plant^{-1} was found from the plant treated with G_7 (6.736) which was statistically similar to G_6 (6.426) and the minimum was found from G_1 (4.016). Primary branches per plant are an indicator of better yield of seed crops. BARI (2007) reported, number of primary branches/plant was 5 to 7 in black cumin. So, this finding is supportable for present study.

4.4 Secondary branches plant^{-1}

GA_3 effect on number of secondary branches plant^{-1} was found significant ($p \leq 0.01$) (Table 2 and Appendix V). The number of secondary branches/plant was increased with the increasing of GA_3 doses. Results revealed that, the maximum number of secondary branches plant^{-1} was found from the plants treated with G_5 (9.036) which was statistically similar to G_6 (8.976) and the minimum was found from G_1 (6.836).

4.5 Number of tertiary branches plant^{-1}

Number of tertiary branches plant^{-1} of black cumin against the effect of GA_3 was found significant ($p \leq 0.01$) (Table 2 and Appendix V). The number of tertiary branches/plant was increased with the increasing of GA_3 doses. Results revealed that, the maximum number of tertiary branches plant^{-1} was found from the plants treated with G_6 (20.237) which were statistically similar to G_5 and (19.767) and G_4 whereas the minimum was found from G_1 (15.207).

Table 2. Effect of GA_3 on primary, secondary and tertiary branches of black cumin

Doses of GA_3 (ppm)	Primary branches plant^{-1}	Secondary branches plant^{-1}	Tertiary branches plant^{-1}
0 ppm	4.016 d	6.836 c	15.207 d
20 ppm	4.566 cd	7.166 bc	16.447 cd
40 ppm	5.086 bc	7.316 bc	17.207 cd
60 ppm	5.556 b	7.756 b	18.217 a-c
80 ppm	5.446 b	9.036 a	19.767 ab
100 ppm	6.426 a	8.976 a	20.237 a
120 ppm	6.736 a	7.446 bc	17.747 bc
140 ppm	5.106 bc	7.296 bc	16.307 cd
CV (%)	6.82	6.29	8.00
LSD (0.05)	0.64	0.85	2.47
Level of significance	**	**	**

Numbers in columns followed by the same letter are not statistically different at $P_{0.05.}$
** = Significant at 1% level of probability

4.6 Dry weight plant^{-1}

Dry weight plant^{-1} at 1st flowering stage (g) of black cumin against the effect of GA_3 was found significant ($p \leq 0.01$) (Figure 1 and Appendix VI). The Dry weight per plant at 1st flowering stage (g) was increased with the increasing of GA_3 doses. Results revealed that, the highest dry weight plant^{-1} at 1st flowering stage was found from the plant treated with G_7 (7.086 g) which was statistically similar to G_6 (6.976 g) and the minimum was found from G_1 (5.016 g). The GA_3 increases the succulence behavior of plant and also plant biomass as a result, the dry weight plant^{-1} was significantly increased under present study.

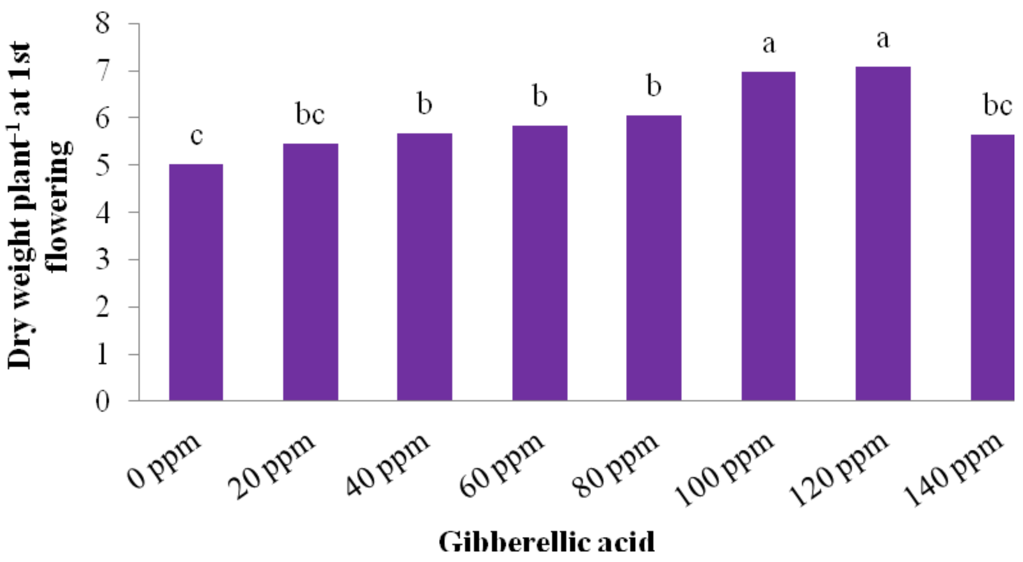

Figure 1. Effect of GA_3 on dry weight plant^{-1} at first flowering of black cumin (LSD value-0.64**).**

Bar followed by the same letter are not statistically different at $P_{0.05.}$
** = Significant at 1% level of probability

4.7 Chlorophyll content (SPAD value) at first flowering

GA_3 did not significantly (p=NS) influenced chlorophyll content of leaves of black cumin plant (Figure 2 and Appendix VI). But, numerically the highest SPAD value was found from the plant treated with G_5 (36.247) and the lowest value was found from G_1 (35.317) treated plant.

The present finding described that, at the advent of flowering, the amount of relative chlorophyll was more or less steady of plants from different plots and that is why there was no variation found among the treatments on SPAD reading resulting non-significant phenomenon.

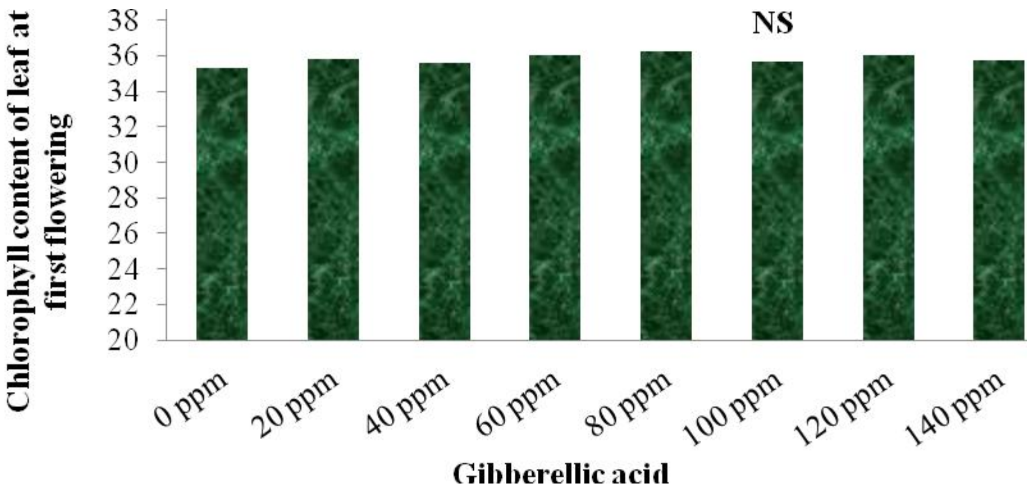

Figure 2. Effect of GA_3 on chlorophyll content of leaf at first flowering stage of black cumin (LSD value-NS)**.**

NS, non-significant

4.8 Days to first flowering

In case of days to first flowering of black cumin against the effect of GA_3 was found significant ($p \leq 0.05$) (Table 3 and Appendix VII). Days to first flowering was decreased with the increasing of GA_3 doses. Results revealed that, the longest days were needed to reach the 1^{st} flowering stage by the plant treated with G_1 (754.207 days) which was statistically similar to G_2, G_3, G_4 and G_5 and the shortest days were needed by the plant treated with G_6 (43.777 days). The application of GA_3 may improve the earlier development of flowering. So, at higher doses of GA_3 the earlier 1^{st} flowering was observed under present study by inducing the more florigen hormone.

4.9 Days to 50% flowering

GA_3 had significant effect on days to 50% flowering ($p \leq 0.05$) (Table 3 and Appendix VII). Days to 50% flowering was decreased with the increasing of GA_3 doses. Results revealed that, the longest days were needed to reach 50% flowering by the plant treated with G_1 (63.337 days) which was statistically similar to G_2, G_3, G_4 and G_5 and the shortest days were needed by the plant treated with G_6 (49.887 days). The application of GA_3 may improve the earlier development of flowering. So, at higher doses of GA_3 the earlier 50 % flowering was observed under present study by inducing the more florigen hormone and interacting with temperature and humidity.

Table 3. Effect of GA_3 on days to first flowering and days to 50 % flowering of black cumin

Doses of GA_3 (ppm)	Days to first flowering	Days to 50% flowering
0 ppm	54.207 a	63.337 a
20 ppm	50.667 ab	59.237 a
40 ppm	49.927 a-c	57.457 a-c
60 ppm	49.117 a-d	58.227 ab
80 ppm	48.537 a-d	56.777 a-c
100 ppm	43.777 d	49.887 c
120 ppm	44.427 cd	50.567 bc
140 ppm	48.007 b-d	57.127 a-c
CV (%)	7.12	8.26
LSD (0.05)	6.06	8.18
Level of significance	*	*

Numbers in columns followed by the same letter are not statistically different at $P_{0.05.}$
* = Significant at 5% level of probability

4.10 Capsule development period

The capsule development period of black cumin was significantly influenced by the application of GA_3 ($p \leq 0.05$) (Figure 3 and Appendix VIII). Capsule development period was decreased with the increasing of GA_3 doses.

Results revealed that, the longest days were needed by the plant treated with G_1 (72.207 days) which was statistically similar to G_2, G_3, G_4 and G_5 and the shortest days were needed by the plant treated with G_6 (60.857 days) which was statistically similar to G_7 (61.057 days).

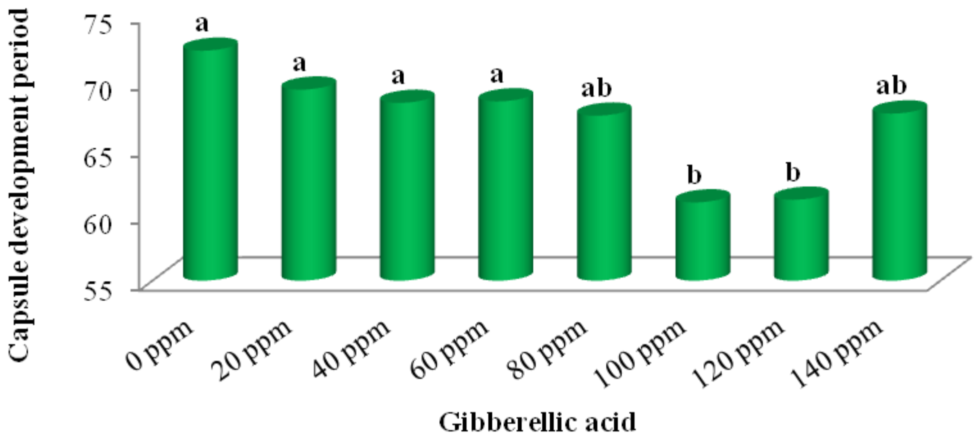

Figure 3. Effect of GA_3 on capsule development period of black cumin (LSD value-6.98).

Bar followed by the same letter are not statistically different at $P_{0.05.}$

4.11 Duration of reproductive stage

GA_3 significantly influenced duration of reproductive stage of black cumin ($p \leq 0.05$) (Figure 4 and Appendix VIII). Duration of reproductive stage was decreased with the increasing of GA_3 doses. Results revealed that, the longer duration for reproductive stage was got from the plants treated with G_1 (33.817 days) which were statistically similar to G_2, G_3, G_4 and G_5 and the shorter duration was got from the plants treated with G_6 (25.317 days). Similar findings were reported by Meena (2005) in coriander, Panda *et al*. (2007) in coriander, Vasudevan *et al*. (2008) in fenugreek, Gour *et al*. (2010, 2012) in fenugreek and Singh *et al*. (2012) in coriander. Panda *et al*. (2007) used GA_3 at 50, 75 and 100 ppm in coriander and revealed that plants treated with GA_3 at 100 ppm showed less number of days to maturity (106.33 days) as compared to control (132.33 days). This result is in agreement with the present result that, 100 ppm of GA_3 gave the lower duration of reproductive stage *i.e.*, it needed shorter duration for the maturity of black cumin than that of control *i.e.*, it needed longer duration for the maturity of black cumin.

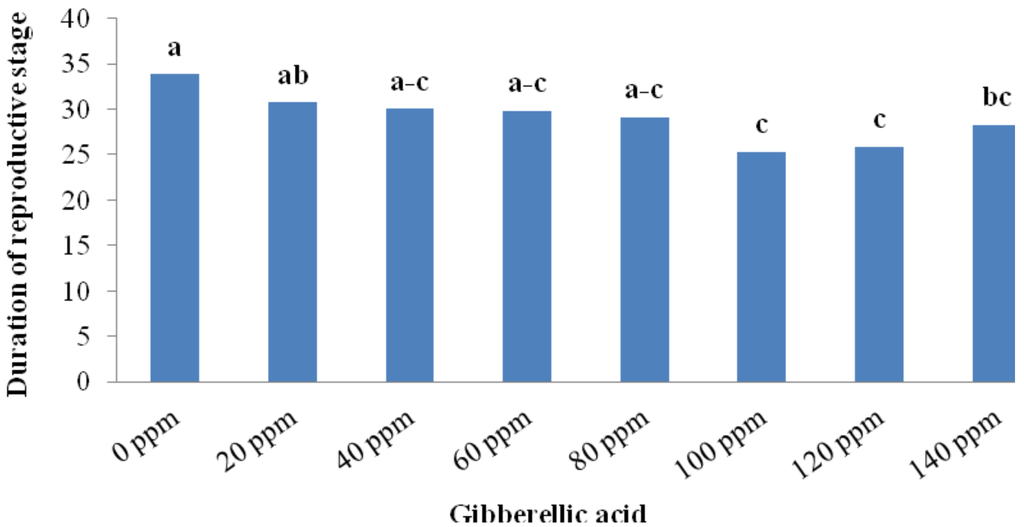

Figure 4. Effect of GA_3 on duration of reproductive stage of black cumin (LSD value-4.83**).**

Bar followed by the same letter are not statistically different at $P_{0.05.}$

4.12 Date of harvesting

Significant ($p \leq 0.05$) variation was found among different doses of GA_3 on date of harvesting of black cumin (Figure 5 and Appendix VIII). Date of harvesting was decreased with the increasing of GA_3 doses. Results revealed that, the later harvesting time was exhibited by the plants treated with G_1 (147.13 days) which was closely followed by G_2 (141.25 days), $G_{3,}$ G_4 and G_5 whereas the earlier harvesting time was needed by the plants treated with G_6 (127.15 days) which was statistically similar to G_4 (127.04 days). The finding was nearly supported by BARI (2007) describing 135 to 145 days for ripening. It might be due to comparatively high temperature and humid weather and the application of GA_3 may improve the earlier development of seed resulting earlier ripening for harvesting.

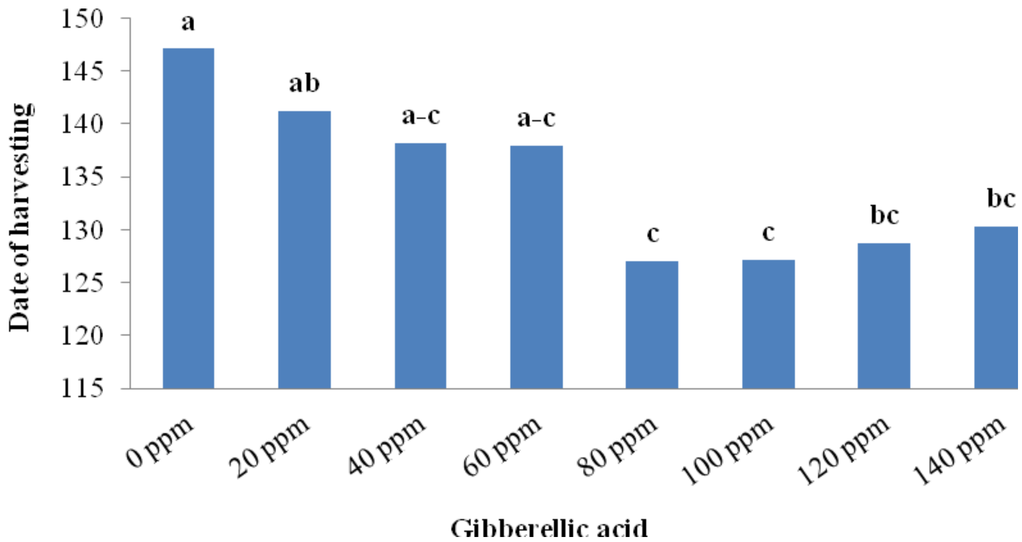

Figure 5. Effect of GA_3 on date of harvesting of black cumin (LSD value-14.01)**.**

Bar followed by the same letter are not statistically different at $P_{0.05.}$

4.13 Capsules plant^{-1}

Significant (p≤0.01) variation was found among different doses of GA_3 on number of capsules plant^{-1} of black cumin (Table 4 and Appendix VIII). Number of capsule plant^{-1} was increased with the increasing of GA_3 doses. Results revealed that, the maximum number of capsules was found from the plants treated with G_7 (26.177) which was statistically similar to G_6 (25.917) and the minimum was found from the plants treated with G_1 (17.157). The application of higher doses of GA_3 increased the florigen hormone which increased the number of flowering primordial resulted into higher of capsules per plant. So, the present finding was in partial agreement with the findings of Haq *et al.* (2013) who got the maximum capsules/plant from the GA_3 100 ppm.

4.14 Seeds capsule^{-1}

Remarkable (p≤0.01) variation was found among different doses of GA_3 on number of seeds capsule^{-1} of black cumin (Table 4 and Appendix IX). Number of seeds capsule^{-1} was increased with the increasing of GA_3 doses.

Results revealed that, the maximum number of seeds was produced by the plants treated with G_7 (94.117) which were statistically similar to G_6 (93.857), G_4, G_5 and G_8 and the minimum was produced by the plants treated with G_1 (72.237). Toncer and Kizil (2004) reported that, number of seeds per capsule varied from 90.7 to 92.8. BARI (2007) also showed that, 75 to 80 seeds per capsule. The present finding was in partial conformity with the findings of Pariari *et al*. (2012) who got the maximum seeds/capsules from GA_3 75 ppm.

4.15 Weight of seeds capsule^{-1}

In case of weight of seeds capsule^{-1} of black cumin due to different doses of GA_3 was found remarkably ($p \leq 0.01$) significant (Table 4 and Appendix IX). Weight of seeds capsule^{-1} was increased with the increasing of GA_3 doses. Results revealed that, the highest weight of seeds was produced by the plants treated with G_7 (0.282 g) which was statistically similar to G_6 (0.275 g) and the lowest was produced by the plants treated with G_1 (0.201 g). The higher and rapid amount of dry matter translocation to seed resulted in the higher weight of seed per capsule.

4.16 Weight of seeds plant^{-1}

Weight of seeds plant^{-1} of black cumin due to different doses of GA_3 was found remarkably ($p \leq 0.01$) significant (Table 4 and Appendix IX). Weight of seeds plant^{-1} was increased with the increasing of GA_3 doses. Results revealed that, the highest weight of seeds was obtained from the plants treated with G_7 (7.407 g) which was statistically similar to G_6 (7.152 g) and the lowest was obtained from the plants treated with G_1 (3.460 g). The higher and rapid amount of dry matter translocation resulted in the higher weight of seeds per plant. This was in consonance with the result of Haq *et al*. (2013) who obtained the seed yield/plant from GA_3 100 ppm applied at 40 DAS.

Table 4. Effect of GA_3 on yield contributing traits of black cumin

Doses of GA_3 (ppm)	Capsules plant^{-1}	Seeds capsule^{-1}	Weight of seeds capsule^{-1} (g)	Weight of seeds plant^{-1} (g)
0 ppm	17.157 e	72.237 d	0.201 e	3.460 e
20 ppm	19.557 de	79.207 cd	0.213 de	4.179 de
40 ppm	21.757 cd	83.447 bc	0.228 c-e	4.977 cd
60 ppm	22.667 c	86.667 a-c	0.235 cd	5.345 cd
80 ppm	22.867 bc	87.427 a-c	0.249 bc	5.713 bc
100 ppm	25.917 ab	93.857 a	0.275 ab	7.152 ab
120 ppm	26.177 a	94.117 a	0.282 a	7.407 a
140 ppm	22.717 c	89.117 ab	0.248 bc	5.653 b-d
CV (%)	7.80	5.84	7.69	15.74
LSD (0.05)	3.05	8.77	0.03	1.51
Level of significance	**	**	**	**

Numbers in columns followed by the same letter are not statistically different at $P_{0.05}$.
** = Significant at 1% level of probability

4.17 1000-seed weight

Effect of GA_3 on 1000-seed weight of black cumin was found remarkably ($p \leq 0.01$) significant (Table 5 and Appendix IX). The 1000-seed weight was increased with the increasing of GA_3 doses. Results revealed that, the highest thousand seed weight was obtained from the plants treated with G_7 (3.286 g) which was statistically similar to G_6 (3.246 g) and G_5 (3.016 g) and the lowest weight was obtained from the plants treated with G_1 (2.406 g). The result was similar to finding of Shah *et al.* (2006) who reported that, the range of 1000-seed weight was 2.45 to 2.50 g and some higher weight was reported as up to 5g by BARI (2007). Although, the 1000-seed weight is a genetical traits but, it can be modified by nutritional management. Due to application of GA_3, it increases the dry matter partitioning in seed and then converted into seed protein content and higher seed protein increases the 1000-seed weight.

4.18 Seed yield plot^{-1}

Application of GA_3 significantly influenced seed yield plot^{-1}($p \leq 0.01$) (Table 5 and Appendix X). The seed yield^{-1} was increased with the increasing of GA_3 doses. Results revealed that, the highest seed yield per plot was produced by the plants treated with G_7 (885.93 g) which was statistically similar to G_6 (855.36 g) and the lowest yield was produced by the plants treated with G_1 (413.90 g). The higher seed weight per plant may be the main reason for higher seed yield per plot under present study.

4.19 Stover yield plot^{-1}

Stover yield plot^{-1} of black cumin due to different doses of GA_3 was found remarkably ($p \leq 0.01$) significant (Table 5 and Appendix X). The stover yield plot^{-1} was increased with the increasing of GA_3 doses. Results demonstrated that, the highest stover yield per plot was obtained by the plants treated with G_7 (1060.9 g) which was statistically similar to G_6 (1030.4 g) and the lowest yield was produced by the plants treated with G_1 (588.9 g). The higher vegetative growth and higher dry weight per plant may be the main reason of higher stover yield per plot under present study.

4.20 Seed yield (t ha^{-1})

Significant ($p \leq 0.01$) variation was found in case of seed yield (t ha^{-1}) of black cumin due to different doses of GA_3 (Table 5 and Appendix X). The seed yield (t ha^{-1}) was increased with the increasing of GA_3 doses. Results demonstrated that, the highest seed yield per hectare was recorded from the plants treated with G_7 (2.954 t ha^{-1}) which was statistically similar to G_6 (2.850 t ha^{-1}) and the lowest yield was recorded from the plants treated with G_1 (1.379 t ha^{-1}). The higher seed yield per plot may be the main reason for higher seed yield per hectare under present study and the result was supported by Haq *et al.* (2013) who found maximum seed yield 2.09 (t ha^{-1}) in black cumin from GA_3 100 ppm applied on the crop at 40 days after sowing.

Table 5. Effect of GA_3 on yield and yield contributing traits of black cumin

Doses of GA_3 (ppm)	1000-seed weight (g)	Seed yield $plot^{-1}$ (g)	Stover yield $plot^{-1}$ (g)	Seed yield (t ha^{-1})
0 ppm	2.406 d	413.90 e	588.9 d	1.379 d
20 ppm	2.446 d	499.95 d	675.0 cd	1.668 cd
40 ppm	2.746 cd	595.35 c	770.4 bc	1.984 bc
60 ppm	2.916 bc	639.29 bc	814.3 bc	2.133 b
80 ppm	3.016 a-c	683.36 b	858.4 b	2.276 b
100 ppm	3.246 ab	855.36 a	1030.4 a	2.850 a
120 ppm	3.286 a	885.93 a	1060.9 a	2.954 a
140 ppm	2.886 c	676.15 bc	851.1 b	2.254 b
CV (%)	6.83	7.30	10.86	8.47
LSD (0.05)	0.34	83.91	158.11	0.32
Level of significance	**	**	**	**

Numbers in columns followed by the same letter are not statistically different at $P_{0.05.}$
** = Significant at 1% level of probability

4.21 Stover yield (t ha^{-1})

Stover yield (t ha^{-1}) of black cumin was found remarkably ($p \leq 0.01$) significant due to the application of GA_3 (Table 6 and Appendix XI). The stover yield (t ha^{-1}) was increased with the increasing of GA_3 doses. Results demonstrated that, the highest stover yield per hectare was produced by the plants treated with G_7 (3.535 t ha^{-1}) which was statistically similar to G_6 (3.434 t ha^{-1}) and the lowest yield was produced by the plants treated with G_1 (1.961 t ha^{-1}). Valadabadi and Aliabadi (2011) reported that, stover yield ranged from 3.49 to 4.23 t ha^{-1}. However, Haq, *et al*. (2013) found non-significant result in respect of stover yield per hectare from GA_3 application.

4.22 Seed yield increase over control

The application of GA_3 had shown the significant improvement of seed yield per hectare of black cumin over the control treatment, G_1 (distilled water spray). In percent of increased seed yield, the highest percent was increased by G_7 (53.32 %) followed by G_6 (51.61 %).

Table 6. Effect GA_3 on stover yield and percent seed yield increase of black cumin

Doses of GA_3 (ppm)	Stover yield (t ha^{-1})	Seed yield increase over control (%)
0 ppm	1.961 c	----
20 ppm	2.249 c	17.33
40 ppm	2.565 b	30.49
60 ppm	2.714 b	35.35
80 ppm	2.860 b	39.41
100 ppm	3.434 a	51.61
120 ppm	3.535 a	53.32
140 ppm	2.839 b	38.82
CV (%)	6.12	
LSD (0.05)	0.29	
Level of significance	**	

Numbers in columns followed by the same letter are not statistically different at $P_{0.05.}$
** = Significant at 1% level of probability

4.23 Harvest Index

The harvest Indexof black cumin due to different doses of GA_3 was found non-significant (p=NS) (Figure 6 and Appendix XI). But, numerically the maximum harvest Index was obtained from the plants treated with G_7 (45.505 %) followed by G_6 (45.360 %) and the minimum was produced by the plants treated with G_1 (41.275 %). This result correlates the result of Shah *et al*. (2006) who obtained non-significant result from the application of GA_3 in the range of 30.01-31.45 %. But Haq, *et al*. (2013) found maximum harvest index (53.32 %) from GA_3 100 ppm applied at 40 DAS.

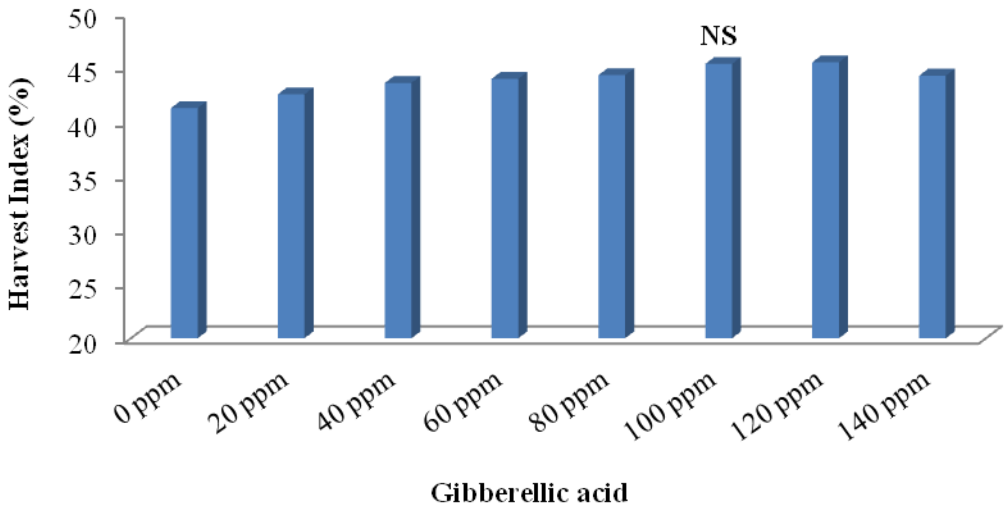

Figure 6. Effect of GA_3 on harvest index of black cumin (LSD value-NS)**.**

Bar followed by the same letter are not statistically different at $P_{0.05.}$

4.24 Correlation coefficient (r)

Data from harvested plant samples were used to calculate the correlation co-efficient (r). The application of gibberellic acid had significantly influence the different traits of black cumin and so, the correlation co-efficient were calculated among some yield and yield contributing traits. A linear relation (r=0.989**) was exhibited between the number of capsules/plant and seed yield (t/ha) of black cumin (Figure 7). In Figure-8, a linear relation (r=0.972*) was found between number of seeds/capsule and seed yield (t/ha). In Figure-9, there was present a strong relation (r=0.995**) between weight of seeds/capsule (g) and seed yield (t/ha) of black cumin. A strong linear relation (r=0.999**) was found between weight of seeds/plant (g) and seed yield (t/ha) (Figure-10). A strong linear relation (r=0.996*) was found between 1000-seed weight (g) and seed yield (t/ha) of black cumin (Figure-11). From the correlation study it may be said that, there was about 97 to 99 % of seed yield of black cumin was dependent on different yield contributing traits which were significantly influenced by GA_3 application.

Correlation among various characters indicated that all these characters had significant contribution to seed yield and yield would be increased by improving these yield attributes with application of GA_3.

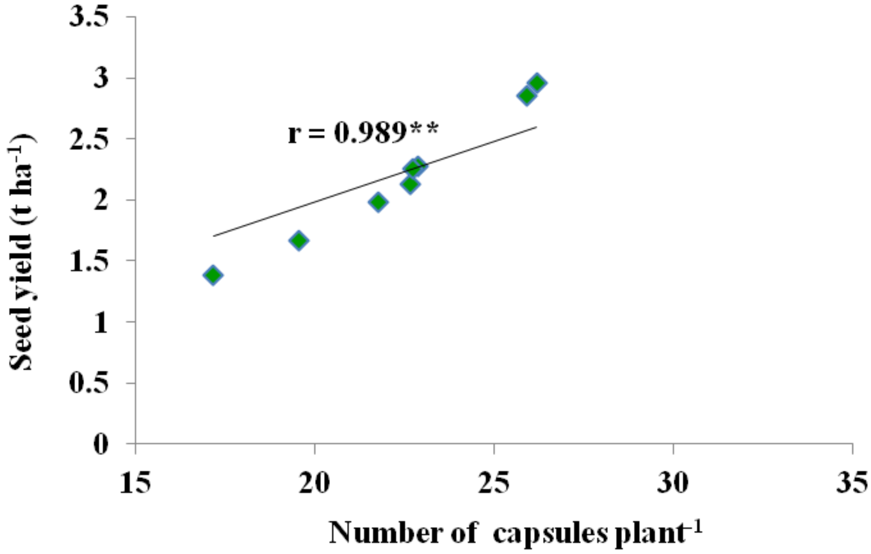

Figure 7. Relationship between number of capsules plant^{-1} and seed yield (t ha^{-1}) of black cumin.

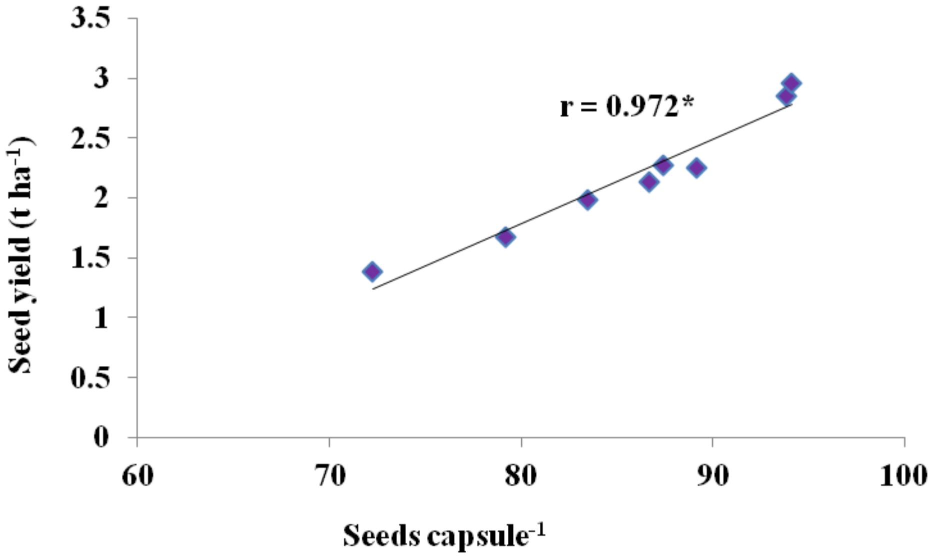

Figure 8. Relationship between seeds capsule^{-1} and seed yield (t ha^{-1}) of black cumin.

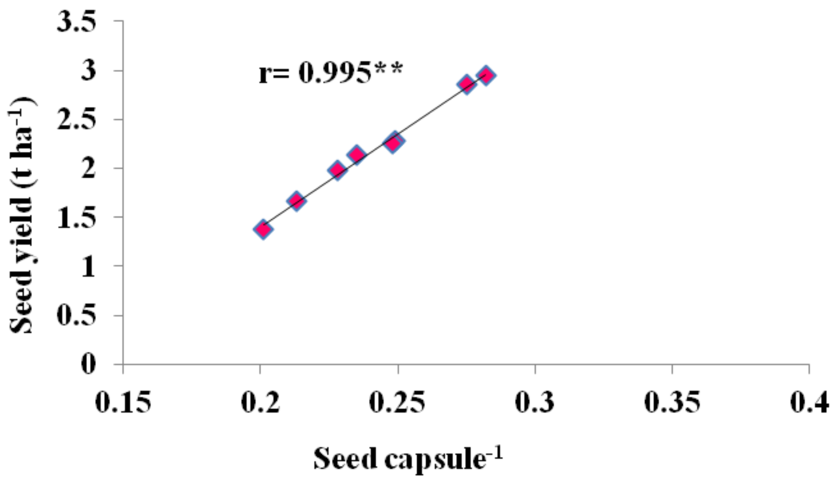

Figure 9. Relationship between weight of seeds capsule^{-1} and seed yield (t ha^{-1}) of black cumin.

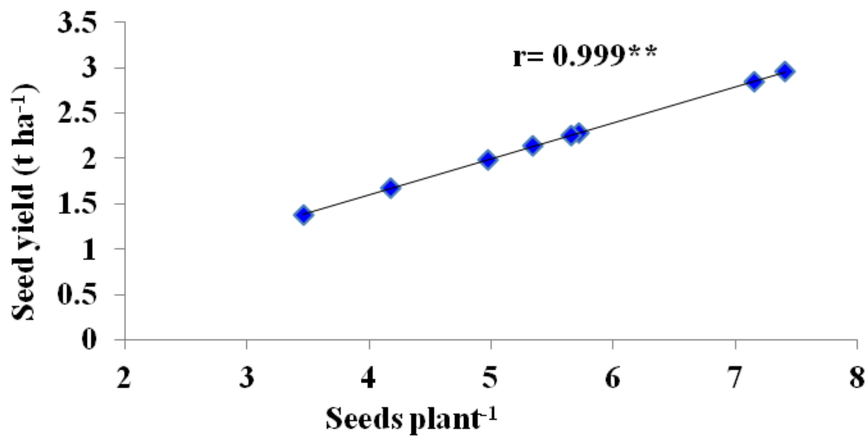

Figure 10. Relationship between weight of seeds plant^{-1} and seed yield (t ha^{-1}) of black cumin.

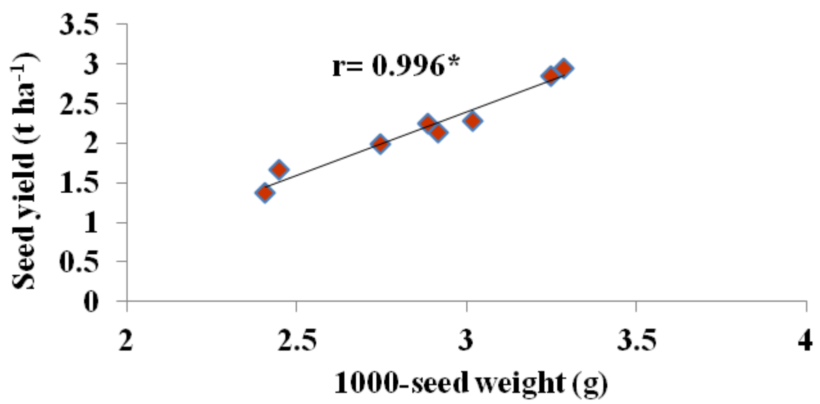

Figure 11. Relationship between 1000-seed weight and seed yield (t ha^{-1}) of black cumin.

CHAPTER V

SUMMARY AND CONCLUSION

The experiment was conducted at the research field of Sher-e-Bangla Agricultural University, Dhaka-1207 during the period from November 1, 2016 to April 30, 2017 in *rabi* season. The experimental area was situated at $23^0$77'N latitude and $90^0$33'E longitude at an altitude of 8.6 meter above the sea level. The experimental site belongs to the agro-ecological zone of "Madhupur Tract", AEZ-28. A sub-tropical monsoon climatic zone was prevailed around experimental site, most provably characterized by winter during the months from November 01, 2015 to April 30, 2016 (*rabi* season). Silty clay in texture, olive-gray with common fine to medium distinct dark yellowish brown mottles was the main traits of top soil. The soil was also characterized by pH-5.6 and organic carbon-0.45%.

The experiment was consisted of eight (8) different doses of GA_3 *viz.*, 0 ppm (distilled water spray), 20 ppm, 40 ppm, 60 ppm, 80 ppm, 100 ppm, 120 ppm and 140 ppm. All the doses of gibberellic acid were applied on the standing crops at 40 days after sowing (DAS). BARI kalojira-1 was used as planting material. Experiment was set in a single factor randomized complete block design (RCBD) with 3 replications. The allocated plots were fertilized by recommended doses of fertilizers. All the intercultural operations and plant protection measures were taken as per when needed. Data on different vegetative growth, morphology, yield and yield contributing characters were collected and analyzed by using WASP-Web Agri Stat Package (Version-1) program and means were compared by Least Significant Difference (LSD) at 5% level of probability. Results revealed that, the tallest plant was found from the treatment G_7 (62.747 cm) followed by G_6 (62.257 cm) and the smallest height was found by the plants treated with G_1 (49.617 cm). The maximum number of leaves was found from the plants treated with G_7 (43.407) which was statistically similar to G_6 (42.447) and the minimum was found from G_1 (32.597).

The maximum number of primary branches plant^{-1} was found from the plants treated with G_7 (6.736) which was statistically similar to G_6 (6.426) and the minimum was found from G_1 (4.016). The maximum number of secondary branches plant^{-1} was found from the plants treated with G_5 (9.036) which was statistically similar to G_6 (8.976) and the minimum was found from G_1 (6.836). The maximum number of tertiary branches plant^{-1} was found from the plants treated with G_6 (20.237) which was statistically similar to G_5 (19.767) and the minimum was found from G_1 (15.207). The highest dry weight per plant at 1st flowering stage was found from the plants treated with G_7 (7.086 g) which was statistically similar to G_6 (6.976 g) and the minimum was found from G_1 (5.016 g). Numerically the highest SPAD value was found from the plants treated with G_5 (36.247) and the lowest value was found from G_1 (35.317) treated plant. The longest days were needed by the plants treated with G_1 (754.207 days) which were statistically similar to G_2, G_3, G_4 and G_5 and the shortest days were needed by the plants treated with G_6 (43.777 days). The longest days were needed by the plants treated with G_1 (63.337 days) which were statistically similar to G_2, G_3, G_4 and G_5 and the shortest days were needed by the plants treated with G_6 (49.887 days).

The longest days were needed by the plants treated with G_1 (72.207 days) which were statistically similar to G_2, G_3, G_4 and G_5 and the shortest days was needed by the plants treated with G_6 (60.857 days) which was statistically similar to G_7 (61.057 days). The longer duration for reproductive stage were got by the plants treated with G_1 (33.817 days) which was statistically similar to G_2, G_3, G_4 and G_5 and the shorter duration were got by the plants treated with G_6 (25.317 days). The later harvesting time was exhibited by the plants treated with G_1 (147.13 days) which followed by G_2 (141.25 days) and the earlier harvesting time was needed by the plants treated with G_6 (127.15 days) which was statistically similar to G_6 (127.04 days).

The maximum number of capsules was found by the plants treated with G_7 (26.177) which was statistically similar to G_6 (25.917) and the minimum was found by the plants treated with G_1 (17.157). The maximum number of seeds was found from the plants treated with G_7 (94.117) which was statistically similar to G_6 (93.857) followed by G_4, G_5 and G_8 and the minimum was found from the plants treated with G_1 (72.237).

The highest weight of seeds was found by the plants treated with G_7 (0.282 g) which was statistically similar to G_6 (0.275 g) and the lowest was found by the plants treated with G_1 (0.201 g). The highest weight of seeds was found by the plant treated with G_7 (7.407 g) which was statistically similar to G_6 (7.152 g) and the lowest was found by the plants treated with G_1 (3.460 g). The highest thousand seed weight was found by the plant treated with G_7 (3.286 g) which was statistically similar to G_6 (3.246 g) and G_5 (3.016 g) and the lowest weight was found by the plant treated with G_1 (2.406 g). The highest seed yield per plot was produced by the plants treated with G_7 (885.93 g) which was statistically similar to G_6 (855.36 g) and the lowest yield was produced by the plants treated with G_1 (413.90 g).

The highest stover yield per plot was produced by the plants treated with G_7 (1060.9 g) which was statistically similar to G_6 (1030.4 g) and the lowest yield was produced by the plants treated with G_1 (588.9 g). The highest seed yield per hectare was obtained from the plants treated with G_7 (2.954 t) which was statistically similar to G_6 (2.850 t) and the lowest yield was recorded from the plants treated with G_1 (1.379 t). The highest stover yield per hectare was produced by the plants treated with G_7 (3.535 t) which was statistically similar to G_6 (3.434 t) and the lowest yield was produced by the plants treated with G_1 (1.961 t). In percent of seed yield, the highest percent was increased by G_7 (53.32 %) followed by G_6 (51.61 %) over control. Numerically the maximum harvest Index (%) was obtained from the plants treated with G_7 (45.505 %) followed by G_6 (45.360 %) and the minimum was produced the plants treated with G_1 (41.275 %).

The results also revealed that, there was strong relation between different yield contributing traits with seed yield per hectare of black cumin.

Conclusion

Based on the results of the present study the following conclusion might be drawn:

1. The growth parameters *viz*., plant height, leaves plant^{-1}, primary branches plant^{-1}, and the yield attributes *viz*., capsules plant^{-1}, seeds capsule^{-1}, weight of seeds plant^{-1} and 1000-seed weight were found maximum from the application of GA_3 120 ppm closely followed by GA_3 100 ppm. GA_3 100 ppm gave the maximum secondary and tertiary branches/pant.

2. There observed a strong positive correlation of seed yield with capsules plant^{-1}, seeds capsule^{-1}, weight of seeds plant^{-1} and 1000-seed weight.

3. Capsule development period, duration of reproductive stage and harvesting date were decreased with the increase of GA_3 concentration.

4. The maximum seed yield of black cumin was obtained from the application of GA_3 120 ppm closely followed by GA_3 100 ppm.

5. Seed yield increase over control due to the application of GA_3 120 ppm and GA_3 100 ppm was 53.32 % and 51.61 %, respectively.

6. Application of GA_3 120 ppm produced the highest stover yield which was identical with GA_3 100 ppm.

Recommendation

1. For seed production of black cumin, foliar application of GA_3 at 100 ppm once to the crop at 40 days after sowing is suitable for obtaining maximum seed yield.

2. The findings obtained from the present study should be confirmed by conducting similar type of experiments in different Agro-ecological Zones (AEZs) of Bangladesh.

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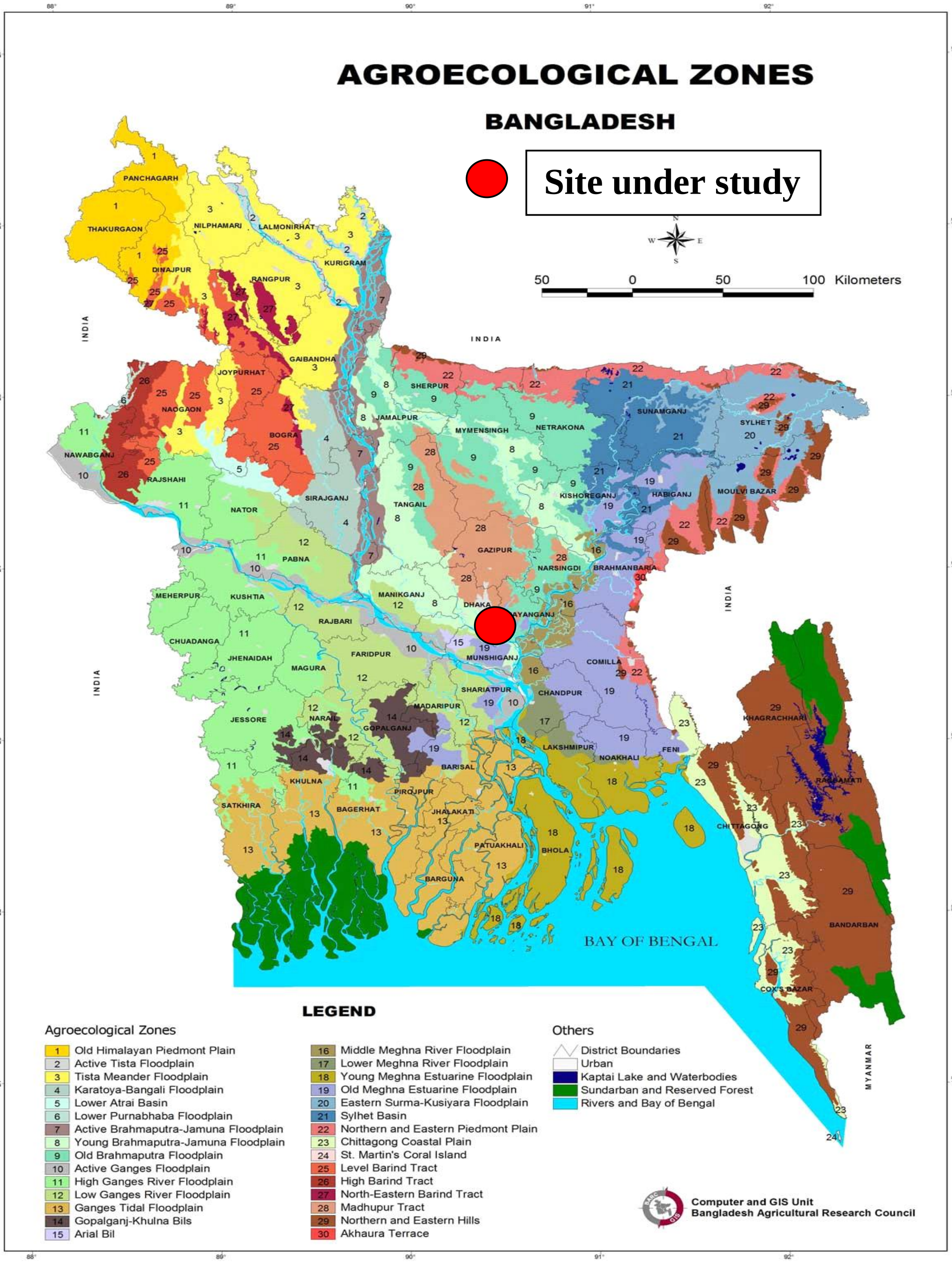
APPENDICES

Appendix I: Map showing the site used for present study

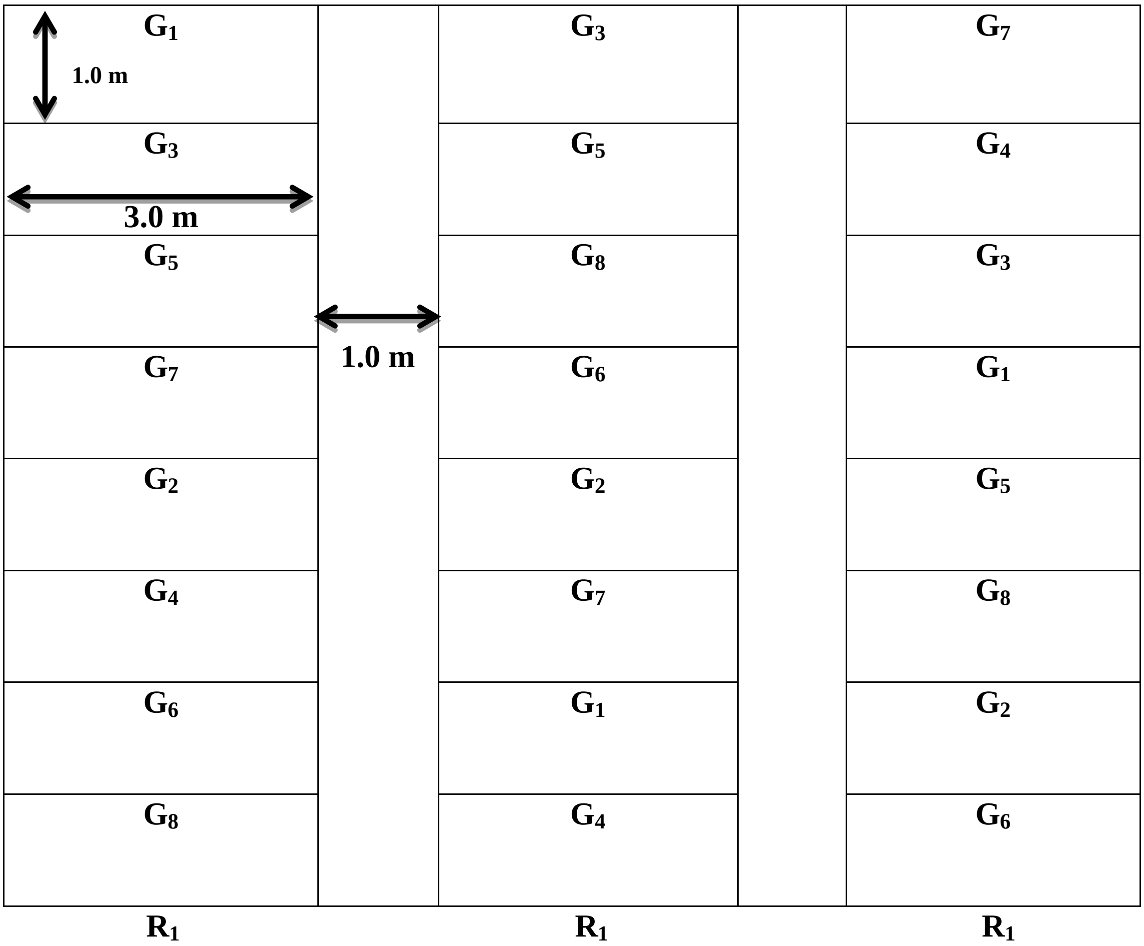


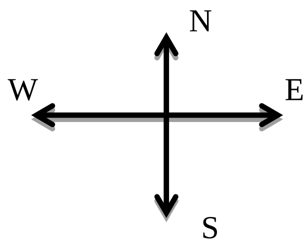
Appendix II. Monthly meteorological information during the period from November, 2016 to April, 2017

Year	Month	Air temperature (^{0}C)		Relative humidity (%)	Total rainfall (mm)
		Maximum	Minimum		
2016-2017	November	29.19	12.23	57.28	49
	December	26.00	9.16	70.43	1
	January	24.92	9.87	72.79	Trace
	February	25.85	14.54	78.42	Trace
	March	31.35	17.26	68.94	63
	April	36.93	22.55	72.89	109

Source: Metrological Centre (Climate Division), Agargaon, Dhaka.

Appendix III. Layout of experimental plot





Legends :

Replication to replication distance : 1 m

Line to line distance : 25 cm

Plant to plant distance : 10 cm

Unit plot size : 3.0 m × 1.0 m

Appendix IV. Mean square values of the data for vegetative traits of black cumin

Source of variation	df	Days to first emergence	Days to 50% emergence	Plant height at 50 % flowering stage	Leaves at 50 % flowering stage
Replication	2	0.00018	0.00158	0.0154	0.0061
Gibberellic acid (GA)	7	3.51274^{NS}	3.94499^{NS}	51.5658*	36.3907*
Error	14	0.29678	0.80216	17.7422	12.8035

* = Significant at 5 % level of probability, NS = non-significant

Appendix V. Mean square values of the data for branching of black cumin

Source of variation	df	Number of primary branches plant^{-1}	Number of secondary branches plant^{-1}	Number of tertiary branches plant^{-1}
Replication	2	0.00003	0.00027	0.00087
Gibberellic acid (GA)	7	2.42207**	2.06424**	8.96571**
Error	14	0.13416	0.23617	1.99254

** = Significant at 1 % level of probability

Appendix VI. Mean square values of the data for plant dry weight and SPAD value of leaf of black cumin

Source of variation	df	Dry weight per plant at 1st flowering stage (g)	Chlorophyll content of leaf at first flowering stage (SPAD value)
Replication	2	0.00012	0.00008
Gibberellic acid (GA)	7	1.56852**	0.25521^{NS}
Error	14	0.13585	8.71417

** = Significant at 1 % level of probability, NS = Non-significant

Appendix VII. Mean square values of the data for first and 50 % flowering of black cumin

Source of variation	df	Days to first flowering	Days to 50% flowering
Replication	2	0.0172	0.0106
Gibberellic acid (GA)	7	33.7576*	58.9238*
Error	14	11.9794	21.8537

*= Significant at 5 % level of probability

Appendix VIII. Mean square values of the data for morphology and yield traits of black cumin

Source of variation	df	Capsule development period	Duration of reproductive stage	Date of harvesting	Capsules $plant^{-1}$
Replication	2	0.0033	0.0221	0.009	0.0056
Gibberellic acid (GA)	7	46.8910*	22.1704*	167.406*	26.9964**
Error	14	15.9279	7.6326	64.070	3.0407

* = Significant at 5 % level of probability, ** = Significant at 1 % level of probability

Appendix IX. Mean square values of the data for yield traits of black cumin

Source of variation	df	Seeds $capsule^{-1}$	Weight of seeds/capsule (g)	Weight of seeds/plant (g)	1000-seed weight (g)
Replication	2	0.051	4.931	0.00435	0.00007
Gibberellic acid (GA)	7	163.472**	2.334**	5.41518**	0.32081**
Error	14	25.106	3.409	0.74594	0.03846

** = Significant at 1 % level of probability

Appendix X. Mean square values of the data for yield and yield traits of black cumin

Source of variation	df	Seed yield/plot (g)	Stover yield/plot (g)	Seed yield (t/ha)
Replication	2	4.7	10.6	0.00008
Gibberellic acid (GA)	7	77437.8**	77436.9**	0.85931**
Error	14	2296.3	8151.8	0.03435

** = Significant at 1% level of probability

Appendix XI. Mean square values of the data for stover yield and harvest index of black cumin

Source of variation	df	Stover yield (t/ha)	HI (%)
Replication	2	0.00011	0.0017
Gibberellic acid (GA)	7	0.86166**	5.9249^{NS}
Error	14	0.02874	13.0726

** = Significant at 1% level of probability, NS = Non-significant

Chapter I

Introduction

Chapter II

Review of literature

Chapter III

Materials and Methods

Chapter IV

Results and Discussion

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Summary and Conclusion

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Appendices