SHADE INDUCED EFFECT ON GROWTH PERFORMANCE OF DIFFERENT CAULIFLOWER (*Brassica oleracea var. botrytis*) VARIETIES

GOPAL SAHA

DEPARTMENT OF AGROFORESTRY AND ENVIRONMENTAL SCIENCE

SHER-E-BANGLA AGRICULURAL UNIVERSITY

DHAKA-1207

DECEMBER, 2021

SHADE INDUCED EFFECT ON GROWTH PERFORMANCE OF DIFFERENT CAULIFLOWER (*Brassica oleracea var. botrytis*) VARIETIES

BY

GOPAL SAHA

REGISTRATION NO.: 19-10320

A Thesis
Submitted to the Faculty of Agriculture
Sher-e-Bangla Agricultural University, Dhaka,
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE
IN
AGROFORESTRY AND ENVIRONMENTAL SCIENCE
SEMESTER: JANUARY- DECEMBER, 2021

APPROVED BY:

Dr. Jubayer-Al-Mahmud
Professor
Supervisor

Abdul Halim
Assistant Professor
Co-supervisor

Dr. Nasrin Sultana
Chairman
Examination Committee

Dr. Jubayer-Al-Mahmud
Professor
Department of Agroforestry and
Environmental Science
Sher-e-Bangla Agricultural University
Sher-e-Bangla Nagar, Dhaka-1207, Bangladesh
Mobile: 01771-606735
E-mail: jamahmud_bd@yahoo.com

CERTIFICATE

*This is to certify that thesis entitled, **"Shade Induced Effect on Growth Performance of Different Cauliflower (Brassica oleracea var. botrytis) Varieties"** submitted to the faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE** in **AGROFORESTRY AND ENVIRRONMENTAL SCIENCE**, embodies the result of a piece of bona fide research work carried out by **GOPAL SAHA**, Registration No.: **19-10320** 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 been fully acknowledged by him.

Dated: December, 2021
Place: Dhaka, Bangladesh

(Dr. Jubayer-Al-Mahmud)
Professor
Supervisor

DEDICATED TO

MY BELOVED PARENTS

ACKNOWLEDGEMENTS

Firstly, the author is prostrated before Almighty God, most merciful and beneficent, for giving the strength and courage to successfully complete the research work.

This thesis owes its existence to the help, support and motivation of several people. Firstly, I would like to express my sincere appreciation and gratitude to my supervisor, ***Professor Dr. Jubayer-Al-Mahmud,*** *for his guidance and constant encouragement during my research. His support and inspiring suggestions have been precious for the development of this thesis content.*

I am also indebted to my co-supervisor ***Abdul Halim, Assistant Professor,*** *and departmental chairman* ***Dr. Nasrin Sultana, Associate Professor,*** *who have been a constant source of encouragement and enthusiasm, not only during this thesis work but also during the two years of my M.S. program.*

I sincerely express the heartiest respect, deepest gratitude, and profound appreciation toall my other teachers of ***Department of Agroforestry and Environmental Science, Sher-e-Bangla Agricultural University****, who have been a constant source of encouragement and enthusiasm, not only during this thesis work but also during the two years of my M.S. program.*

My deepest gratitude goes to my family for their unflagging love and unconditional support throughout my life and my studies. You made me live the most unique, magic and carefree childhood that have made me who I am now.

Finally, I wish to thank all my fellow lab mates for being there in all the hard work and sharing my joys and sorrows. To them I say, "You make the bad times into good and the good times unforgettable".

The Author

SHADE INDUCED EFFECT ON GROWTH PERFORMANE OF DIFFERENT CAULIFLOWER (*Brassica oleracea var. botrytis*) VARIETIES

ABSTRACT

In agroforestry system, light is a limiting factor for maximum crop production. Therefore, a pot experiment was conducted in the Field Laboratory of the Department of Agroforestry and Environmental Science, Sher-e-Bangla Agricultural University, Dhaka- 1207, during the months of October 2020 to March 2021 with three cauliflower varieties viz. V_1 (Chandi), V_2 (Snow White), V_3 (Indian Crown) under four shade treatments/light intensities, [100%, 75%, 50% and 25% light intensity which indicate control (S_0), S_1, S_2 and S_3, respectively] to evaluate their morpho-physiological and growth performances. Low light stress [mainly 50% light intensity (S_2) and 25% light intensity (S_3)] substantially reduced the germination rate, plant height, plant weight (fresh and dry weight), leaves number, leaf length, leaf width, flowering dates, stem diameter, photosynthetic performance (SPAD value) of different cauliflower varieties. However, considering the obtained findings Snow white variety showed less negative performance than the other varieties under shaded condition. So, among the tested cauliflower varieties Snow white might be suitable for shaded condition with low light intensities.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

ABBREVIATIONS

Full word	Abbreviations	Full word	Abbreviations
Agro-Ecological Zone	AEZ	International	Intl.
Applied	App.	Journal	J.
Agriculture	Agric.	Kilogram	Kg
Agronomy	Agr.	Microgram	µg
Bangladesh Agricultural Research Institute	BARI	Milligram	mg
		Micrometer	µm
Biology	Biol.	Millimeter	Mm
Biotechnology	Biotechnol.	Liter	L
Biochemistry	Biochem.	Muriate of Potash	MoP
Botany	Bot.	Negative logarithm of hydrogen ion concentration (-log[H+])	p^H
Bangladesh Bureau of Statistics	BBS		
Centimeter	Cm	North	N
Completely Randomized Design	CRD	Nutrition	Nutr.
Days after transplanting	DAT	Percentage	%
Degree Celsius	°C	Photosynthetically Active Radiation	PAR
East	E	Physiology	Physio.
Ecology	Ecol.	Plant Genetic Resource Centre	PGRC
Environment	Environ.	Review	Rev.
Experiment	Exp.	Science	Sci.
Forestry	Fort.	Soil Plant Analysis Development	SPAD
Gram	G	Specific Leaf Area	SLA
Hectare	Ha	Triple Super Phosphate	TSP
Horticulture	Hort.	“which is” or “as follows”	viz.

CHAPTER 1

INTRODUCTION

Agriculture is closely related to Bangladesh because of its fertile land which are ideal for crop cultivation. The vegetable sector is one of the most important in agricultural sectors next to the rice. As with rice, vegetables are grown all over the country and a large number of farmers are involved in vegetable cultivation (Rupasena, 1999). The cool and winter conditions are ideal for temperate vegetable crops such as carrot, leek, cabbage, cauliflower, salad leaves, beet, bean and bell pepper (Sharmin *et al.,* 2018). Among the winter vegetables cultivated in Bangladesh, cauliflower is cultivated as an off-season vegetable in vast area due to its nutritional value and remunerative price which improves farmers economic status (Islam *et al.,* 2020).

Cauliflower (*Brassica Oleracea Var. botrytis L.*) belongs to the family of Brassicaceae originated from Europe and Africa (Ajithkumar *et al*.,2014). Cauliflower is rich in minerals such as potassium, calcium, iron, phosphorus, magnesium and carbohydrates. The nutritive value per 100g of fresh cauliflower is given as follows: Moisture 90.8 g, Protein 2.6 g, Fat 0.4 g, Carbohydrate 4.0 g, Minerals 1.9 g, Fiber 1.2 g, Vitamin-A 30 mg, Thiamine 0.043 mg, Riboflavin 0.10 mg, Nicotinic acid 1.00 mg, Vitamin C 56 mg, Calcium 33 mg, Phosphorus 57 mg, Iron 1.50 mg, Potassium 11.3 mg, Magnesium 20 mg (Sen *et al*., 2017). Cauliflower helps in boost the cardiovascular system, strengthen bones, reduce stroke, prevent cancer, boost heart health, reduce diabetes, boost brain health, detoxification support and digestive benefits (Kumar *et al*., 2020).

The edible part of cauliflower is called curd which is made up of abortive flowers. The lower part named as stalk is short, fleshy and closely crowded (Shanmugavelu., 1989). The farmers can grow cauliflower by providing the temperature, humidity and light, as required by the plant species. The optimum temperature range for cauliflower production is 15 to 20°C with maximum of 25°C and minimum of 8°C (Angmo *et al.,* 2020; Giri *et al*., 2020). Plant needs light for expected growth and development, but light quality, quantity and duration also have a significant effect on growth and development (Cervera *et al.,* 2007). Plant receives light from the sun; the quality, quantity and duration depend on the different months of a year, hours of the day light, geographical position and climate condition. Plants use light for photosynthesis. It is the primary metabolites in all plants (Kopsell., 2008; Perez-Balibreaet *et al*., 2008).

Carbohydrates generate during photosynthesis are in plant body as a source of nutrition. Photosynthetically Active Radiation (PAR) influences flowering, plant canopy, color and leaf size in both herbaceous (Jeong *et al.,* 2009; Vendrame *et al*., 2004) and woody species (Hampson *et al.,* 1996).

In agroforestry system, low light stress is observed under plant canopy. Photosynthetic pigments in leaves of higher plants selectively absorb red and blue light spectrum (Zheng and Labeke., 2017; Hogewoning *et al*., 2010; Wang *et al*., 2010; Johkan *et al*., 2012; Demotes-Mainard *et al*., 2016; Nguyen *et al*., 2021). So, plants growing under shade receive more far-red (FR) wavelength reflected from higher trees (Wiebe and Krug., 1974). About 90% red and blue light are absorbed by plant leaves. So, plant under shade gets far-red light from the light reflected from the higher plants. It is known that plant development is strongly influenced by blue or red light. For plant development and pant health, combination of red and blue light is an effective lighting source (Wheeler *et al*., 1991; Nhut *et al*., 2003). Additionally, the combination of red and blue light in 1:1 ratio may promote fresh weight and dry weight in many plant species such as Lilium, Chrysanthemum, Cauliflower, Chili pepper, Tomato etc (Lian *et al*., 2002; Kim *et al*., 2004; Liu *et al*., 2011). Combination of these light is used not only in research but also in commercial crop production because of its effectiveness at leaf level in short terms and long terms. The absence of one of the two light wavebands (red or blue) creates photosynthetic inefficiencies (Hogewoning *et al*., 2010).

Plants can be grouped into three categories, i.e., shade-sensitive, shade-tolerant, and shade-loving genotypes. Generally, cauliflower is grown under cold season or under shade condition during winter. It needs a minimum photoperiodic length for better production; but during winter it is very hard to get minimum photoperiodic length (D'Souza *et al*., 2015; Robberecht, 1989; Coohill, 1989; Frederick, 1993). Generally, cauliflower gets far-red light under shade condition. It is not sufficient for getting enough photoperiodic light and temperature. But light intensity is an important factor for plant germination, growth, photosynthesis, development and yield. So, it is very necessary to supply enough light to cauliflower plant. Otherwise, the germination, growth and yield of cauliflower may be hampered. On the other hands, low-light grown crops have been shown to be more susceptible to photoinhibition than those plants grown under higher light intensity (Long *et al*., 1994; Pierson, 1990; Bazzaz and Carlson, 1982; Bjorkman and Holmgren, 1963). The increases in photosynthesis rate

(Pn) correlates with increases in light intensity. However, very high light intensity resulted in decreases of net photosynthesis rate (Bowes *et al*., 1971; Khatib and Paulsen, 1989; Boardman, 1977; Brouwer *et al.*, 2012). Low radiation intensity may lead to increase specific leaf area (SLA), plant height and maximize available light absorption for photosynthesis (Steinger *et al*., 2003; Yavari *et al*., 2021; Assmann, 1992; Miller and Machlis, 1968; Gao *et al*., 2021). On the contrary, high irradiances is associated with acclimating many physiological and morphological characteristics; such as reduced specific leaf area (SLA), increase leaf thickness due to growth of palisade tissue. Such type of modification helps to prevent the damage caused by excessive radiation intensity and ensuring good photosynthesis (Givnish *et al*., 2004; Matos *et al*., 2009; Morais *et al*., 2004; Sims and Pearcy, 1994; Wentworth *et al*., 2006). The light intensity, quality, quantity and duration are essential for the plant growth, development, morphology and physiological responses. Visible light ranges between 380 and 750 nm but this varies among individuals. The range between 400 and 700 nm is used by plants to ensure photosynthesis which named as PAR. Changes in PAR light has strongly influenced on the anatomy, morphology and physiology of crop leaves (Hogewoning *et al.,* 2010). Blue light increased the thickness of the epidermis and palisade mesophyll cells, on the other hand, the red light decreased the thickness of the abaxial-face and spongy tissues.

In Bangladesh, among the winter vegetables, cauliflower is one of the most popular vegetables. Lack of proper research and find out the shade tolerant cultivars are the main problems for cauliflower cultivation in agroforestry system. Shade stress hampers photosynthesis activities and fruits drop frequently, which causes low yield of cauliflower in homestead area (Haque *et al*., 2009; Dong *et al*., 2014; Shao *et al*., 2014). So, farmers hesitate to cultivate cauliflower in the homestead or with agroforestry practices. Now-a-days, many scientists have released different cauliflower varieties which can grow under different levels of shade condition. However, screening to find out shade tolerance varieties of cauliflower has not been studied in different homestead and agroforestry conditions. For this reason, it is highly necessary to observe the growth and yield parameters in response to different level of shade to evaluate the performances of different cauliflower varieties. This study will help in identifying a potential solution to the problem by determining proper cauliflower variety (ies) for partial shaded environment which will contribute in nutritional food security in Bangladesh.

The specific objectives of this study are:

a. To evaluate growth performance of different cauliflower varieties under different shade stress;

b. To appraise the physiological changes of different cauliflower varieties under shade stress and

c. To recognize the most suitable and adaptive variety under shade stress condition.

CHAPTER 2

REVIEW OF LITERATURE

Brassica species has received much attention by a large number of researchers on various aspects of its production and utilization. Cauliflower species is one of the most important winter vegetable crops in Bangladesh and many other countries of the world. Many studies have been carried out about shade effect on the growth, germination, physiology, yield, in different countries of the world. The work so far done in Bangladesh is not adequate and conclusive. Nevertheless, some of the informative works and research findings so far been done at home and abroad on this aspect. The review of literature concerning the studies presented under the following headings:

2.1 Cauliflower

2.2 Light

2.3 Effect of Light Stress on Germination

2.4 Effect of Light Stress on Growth

2.5 Effect of Light Stress on Physiology

2.1 Cauliflower

Islam *et al.* (2020) conducted an experiment in Trishal Upazila of Mymensingh district. 100 farmers were chosen from 3 villages. The experiment found that the production of the cauliflower was profitable. Benefit cost ratios of cauliflower was 2.44. The peasant earned the highest profit from cauliflower production. The results of cauliflower cultivation referred that 3main input viz. seed, labor and fertilizer cost were highly impacted on cauliflower production. The experiment found out few problems faced by peasant for cauliflower production viz. capital problem, insect infestation, storage facilities problem, quality seeds production problem, marking lacking etc. So, more extension service and research facility need to be implemented for recuing from the problems and ensuring nutritional value in the country.

Uher *et al*. (2017) conducted a study to find out the nutritional value of cauliflower. He found cauliflower is highly nutritious and value for money product. Its nutritious value such as high proportion of water, up to 91%, sugar content is 4.5%, protein content is 2.5%, crude fiber 1.8%and low fat, only 0.3%. In case of minerals cauliflower is highly effective food, contains calcium, sodium, magnesium, potassium, phosphorus, as well as iron (Xie *et al*.,2016). On the other hands, it represents phytochemicals, vitamins.

Markovic *et al.* (1996). conducted a field experiment about 3 years to find out the effect of nitrogen (0 to 200 kg ha^{-1}) on the yield quality and basic nutritive elements accumulation in cauliflower. Various nitrogen fertilizer doses were applied for 2 cauliflower races (Imperial and Snowball). Different parameters such as ascorbic acid, dry matter proteins, nitrites, nitrates P, K, N, Fe, Mg and Ca accumulation in all above ground parts were recorded. They showed that cauliflower yield was enhance by enhancing nitrogen fertilizer from0-200 kg ha^{-1} and quality was not affected except vitamin C, which was increased. Some nutrient production was increased with rising of cauliflower yield.

Yoldas *et al.* (2008) study on fertilizer requirement of cauliflower plant in variety wise. The scientific researches show that application of optimum dose of boron and nitrogen increase macronutrient and micronutrient concentrations such as nitrogen, phosphorus, potassium, iron and zinc in broccoli head (Xie and Kristensen, 2016). Nitrogen fertilizer positively affected on crop yields as well as vitamin C, E1 and ß-carotene content in cauliflower edible heads (Uher *et al*., 2013) and accumulation of sulforaphane (Čekey *et al.*, 2011). Chemical fertilizers help in highest yield and quality of the final product (Theofanoudis *et al*., 2015). Nitrogen fertilizers are commonly used to ensure the yields in brassicas productions. But, if other factors are not properly managed, fertilizer will have a minimal effect on increasing yields (Quiro´s *et al*.,2015).

O'Connell and Tate (2017) experimented on the climate requirement of cauliflower. The optimal temperature range is 18 to 20°C for growth and development. In higher temperatures, at 27 °C, it tends to small leaves, small curds, solar yellowing and raciness of the curd. At lower temperatures, the curds would be damaged or secondary decay occurs. Cauliflower cultivated on many types of soil, from clay to loamy sand. A high moisture-holding capacity is better in the summer, but flood stress negatively affects curd production. In winter, soils are drying rapidly the irrigation is most suitable so that performing of cultivation of land become easy. Cauliflower generally sensitive to salinity. However, it is less sensitive to salinity than lettuce but more sensitive than broccoli.

2.2 Light

Light is an essential environmental factor affecting plant growth, development, and phytochemical biosynthesis over short and long periods of growth as a result of the functionality exerted by radiation intensity and spectral composition. Plants exhibit high plasticity to variations in light characteristics either when using radiation as a source of energy for photosynthetic processes, or when it represents a signal to regulate photo-morphogenetic responses via a complex system of wavelength-specific photoreceptors (Paik and Huq, 2019; Paradiso and Proietti, 2021). The optimal light setting, in terms of light quantity and quality is a key element of controlled environment agriculture (CEA) where all factors are controlled to optimize productivity and resource use efficiency (Graamans *et al*., 2018).

Kulkarni *et al.* (2005) experimented on *Albucapachychlamys* and *Drimiarobusta* and observed the effects of light and temperature on seed germination. At 25/20°C given a significant ($P < 0.05$) effect on seed germination of *A. pachychlamys*, and showed 100% germination under 16:8h light conditions. For *D. robusta*, Germination percentage was observed at a constant temperature of 20°C/ 75% PAR and alternating temperatures of 25/20°C (90% PAR).

Ptushenko *et al*. (2020) studied on the effect of the light spectra on the growth and physiology as well as photosynthesis. Its badly effect on the macroscale (e.g., in each crop growing under the forest canopy) as well as on the meso- or microscale (e.g., mutual shading of leaf cell layers and chloroplasts). The variation of the effects of light spectrum differences come out from (i) the triggering of different photoreceptors, (ii) the non-uniform efficiency of spectral components in driving photosynthesis, and (iii) a variable depth of penetration of spectral components into the leaf.

Leyla *et al*. (2018) experimented on negative influence of light intensities upon rose plant. Rose plant were grown under different light spectra including red (R), blue (B), 70:30 % red:blue (RB) and white (W)and were exposed to HL (1500 µmol m^{-2} s^{-1}). Polyphasic chlorophyll a fluorescence (OJIP) transients revealed that although monochromatic R- and B-grown plants performed well under control conditions, the functionality of their electron transport system was more sensitive to HL than that of the RB- and W-grown plants. Ascorbate peroxidase and catalase activities reduced, while superoxide dismutase performance was increased after exposure to HL. This caused an increase in H_2O_2 concentration and malondialdehyde content following HL exposure.

Kim *et al.* (2020) conducted a study to determine the optimal light intensity and temperature for cultivation of *Peucedanum japonicum Thunb*., and to estimate the functional ingredients through short-term shade stress just before harvesting. Crops were grown in full sun light condition at a temperature of 25 ± 1°C and relative humidity (RH) of 60 ± 5% for 15 days. Plants 3-5 cm long with 1st and 2nd true leaves were grown with different light and temperatures. Treatments were 50, 100, 250, or 500 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and average 15°C, 20°C and 25°C of temperature. During harvesting time of the baby leaf vegetables, chlorophyll content, growth, and functional compounds were calculated. The optimum light intensity for growth of P. *japonicum Thunb*. was 250 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD for 15 days, and the best temperature was 24/20°C. Phenolic accumulation was more under higher light intensity and low temperature. After treated for 3 days with temperature (15°C and 20°C) and light intensity (PPFD 200 and 500) before harvesting, no difference in growth was found, but total phenolic content was higher in PPFD 200 or 500 under 15°C treatments. Free radical activity was significant for temperature and light treatment. Highest free radical activity was in PPFD 500 under 15°C treatments. So, after cultivation at optimal light and temperature, low-temperature treatment for 3 days before harvesting was enough for enhancing the functional contents.

2.3 Effect of Light Stress on Germination

Zheng (2010) studied the effect of low temperatures and shade on the germination of cauliflower (*Brassica oleracea)*. Temperature affects both the capacity for germination and the rate of germination (Bewley and Black, 1983). Different species have different temperature ranges within which they germinate. At very low temperatures and very high temperatures the germination of all seeds is reduced. There also found 33 species are indifferent to light or dark (Mayer and Poljakoff-Mayber, 1989). A certain variety has an optimum germination temperature at which percentage of germination is the highest. Below and above the optimal temperature germination will reduce. The best germination temperature of cauliflower is 21°C. However, cauliflower will germinate at temperatures as low as 10°C. Germination at low temperatures could be used to test the stress-tolerance of germination of different seed of Cauliflower.

Veloso *et al.* (2017) experimented on *Copaifer aoblongifolia* that these plant seeds opened to the tremendous light need more time to germinate. Seeds sown in open field had low germination percentage than seeds sown in low light. Seedlings grown in open field had higher shoot mass than seedlings grown in shade.

A study was carried out by Anusiya and Sivachandiran (2019) to observe the responses of lettuce under low light stress conditions using 3 different low light intensity (0 %, 50 %, and 75 %). They found that plant height, weight, leaf area, leaves number and yield are seriously hampered by low light stress. All an average it is found that the growth and yield of lettuce were greatly affected by 50 % shade level.

Mo *et al.* (2015) conducted an experiment upon Thai jasmine and Indian basmati phenotypes, that has 2-acetyl-1-proline (2-AP); responsible for the aromatic character. The effect of full sun light to which plant is opened may affect yield, growth and production quality. This treatment also has bd effect on photosynthetic and physiological characteristics. This experiment evaluates the bad effect of shade stress on quality, grain yield and 2-AP concentration upon ‘Yuxiangyouzhan’ and ‘Nongxiang 18’ traits. On the other hand, accumulation of gamma-aminobutyric acid and proline molecules under shade stress which have been influence in pathways modifying 2-AP production, was counted to shade effects on these rice varieties. And to further possibly estimated changes in biochemical pathways leading to 2-AP accumulation during germination.

Rakhmawati and Rahmadiyanto (2015) examined the effect of light intensity on germination mechanism of *Markhamia stipulata* Seem. In this experiment used a Randomized Complete Block Design (RCBD) consisting of 3 treatments (far red light, red light and dark) and one control environment with 4 replications. Every group contains 10 seeds. Percentage of seed germination, cotyledon width, seedling height and leaves number were calculated. This experiment showed that germination of seed begins at 3rd DAS (Day after sowing). Germination rate coefficient showed no significant difference among treatments but far-red light performs highest number (100%, 0.755). Moreover, light intensity influence on seedling growth. Far red light affected internodes distance. Dark light affected on leaves and cotyledon size.

Onyekwelu *et al*. (2012) investigated the influence of shade stress on the germination and initial growth of *Chrysophyllum albidum*and *Irvingiagabonensis*. Both varieties seed were sown in 3 controlled environment that permitted the penetration of 40%, 60% and 100% PAR. Early germination was observed for 10 and 25 weeks for *Chrysophyllum albidum* and *Irvingiagabonensis* species respectively. Shade stress significantly reduced the germination and establishment of *Chrysophyllum albidum* seeds but did not affect *Irvingiagabonensis* seeds. Early growth rate of both species seedling was highly reduced under shade condition. From 10th and 25th weeks, plants' height and diameter ranged from 9–15 cm and 0.26–0.45 cm respectively for *Chrysophyllum albidum* and from 37.5–76.5 cm and 0.6–0.8 cm respectively in case *Irvingiagabonensis*. Both two varieties showed lower performance under forest canopy. On the other hand, both varieties can't perform good under very low light. *Chrysophyllum albidum* seedling under open sky died quickly after germination. Although *Chrysophyllum albidum* seedlings under 40 and 60% shade had comparable growth performance, the best growth and suitable seedlings were found under 60% shade. *Irvingiagabonensis* seedlings showed best result under 0, 40, 60% shade stress. Therefore, *Irvingiagabonensis* seedlings had better growth under full sun light, implies that the variety might survive if grown without shading.

Ohadi *et al.* (2010) reported the effect of light intensity and duration of exposure on seed germination of Phalaris minor and Poa annua. Photocontrol of weeds need a better performance of the effect of light on seed establishment. Therefore, the effect of low light intensity and exposure duration was tested on seed germination of 2 winter weeds Phalaris minor and Poa annua. Photo-sensitive seeds of both varieties including 130, 250, 500 and 1000 μmol m^{-2} s^{-1}, each at 6 exposure durations of 0.1, 1, 10, 100, 1000 and 10000 seconds. Light enhanced the germination of both weeds. This approach described the relationship between light intensity and exposure duration with the germination of weed seeds. A combination of logistic and Gaussian prove provided good fits to *P. minor* percentage germination data, whereas in the case of *P. annua*, associated of logistic and quadratic models better shown the result. In this experiment, increasing light level from 0 to 1000 μmol m^{-2} s^{-1} enhance the germination of *P. minor* and *P. annua* from 25% to 55% and from 1% to 35% respectively. The seed germination of both weed varieties enhance with exposure time, but reduced at duration time longer than 100 seconds in *P. minor* or 1000 seconds in *P. annua*. The study ensures a trade-off between light intensity and light duration for both weeds.

2.4 Effect of Light Stress on Growth

Dhatt and Kaler (2009) revealed that in tropical cauliflower faces major set hostile condition during summer and rainy season under north Indian conditions. For identifying better shade nets to protect nursery growing media in plug-trays which was done with split plot design. Among the 3 shade treatments, agro-shade net (green color, 6 mesh size, 25% reduction of sunlight), monofilament insect net (white color, 26 mesh size, 10% reduction of sunlight) and open field, the monofilament showed the best result for germination, seedling length, number of true leaves, dry matter, field establishment of transplant, plant height, days of harvesting and yield. Among 17 nursery growing media combination in plug trays, decomposed cow dung, rice husk charol mixed in 1:1:1(v/v) ratio gave the best results for nursery and plant growth parameters.

Chatterjee and Mahanta (2013) examined that Cauliflower cultivation during summer months inside shade net offers higher wages as compared to winter season crop. This experiment includes 4 different planting dates (1st May, 7th May, 14th May and 21st May) and four nutrients sources (100% recommended inorganic fertilizers plus 10 t/ha farmyard manure; 75% recommended inorganic fertilizers plus 10 t/ha farmyard manure plus biofertilizer; 75% recommended inorganic fertilizers plus 5 t/ha vermicompost plus biofertilizer and 75% recommended inorganic fertilizers plus 5 t/ha farmyard manure plus 2.5 t/ha vermicompost plus biofertilizer) were laid out in two factor factorial RBD with three replications inside shade net house. The finding established that 14th May planting coupled with 75% recommended inorganic fertilizers, vermicompost (5 t/ha) and biofertilizer seedling inoculation will bring desirable growth, yield and quality attributes of off-season cauliflower under agro shade net.

Rahman *et al.* (2006) studied that cauliflower growth and development reduced with increasing shade levels after curd initiation. Total above ground dry matter increased linearly associated with radiation incident integral after curd initiation. Even under lower radiation conditions, the rate of increase per unit incident radiation integral was greater than under higher radiation conditions. Moreover, radiation conversion coefficient declined linearly with increasing incident radiation integrals up to approximately 6.1 MJ m^{-2} d^{-1}. Thereafter, reduced more slowly with further increase of radiation integrals. Therefore, dry matter production was more successful under lower radiation than higher radiation levels. Radiation coefficients for plants under low radiation levels were greater than under high radiation levels. Curd growth also increased linearly with increasing radiation integral with greater mean relative curd dry matter accumulation increase per MJ under lower radiation conditions than higher radiation levels.

A general study was carried out by Paul (2019) on temperature and shade effect on cauliflower (*Brassica oleracea L. var. Botrytis)* curd formation for 4 consecutive cultivation seasons in two areas of West Bengal in India. Observations indicated that9-12 days hardening off period is beneficial for best quality curd and extreme cold or high temperature or fluctuating temperature leads to different curd disorders. Results obtained were critically discussed.

Shikata *et al.* (2003) experimented a field study to find out the effect growth and light environment maize+cowpea intercropping and to calculate the photosynthetic rate of the intercropping in relation to the light interception, leaf area index (LAI) and photosynthetic rate of the leaf net. Superior light interception is found by intercropping maize+cowpea that led to an increase in LAI with a decrease high photosynthetic rate and coefficient of light extinction.

An experiment was carried out by Argade *et al.* (2018) on the effect of different (35, 50, and 75 %) low light intensities on the germination and growth of cherry tomato. Maximum plant height was found in 75% shading intensity and genotype KSP-113 at 30 days intervals. 50 % flowering of cherry tomato needed minimum days were found in tomatoes grown under 35 % low light intensity and genotype KSP-113 and the maximum cluster length observed (9.58 cm) also observed under 35% shading genotype KSP-113. The cultivation of KSP-113 genotype under 35% low light intensity was observed to be most sustainable for improving the growth and yield of tomato during the summer.

A study was carried out by Rezai *et al.* (2018) on Sage (*Salvia officinalis L.*) crop with various shade level. different level of shade effect influences on different level of modification upon different crop characteristics such as photosynthetic capacity, leaf morphology and chlorophyll content.

Masabni *et al.* (2016) was conducted a study on 50% shade had almost the same growth capabilities as the controlled condition; but fresh shoot, dry matter weight photochemical has bad effect under shade condition. On the other hand, 50% and 70% shades decrease weight of both plant and fruit. Both 50% and 70% shade net decrease leaf temperatures condition of tomato. Growth index (GI) of tomato was better with 50% shade, the lower under open sun light along with 70% shade. Higher temperature has a bad impact on plant germination and growth (Lopez-Marin *et al*., 2012). High light and heat impact on leaves of tomato is created of high solar radiation (Lopez-Marin *et al.*, 2011) that highly reduces the growth are found in Mediterranean condition (Katsoulas and Kittas, 2008).

Gao *et al*. (2021) carried out an experiment improvement of broccoli production in different light intensity for growth and phytochemical contents of broccoli in an artificial light plant factory. Broccoli was exposed under various photosynthetic photon flux density (PPFD): 30, 50, 70 and 90 μmolm^{-2}s^{-1} with red: green: blue = 1:1:1 light-emitting diodes (LEDs). The broccoli grown under 50 μmol·m^{-2}·s−1 had the highest fresh weight, dry weight, and moisture content, while the phytochemical contents were the lowest. By increasing light intensity, the chlorophyll content is also increased, on the other hands the carotenoid content reduced. Soluble sugar, soluble protein, free amino acid, glucosinolates and vitamin C except for progoitrin in broccoli were higher under 70 μmol·m^{-2}·s^{-1}. However, 50 μmol·m^{-2}·s^{-1} was suitable light intensity for enhancement of the growth of broccoli, while 70 μmol·m^{-2}·s^{-1}was more practicable for the phyto-chemicals development of broccoli.

Arenas-Corraliza (2019) stated that most of the cereal crops had been selected for open sun light conditions. So, it was necessary to estimate those able to acclimate to low sun light condition, choosing varieties with this acclimation. A greenhouse study was carried out in central Spain to calculate the crop yield, photosynthetic response and leaf characteristics of nine varieties of winter wheat (*Triticum aestivum L*.) and barley (*Hordeum vulgare L*.) at three different levels of photosynthetic active radiation (PAR) that is 100%, 90% and 50% PAR. Varieties were chosen consequent upon three distinct precocity classes and were vastly used in the experimented location. To assess either the varieties could acclimate to partial shade through morphological and physiological acclimations or not was the main objective. Both the two varieties increased grain production by 19% under shade conditions. Whatever, both varieties conduct different acclimation technique. Barley mainly showed a physiological acclimation, while wheat mostly showed morphological acclimatization under shaded stress condition. Barley showed lower shade respiration (42%), lower light compensation point (73%) and higher maximum quantum yield (48%) than wheat in open sun light conditions. Revealing that was highly shade-tolerant variety than wheat. Therefore, for acclimatization with shade stress conditions, barley performed a 21% decrease of the chlorophyll ratio in the shade condition than open sun light availability. On the contrary, wheat performed a 48% enhancement of single leaf area in the 50% sun light than in open sun light. This experiment showed that current cultivated wheat and barley crops had enough plasticity for adaptation to shade stress condition including agroforestry condition as a tool to decrease the negative influence of shade stress condition.

A study was carried out by Baharuddin *et al*. (2014) that under a shade level of 50%, 20 tomato genotypes cultivated in polybags showed high variances in plant growth, yield, and quality as responses to low light intensity.

Chen *et al.* (2019) experimented upon two different types of shade such as black nylon net (Shading (B) and white cotton yarn (Shading (W) with 4 different rice variety (*Oryza sativa L*.) were used. Production reduced under shading (W) (15–17%) and shading (B) (16–20.0%) in comparison with open field. Some effects on rice quality and quantity that is influences by changes in light duration, were observed. Change of light quality (Red, Green, Blue and R/FR proportions) under Shading (W) was different from Shading (B). Red light acceptance under Shading (W) was widely related to that of the cloudy day situation. The blue light under Shading (W) was lower than that of CK conditions. Under Shading (B), it was more than that under all situation. The variation in light quality might affect photosynthesis and starch synthesis whose result is increased chalky grain rate, chalkiness, and low rice quality.

Dong *et al.* (2014) investigated the influence of shade stress at various stages on pigment composition, growth, biological production, photosynthetic efficiency and antioxidant defense process of wheat (*Triticum aestivum L*.) plant. This study said that reducing energy growth are main problem for crops. Light is the main source of energy that is essential environmental factors to crop growth. This study was categories in three intensity-controlled phases in according to growth time: seedling phase, heading and flowering phase and grain filling phase. Primary light in controlled condition was 425 lmol $m^{-2}s^{-1}$ and this light condition increased according to the growth stage of wheat (*Triticum aestivum L*) plants. Light intensity of class I and II at primary phase and last phase was accumulated to half level of the control. In case of class III, primary and last phase were adjusted to the half level of control. During central 30-35 days, treatments were continued equal intensity. This finding refers that shade stress at seedling phase, nutritional contents, biomass, components of inedible biomass, nutritional contents, malondialdehyde and healthy index activity of wheat variety have no effective variation to the control condition.

Venkateswarlu *et al.* (1977) experimented to find out the effects of shade stress on different cultivers of rice (*Oryza sativa* L.). They observed that shade stress hampered plant growth and development which ultimately reduced rice production.

2.5 Effect of Light Stress on Physiology

Johnson and Hilton (1978) conducted an experiment upon the effect of light on the phytochrome content of cauliflower (*Brassica oleracea (L.) var. botrytis*) curd was studied using in vivo spectrophotometry. The result showed that light caused a rapid increase in phytochrome level; on the other hands, when used to darkness result was a rapid loss regarding the amount of phytochrome, initially present in the far-red light absorbing form. The phytochrome amount found during highly radiation appears to be linked to the photo-equilibrium.

Haque *et al.* (2009) conducted an experiment to find out hybrid high-green bottle gourd physiological and morpho-physiological and production variation with 4 different light intensity (100, 75, 50 and 25 % light level). Different morphological parameters including internode length, main stem length and individual leaf area have been observed. Here, leaf numbers per plant and main stem diameter have reduced for decreasing light intensity. Per plant leaves number did not reduce highly at 50% light intensity. Leaf weight ratio (LWR) remains almost similar due to decrease light intensity up to 50 %. With the reduction of light intensity; induced chlorophyll synthesis in leaves, the SPAD value are increased. There was no decrease in overall dry matter in comparison with 100% light intensity. The maximum production (42t ha^{-1}) was ensured by bottle gourd 75% light intensity and was no significant decrease in bottle gourd production at 25% light intensity compared to 100% sunlight. Nevertheless, for increasing shade level (up to 50 %), total dry matter (TDM) and fruit production of bottle gourd, was thought allowable.

Smith (1982) establish a theory that a high number of photo-responses of plants growing in simulated natural light environments are quantitatively correlated with the photo-equilibrium of phytochrome (~p = [Pfr]/[Pfr + Pr]) which could be established in etiolated material by that light regime. These responses showed that some similarity to those get in etiolated seedlings radiated for normal periods with actinic light establishing different photo-equilibria.

Yuan *et al*. (2022) conducted a pot experiment to find low light effect on maize 'LY336' (shade tolerant) and 'LC803' (shade sensitive) variety. The impact of 50% PAR stress treatment on photosynthetic parameters, shoot biomass, malondialdehyde (MDA) content and chlorophyll fluorescence was evaluated. The shoot biomass of 2 maize variety was decreased significantly by low light stress treatment, for 7 days the LC803 and LY336 variety were decreased by 56.7% and 44.4% compared with open field condition. Chlorophyll fluorescence parameters of LY336 were not significantly affected by shade stress, whereas LC803 were significantly affected. Stomatal conductance (Gs), net photosynthetic rate (Pn), and transpiration rate were significantly reduced compared with natural light, LY336 and LC803 reduction by 28.0%, 22.2%, 57.7% and 35.5%, 18.9%, 62.4%. However, intercellular CO_2 concentration was significantly increased, for the two cultivars. Under low light stress for different durations (1, 3, 5, 7 d), Pn, Gs, Ci, and MDA content differed significantly between the 2 varieties. Results indicated that different maize variety showed different responses to low light. Low light-tolerant variety are only weakly affected by low light stress.

An experiment was carried out by Nowbuth and Pearson (1998) on the effect of temperature and shade were studied on the temperate and tropical cauliflower varieties Revito and a local from Mauritius (B24/94). Plants of both varieties were grown in 6 different temperature compartments averaging 11, 13.5, 19.5, 22.5, 25 and 29 °C. In each temperature compartment, 3 levels of shade were given to the plants; no shade, 40% shade and 60% shade. Results showed that curd initiation was influenced by both temperature and shade. Curd initiation for both varieties occurred earliest at 13.5°C and was delayed by both cooler and warmer temperatures. Initiation was more rapid at all temperatures for the local Mauritian variety B24/94 as compared to Revito. At all temperatures where curds were initiated, the variety Revito was found to be more responsive to the effect of shade than B24/94. Local Mauritian variety, showed progress to curd initiation was linearly related to both effective temperature (14 °C) and light (r2

= 0.98, 10 df). An increase in temperature and shade caused high number of leaves formed below the curd. Results are showed with the effects of environment on the initiation of temperate and tropical cauliflower. They suggested that tropical varieties may be adapted because they initiate in a shorter period of time than temperate varieties.

Kengere *et al.* (2022) was conducted a field experiment at Pwani University Crop Science farm, to examined the effects of black shade net on production of *Brassica rapa* and *Brassica oleracea*. Randomized complete block design (RCBD) experiment along with 3 replications were set down. The 3 treatments, 50%, 70% black shade net and 100% open sun light. Fresh shoot weight, fresh grain weight, leaf chlorophyll content and dry matter weight information were collected. Analysis of variance of the collected data was used in general linear model (GLM). Results showed that, shading reduced the chlorophyll content by using 50% and 70% shading net intensity.

An experiment was carried out by Manolopoulou and Varzakas (2016) on the effect of temperature on color degradation and chlorophyll content of green vegetables. The experimented vegetables were lettuce (leafy) and broccoli (inflorescence). The chlorophyll was extracted with the solvent dimethyl sulfoxide. Under the environmental condition of 60°C and 665 nm and 648 nm wavelength the experiment was conducted until complete depigmentation. Lower temperature and higher relative humidity increase the life of most fresh vegetables (Cantwell and Kasmire, 2002), delaying degradation of chlorophyll (Pogson and Morris, 1997). The degradation of chlorophyll is known as the 1st symptom of aging, but when resemblances in fact aging is almost advanced (Ansaril and Chen, 2011). Reduction of chlorophyll is a complex multi-pathway of which may be calculated in 2 basic group of reactions; the 1st one produce greenish derivatives while the 2nd one, colorless element (Marquez and Sinnecker, 2007). Chlorophyll degradation decreases the green color and leads to yellowing. Yellowing of leafy vegetables and broccoli is characterized by the activities of the enzyme peroxidase and lipoxygenase (Murcia *et al*., 2000). Decrease of the intensity of green vegetables is compared with reduction of the nutritional value, aging and quality (Shewfelt, 2000; Cantwell and Kasmire, 2002). The results reported that as the temperature increases, chlorophyll degradation rate is increases; as a result, the color is also damaged significantly. Between the tested vegetables, the lettuce was proved to be more sensitive to chlorophyll and color degradation.

Yi-bo *et al*. (2021) observed that in agroforestry systems, higher plant created low light stress on lower crops. They took 4 peanut variety, S60, C4, P12, and YS151 that were cultivated in the field and creating low light stress for 77 days. S60 and P12 resulted production biomass reduction than C4 and YS151 under low light stress. Shading stress reduced antioxidant enzyme activities in S60 and P12, relative to C4 and YS151. Under shading stress, S60 and P12 resulted light trapping than C4 and YS151, which was associated with modification in chlorophyll (Chl) a and b contents, and Chl a/b ratio. The net photosynthetic rate, stomatal conductance and transpiration rates of C4 and YS151 were reduced, but the intercellular CO_2 concentration increased under low light stress. The results showed that non-stomatal limiting factors decreased the photosynthetic capacity of peanut under low light stress. The maximum photochemical efficiency of PSII (Fv/Fm) and non-photochemical quenching (NPQ) were higher in S60 and P12 than in C4 and YS151 under low light stress. These results showed that S60 and P12 could take more light energy from weak light environments for photosynthesis than C4 and YS151 and dissipate the additional light to improve their light access ability.

Yasoda *et al.* (2018) was conducted an experiment at the Faculty of Agriculture, University of Jaffna, Ariviyal Nagar, Kilinochchi to study the effects of different shade levels on growth and yield performances of cauliflower. Different shade levels such as 25 % (open field), 50 % (single net house) and 75 % (double net house) were used as treatments. The experiment was conducted in completely randomized design (CRD) with four replications. parametric (growth & yield) analysis were done by using SAS 9.1 package. The influence of environmental variables such as temperature, relative humidity and light intensity were also studied. The result revealed that growing of cauliflower in different shade levels showed great influence on plant growth and yield attributes. There were significant variations in number of leaves, plant height, curd weight, curd diameter and curd circumference of cauliflower under different light intensities. Light intensity in the shade net house was lower than in the open field. The highest vegetative growth and yield were observed in cauliflower which was grown in 50 % shade levels and the lowest yield was in 25 % shade level (open field). It can be concluded that cauliflower can be cultivated in 50 % shade levels successfully to produce quality curd during off season of the dry zone of Sri Lanka.

Lin *et al.* (2015) conducted a study on shade and temperature effect on the yield and quality of cauliflower. Cauliflower cultivars 'H41' and 'H69' are tolerant to high temperature and shade respectively. However, 'H71' is sensitive to both shade and temperature stresses. This study helped to identify the morphological and physiological transformation that occurred during different time periods in 'H41', 'H69', and 'H71' when reacted to treatments of shade and temperature stresses. High temperature causes cauliflower to form uneven and loose puffy buds, heads, yellow eyes, leaves in the head, delayed initiation of heading, narrow leaves, reduced leaf growth and increased petiole-to-blade ratio which lower the quality of or making the heads unmarketable (Wurr *et al.,* 1996; Shih *et al.,* 2013).

Thomas *et al.* (1992) carried out an experiment to show the production of pigments in plants that can be regulated by light. Cauliflower curds were covered with their leaves a spun bounded olefin material, during curd growth to minimize the light transmitted. Exposure of cauliflower curds to sunlight resulted in yielding of pink and yellow-colored curds. But the pigments which are responsible for this have not been estimated (Burt *et al.,* 1989). Carotenoid, chlorophyll, and flavonoid production are under genetic control in various cauliflower species (Crisp *et al.,* 1975; Crisp and Angell, 1985; Dickson *et al.,* 1988). Flavonoid production can be stimulated by light of the far red, red, blue, or ultra violet regions (Mancinelli, 1985; Beggs *et al.,* 1986). In seedlings Tlavoid production can be enhanced by as little as 4 h exposure to light in the region 400-800 nm followed by an incubation period of 24 h (Mancinelli, 1985). Photocontrol of carotenoid production in the leaves of higher plants is usually dependent on the stimulation of chlorophyll production by light (Kasemir, 1983). The covered curds were whiter and had 20% (Tyvek) or 40% (leaves) of the concentration of flavonoids in the florets (estimated by absorbance at 366 nm) of the curds grown without covers. The carotenoid concentration did not differ significantly ($P > 0.05$) between covered and uncovered curds.

Cregg *et al.* (1993) reported that decrease light by 50% and 72% compared with open field resulting in highly reduction in total photosynthesis. Branch growth reduced significantly within low light portion of the branch. Lateral branches terminal shoots were marked with 14°C, 2 times at the time of growing season. No movement of 14°C into the terminal portions of the branch during the 1st growth flush. However, during the 2nd flush of growth small but statistically significant amounts of 14°C were imported into the terminal portion of the shaded branches from subtending laterals. It was concluded that loblolly pine shoots were autonomous according to carbohydrate given, but that carbohydrate movement into the terminal shoot from subtending foliage could occur under conditions at high low light stress.

Yan *et al.* (2011) studied the effects of shading on growth and quality of flowering Chinese cabbage (*Brassica campestris* L. ssp. *chinensis* var. *utilis* Tsen et Lee) by different color shading-nets at November to December in Guangzhou, China. Under grey, blue, red and black net at 12 am, temperature decreased 5.81, 1.27, 3.93 and 8.58°C. The relative humidity increased 18.75, 18.32, 26.69 and 2.48% respectively. Plant fresh weight increased 41.71 and 5.36% under red and blue net, while decreased 14.66 and 49.55% under grey and black net, respectively. Shoot fresh weight increased 43.80 and 9.00% under red and blue net, while decreased 12.81 and 48.62% under grey and black net, respectively. Plant height increased 16.25% under red net, however decreased 12.73, 33.01 and 47.50% under blue, grey and black net. Leaf area increased 41.44, 23.05 and 15.70% under red, grey and blue net, respectively.

Ismail and Ann (2004) observed that the effects of root cooling and aerial shading on the growth and yield of tropical cauliflower (*Brassica oleraceae var. botrytis*) grown in coconut dust soilless culture were investigated under protected structure at University Putra Malaysia. Cooling treatments were imposed to the root zone of plants one hour daily. There were three root cooling treatments i.e. continuous root cooling, root cooling after flower initiation and control (no root cooling) and grown at either 40% shade or unshaded condition. The experiment was conducted in a completely randomized design with factorial arrangement. There were no significant interactions between root cooling and shading treatments for vegetative, physiological processes and curd weight. Root cooling significantly reduced vegetative growth and curd weight. Stomatal conductance and photosynthetic rate were not affected by root cooling treatments. Shading significantly reduced vegetative growth and curd size but color of shaded curd was whiter than that of unshaded curd.

CHAPTER 3

MATERIALS AND METHODS

This chapter illustrates the concerning methodology used in execution of the experiment to find out the results of different low light on growth, morpho-physiology and yield performance of different species of Cauliflower (*Brassica Oleracea Var. botrytis L.*) varieties. A short explanation of locations of the study area, planting materials, climate and soil, seedling establishment, layout and design of the experiment, pot preparation, fertilization, transplanting of seedlings, intercultural operations, harvesting, data recording procedure, statistical analysis etc. have been discussed in this section as follows:

3.1 Experimental site

The experiment was conducted at the Agroforestry and Environmental Science Farm of Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh during the period from October 2020 to March 2021. The location of the experimental site was 23°74′ N latitude and 90°35′ E longitude with an elevation of 8 meter from the sea level (Islam, 2014; Laylin, 2014) in Agro-ecological zone of "Madhupur Tract" (AEZ-28) (Anonymous, 1988). The experimental site is shown in the map of AEZ of Bangladesh in (Appendix 1).

3.2 Climate and soil

Experimental site is located in the subtropical monsoon climatic zone, which is characterized by heavy rainfall during the months from April to September (Kharif season) and scanty of rainfall during rest of the year (Rabi season). Plenty of sunshine and moderately low temperature prevail during October to March (Rabi season), which are favorable for cauliflower production in Bangladesh. Weather information and physiochemical properties of the soil during October 2020 to March 2021 are listed in Appendix 2 and 3, respectively.

3.3 Planting materials

Three (3) popular varieties of cauliflower were collected from Siddique Bazar, Dhaka on September 2020. The list of 3 selected cauliflower genotypes is presented in Table 1:

Table 1. Name and origin of 3 cauliflower varieties used in the study

Sl. no.	Variety no.	Variety name
1	V_1	Chandi
2	V_2	Snow White
3	V_3	Indian Crown

3.4 Treatments of the experiment

The experiment was carried out to evaluate the performance of 3 cauliflower varieties [Chandi (V_1), Snow White (V_2) and Indian Crown (V_3)] under 4 different shades level/ light intensities. These treatments are (1) S_0-Control, 100% light intensity /full sunlight, (2) S_1-75% light intensity, (3) S_2-50% light intensity, (4) S_3-25% light intensity. The light intensity was measured by lux meter in an open field condition which was considered as 100% light intensity. One layer of nylon net was used and it gave approximately 75% light intensity. Likewise, two layers of nylon net gave 50% light intensity and three layers of nylon net gave about 25% of light intensity. These four light intensity levels were maintained in this study for each variety to create low light stress by using white nylon nets.

So, total number of treatments was 12. They are listed following:

1. V_1S_0
2. V_1S_1
3. V_1S_2
4. V_1S_3
5. V_2S_0
6. V_2S_1
7. V_2S_2
8. V_2S_3
9. V_3S_0
10. V_3S_1
11. V_3S_2 and
12. V_3S_3

So, there was 36 experimental pots were placed in different levels of shade at the Agroforestry farm premises of Sher-e-Bangla Agricultural University, Dhaka.

3.5 Design and layout of the experiment

The experiment was laid out and evaluated in completely randomized design (CRD) in Rabi season, 2020-21 having two factors where Factor A included 3 cauliflower varieties and Factor B included 4 light intensity treatments. The experiment was carried out with 3 replications and total 36 plastic pots were used for growing plant.

3.6 Pot preparation

The experimental pot size was 35 cm in height, 30 cm in top diameter and 20 cm in bottom diameter. Pots were filled with soil after mixing appropriate doses of cow-dung on October 5, 2020. Before pot filling, weeds and stubbles were needed to completely removed from soil to ensure proper plant growth. Soil was treated with Formaldehyde (45%) for 48 hours before filling the plastic pots to keep soil free from pathogen. Each plastic pot was filled with 10 kg of soil.

3.7 Seed sowing and raising of seedlings

Seed sowing was carried out on October 5, 2020 in the treatment pots. Before sowing, seeds were treated with 70% ethanol for five minutes. Seedlings were raised in the pots using regular nursery practices. Recommended cultural practices undertaken before and after sowing seeds. 20 days later, the homogenous two seedlings were transferred to each main plastic pot for further growing while additional seedlings were uprooting. But after establishment, the weaker seedling needed to remove and stronger one was grown for performing the experiment.

3.8 Manure and fertilizers application

Before transplanting seedlings to the pot, soil was dried under sun and ensured well pulverization. Then well decomposed cow dung was mixed with the soil. After transplantation the required amount of fertilizer was calculated for each pot considering the dose required for 1 ha land. Overall total decomposed cow dung was applied before transplanting the seedlings to plastic pots. On an average, each plastic pot was filled with soil containing 100gm decomposed cow dung (10 tons/ha). Fertilizers (urea, TSP, MP) were applied in each pot following recommended dose.

3.9 Establishment of different light intensity treatments

After transplantation to the main pot, white nylon nets of different sieve size will be hanged with the help of bamboo sticks at a height of 2.3 meters to create shade treatments. Light treatments will be consisted as 25%,50%, 75% and 100% intensity.

3.10 Intercultural operations

Recommended watering and intercultural operations were provided when required. Weeding was performed in all pots at regular interval to keep pot free from weeds. Pest attack and diseases are a major factor to cauliflower growth, development and overall production. Cauliflower plants were treated with Bavistin DF and Cupravit 50WP to prevent undesired pest and diseases @1g/L and 2g/L respectively. Leaf miner and aphid were controlled by using Malathion 250EC @ 0.5ml/L. Almost all fungicide and pesticide were sprayed in two intervals, first dose at vegetative growth stage and another during card initiation to manage pest and diseases. Proper tagging and labeling were done for each plant using thin sticks.

3.11 Harvesting

Harvesting was done at the maturity stage of plant. Plant was harvested when plant become enough mature and complete its life cycle. Harvesting was started from March 1, 2021 and completed by March 20, 2021.

3.12 Data recording and parameter studies

Data were recorded from each pot based on growth and physiological parameters. Data were recorded from each pot throughout the experiment in respect of the following parameters:

3.12 Growth (vegetative) and physiological parameters

3.12.1 Plant height

Plant height of each plant was recorded with SI unit (cm) using meter scale in every 2 weeks interval.

3.12.2 Stem length

Stem length of each plant was measured using a meter scale in centimeter (cm) unit and mean was calculated for each treatment. This parameter was taken after every week of seedling transplantation.

3.12.3 Stem diameter

Stem diameter per plant was measured using Digital Caliper-515 (DC-515) in millimeter (mm) unit. Later it was converted to centimeter (cm) unit and then mean was calculated for each treatment. This parameter was taken during harvesting or after 11 weeks after seed sowing.

3.12.4 Number of leaves per plant

Number of leaves per plant was measured using a meter scale in centimeter (cm) unit. This parameter was taken after every week of seedling transplantation.

3.12.5 Average leaf length per plant

Each leaf length of a plant was measured by using a meter scale in centimeter (cm) unit then average leaf length was calculated. This parameter was taken after every week of seedling transplantation.

3.12.6 Average leaf width per plant

Each leaf width of a plant was measured by using a meter scale in centimeter (cm) unit then average leaf width was calculated. This parameter was taken after every week of seedling transplantation.

3.12.7 Fresh shoot weight

Fresh shoot weight (FW) of plant was recorded at the time of last harvest. After uprooting each plant shoot were weighed using electrical balance machine which was expressed as gram (g).

3.12.8 Fresh root weight

Fresh root weight (FW) of plant was recorded at the time of last harvest. After uprooting each plant root were weighed using electrical balance machine which was expressed as gram (g).

3.12.9 Plant dry weight

Plant dry weight (DW) excluding fruits was counted after sun drying. Then the uprooted plant samples were weighed using electrical balance machine and mean was calculated.

3.12.10 First flowering days

First flowering days were recorded from the date of cauliflower seedling sowing and the mean were calculated.

3.12.11 Relative growth rate

Relative growth rate on height basis was counted in cm/week unit by using the following formula:

Relative growth rate (cm/week) = (Final plant height – Initial plant height) / (Time interval between two heights)

Initial plant height was measured at the time of seedling transplantation and final plant height for different plants was measured after 11 weeks of transplanting.

3.12.12 SPAD value of leaf

Chlorophyll (Chl) content in terms of SPAD (soil plant analysis development) values was collected by using a portable SPAD 502 Plus meter (Konica-Minolta, Tokyo, Japan). In each calculation, the SPAD reading was repeated 5 times from the leaf tip to base and the average was used for analysis. The SPAD-502 chlorophyll meter can calculate total chlorophyll amounts in the leaves of a variety of species with a high degree of accuracy which is a nondestructive method.

3.13 Statistical analysis

All values of measured parameters are the means of three replications. One way analysis of variance (ANOVA) was undertaken using Statistix 10 and MS Excel and mean differences were compared by Fisher's LSD test. Differences at $P \leq 0.05$ were considered as significant.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Growth and physiological parameters

4.1.1 Plant height

Shade stress highly reduced the height of all experimented cauliflower plants with the raise of shade stress percentage. At 3 weeks after transplanting (WAT), the plant height of Chandi (V_1) was 14.7, 13.6, 12.9 and 12.2 cm under 100% (control), 75%, 50% and 25% light intensity, respectively. For Snow white (V_2), plant height was 14.5, 14.1, 13.6 and 13.1 cm under 100%, 75%, 50%, 25% light intensity, respectively and the plant height for Indian crown (V_3) under 100%, 75%, 50% and 25% light intensity was 15.6, 14.5, 13.6 and 12.5 cm, respectively. In contrast to control (100% light intensity), in 75% light intensity (S_1), plant height decreased by 7.87, 3.24 and 6.67% in V_1 (Chandi), V_2 (Snow white) and V_3 (Indian crown), respectively. In 50% light intensity, plant heights were decreased by 11.95, 6.4 and 12.85% in V_1, V_2 and V_3, respectively. Finally severe stress (25% light intensity) reduced plant height by 17.18, 9.45 and 19.5% in V_1, V_2 and V_3, respectively. This result shows that minimum plant height reduction was observed in Snow white variety under different shade stress (Figure 1).

At 5 weeks after transplanting (WAT), the plant height of Chandi (V_1) was 21.8, 19.6, 18.4 and 17.5 cm under 100% (control), 75%, 50% and 25% light intensity, respectively. For Snow white (V_2), plant height was 20.5, 19.6, 18.8 and 18.4 cm under 100%, 75%, 50%, 25% light intensity, respectively and the plant height for Indian crown (V_3) under 100%, 75%, 50% and 25% light intensity it was 24.6, 21.6, 20.2 and 18.5 cm, respectively. At 5 weeks after transplanting (WAT), in contrast with controlled condition (100% light intensity), at 75% light intensity condition (S_1), plant height decreased by 10.1, 4.05 and 12.08% in V_1 (Chandi), V_2 (Snow white) and V_3 (Indian crown), respectively. In 50% light intensity, plant heights were decreased by 15.6, 8.29 and 17.78% in V_1, V_2 and V_3, respectively. Finally severe stress (25% light intensity) reduced plant height by 19.6, 10.24 and 24.7% in V_1, V_2 and V_3, respectively (Figure 1). In this experiment, we also observed the similar results in case of 7, 9 and 11 WAT (weeks after transplanting) (Figure 1 and 2).

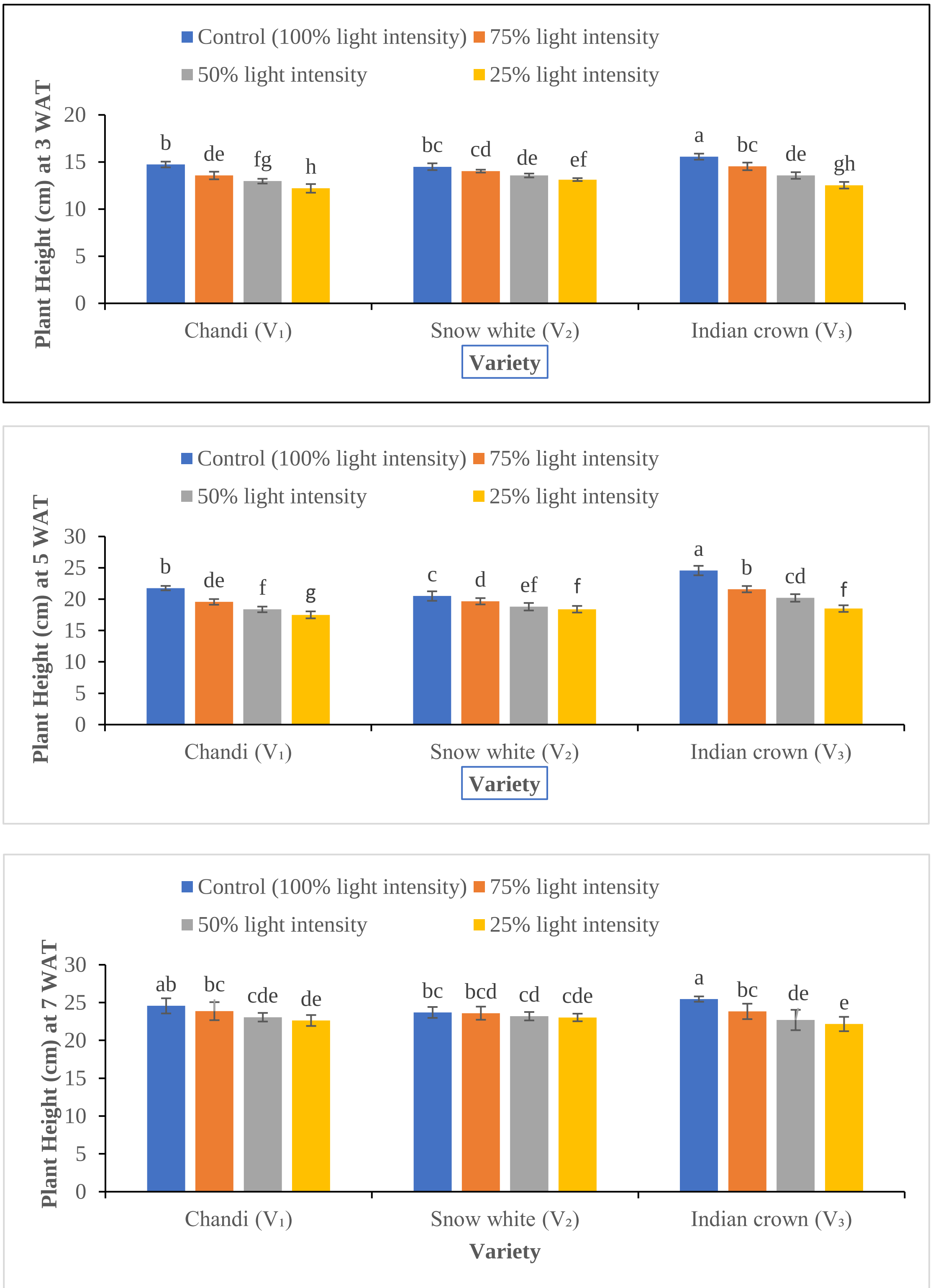


Figure 1. Effect of different low light stress on plant height at 3, 5 and 7 weeks after transplanting (WAT) of different cauliflower varieties. Control, Shade-1 (S_1), Shade-2 (S_2) and Shade-3 (S_3) indicate 100%, 75%, 50% and 25% light intensity, respectively. Means (±SD) were calculated from three replications (n = 3) for each treatment. Bars with different letters are significantly different at P≤0.05 applying Fisher's LSD test.

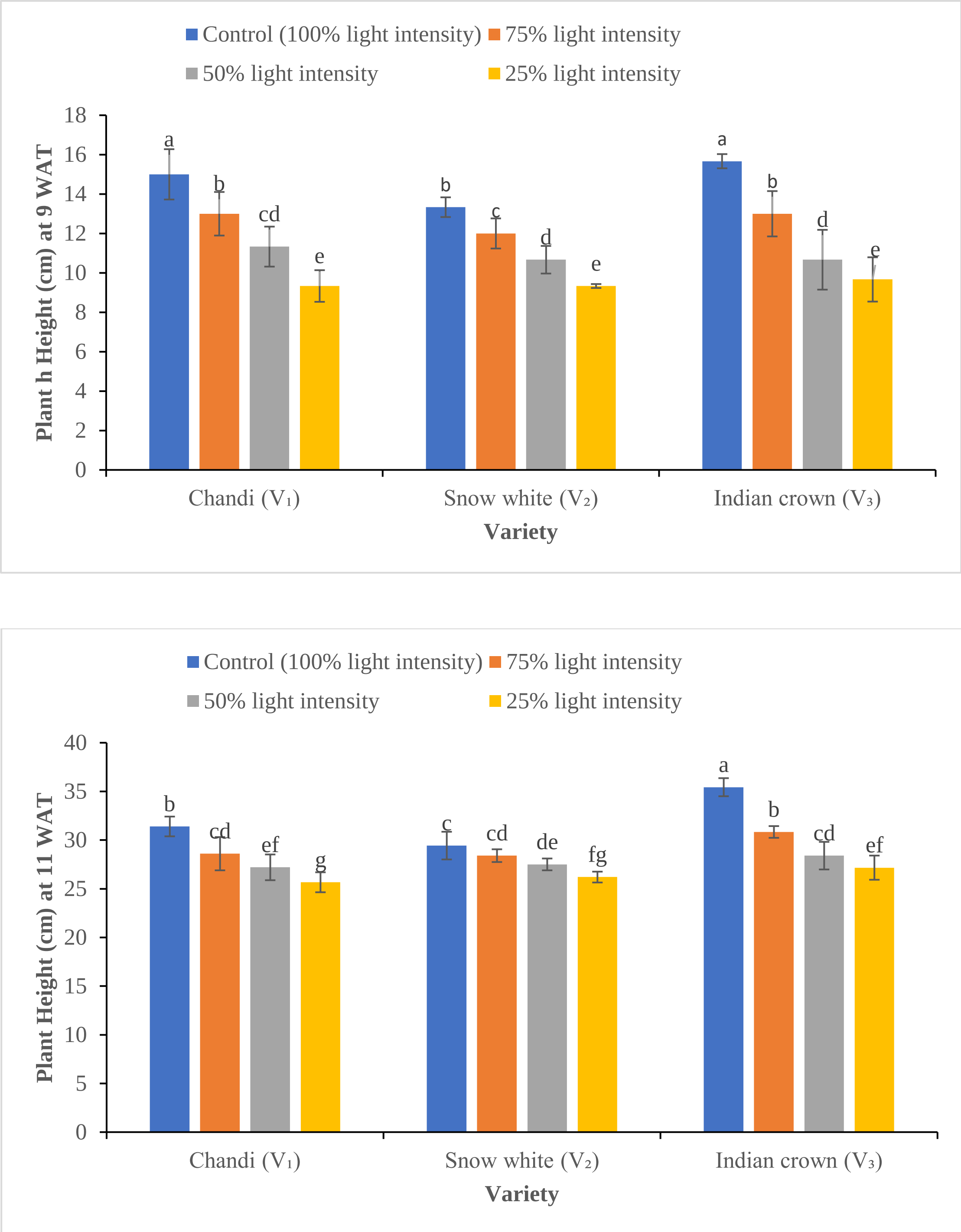


Figure 2. Effect of different low light stress on plant height at 9 and 11 weeks after transplanting (WAT) of different cauliflower varieties. Control, Shade-1 (S_1), Shade-2 (S_2) and Shade-3 (S_3) indicate 100%, 75%, 50% and 25% light intensity, respectively. Means (±SD) were calculated from three replications (n = 3) for each treatment. Bars with different letters are significantly different at P≤0.05 applying Fisher's LSD test.

So, it is conformed that highest reduction was found in case of 25% light treatment in all varieties and lowest plant height reduction was found in case of 75% light intensity in all variety according to variety wise performance. The result of this experiment is supported by Dong *et al*. (2014) who explained that low light intensity affected plant height mainly reduced the plant height of wheat (*Triticum aestivum* L.) at different growth phases. Similar result also found by Amin *et al.* (2014) that tomato plant height is decrease at 20% and 40% light intensity compared with full sunlight. Interestingly Steinger *et al*. (2003) observed that the reverse result which show an increase in plant height under shade condition. Thakur *et al.* (2019) in damask rose (*Rosa damascena* Mill.) and Haque *et al*. (2009) in bottle gourd also found that low light intensity severely hampered the plant height.

4.1.2 Leaf Number

For energy production leaves are the main body part which has photosynthetic activity for energy production of plant. Stress significantly reduced the leaf number of cauliflower plant. In this study, with the increases of light stress the leaves number decreased in similar fashion. Noteworthy discrepancy of the leaves number per plant with various low light intensity, variety and their interaction effect were collected from. Leaf number was counted 5 times at 3, 5, 7, 9 and 11 weeks after transplanting. Leaf number at 3 WAT was found 6.7, 6, 5.3 and 4.7 under 100%, 75%, 50%, and 25% light intensity, respectively for Chandi variety (V_1). Again, under 100%, 75%, 50%, and 25% light intensity, the leaf number was found 6.3, 6, 5.7 and 5, respectively for Snow white variety (V_2). On the other hands,7.3, 6.3, 5.3 and 5 leaves were recorded under 100%, 75%, 50%, and 25% light intensity, respectively in Indian crown variety (V_3). In contrast to, control (100% light intensity), 75% light intensity (S_1) decreased leaf number by 10, 5.26 and 13.64% in V_1 (Chandi), V_2 (Snow white) and V_3 (Indian crown), respectively at 3 weeks after transplanting (WAT). In 50% light intensity, leaf number were decreased by 20, 10.53 and 27.27% in V_1, V_2 and V_3, respectively. Finally severe stress (25% light intensity, S_3) reduced leaf number by 30, 21.05 and 31.82% in V_1, V_2 and V_3, respectively (Figure 3). This result shows that minimum leaf number reduction was observed in Snow white and maximum reduction was observed in Indian crown variety. This reduction percentage is not significant at $P \leq 0.05$ applying Fisher's LSD test.

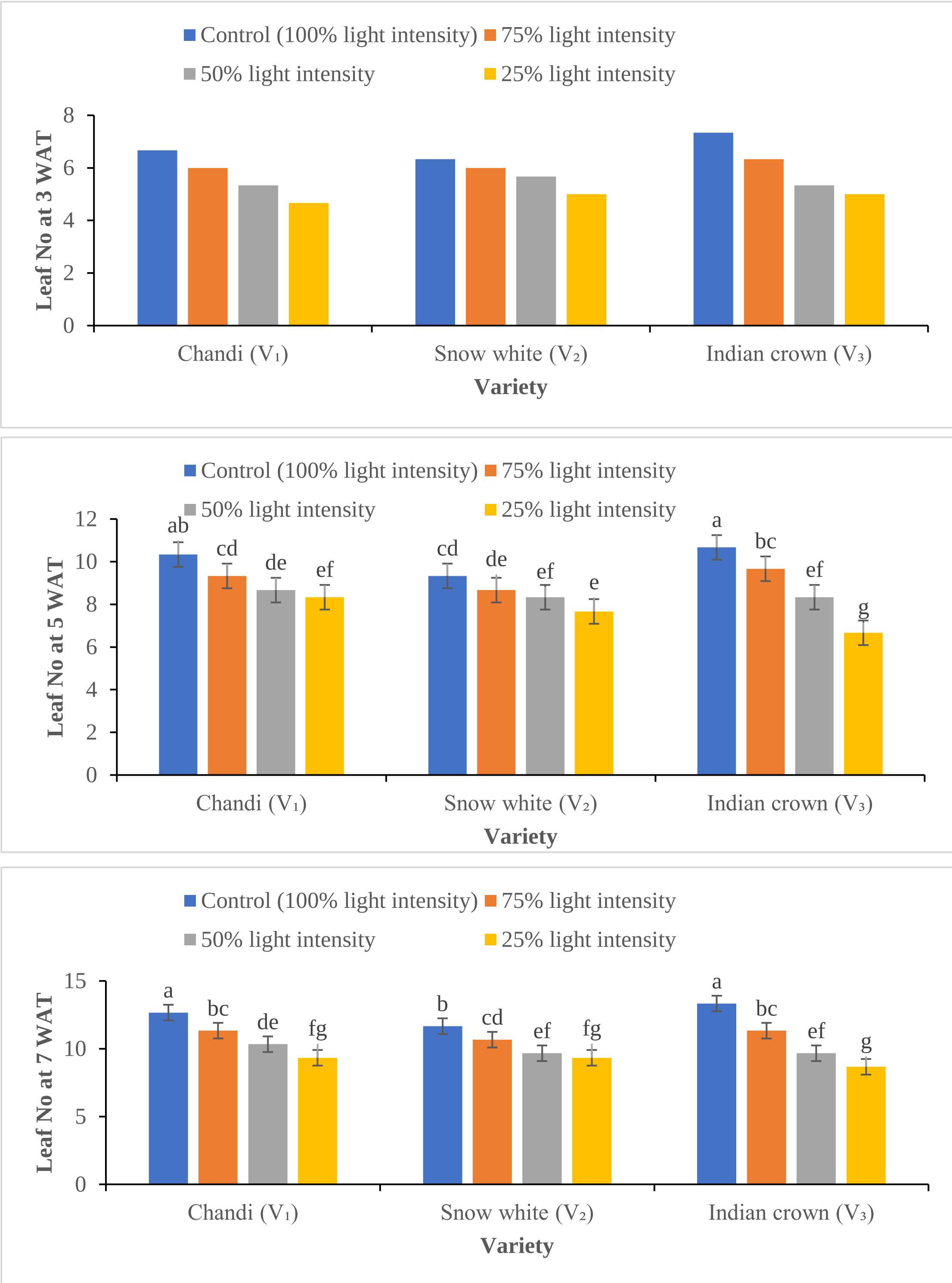
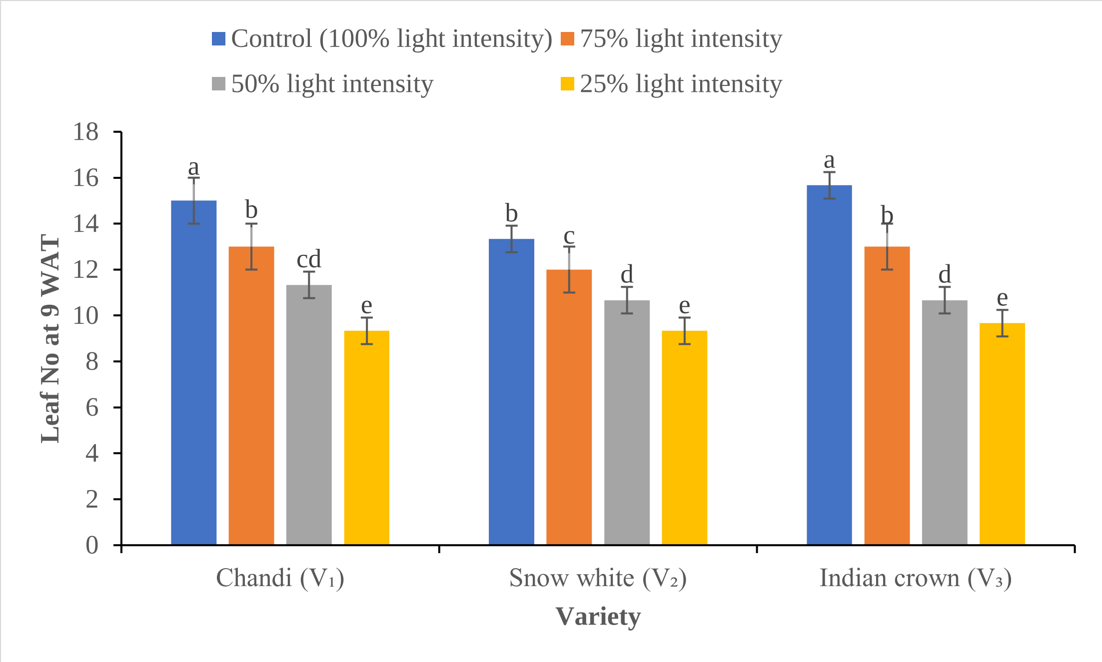


Figure 3. Effect of different low light stress on leaf number at 3, 5 and 7 weeks after transplanting (WAT) of different cauliflower varieties. Control, Shade-1 (S_1), Shade-2 (S_2) and Shade-3 (S_3) indicate 100%, 75%, 50% and 25% light intensity, respectively. Means (±SD) were calculated from three replications (n = 3) for each treatment. Bars with different letters are significantly different at P≤0.05 applying Fisher's LSD test.



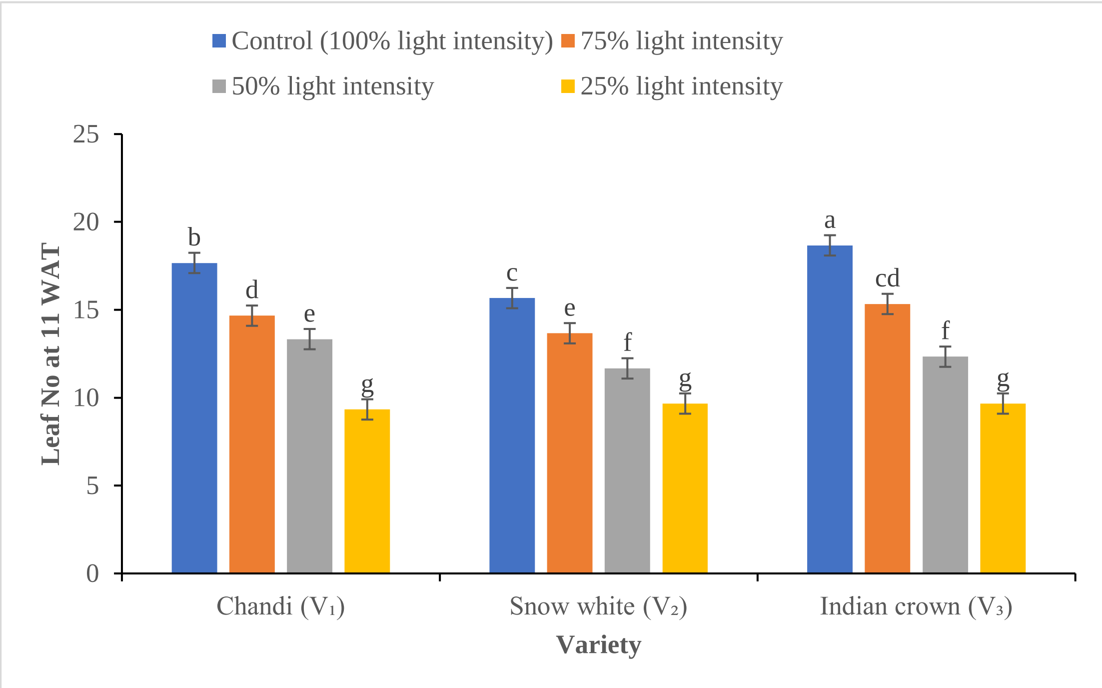


Figure 4. Effect of different low light stress on leaf number at 9 and 11 weeks after transplanting (WAT) of different cauliflower varieties. Control, Shade-1 (S_1), Shade-2 (S_2) and Shade-3 (S_3) indicate 100%, 75%, 50% and 25% light intensity, respectively. Means (±SD) were calculated from three replications (n = 3) for each treatment. Bars with different letters are significantly different at P≤0.05 applying Fisher's LSD test.

Leaf number at 5 WAT was found 10.3, 9.3, 8.7 and 8.3 under 100%, 75%, 50%, and 25% light intensity, respectively for Chandi variety (V_1). Again, under 100%, 75%, 50%, and 25% light intensity the leaf number was found 9.3, 8.7, 8.3 and 7.7, respectively, for Snow white variety (V_2). On the other hands, 10.7, 9.7, 8.3 and 6.7 leaves were recorded under 100%, 75%, 50%, and 25% light intensity, respectively in Indian crown variety (V3). Under 75% light intensity treatment, the reduction of leaves number is slight but under 50% and 25% light treatment, leaves number decreased significantly in all varieties. In contrast to controlled condition (100% light intensity), at 5 WAT, the reduction of leaves number is 9.67, 7.14 and 9.37% in V_1, V_2 and V_3 variety, respectively at 75% light intensity level. On the other hand, at 50% light intensity the leaves number reduction is 16.1, 10.7, 21.8% in V_1, V_2 and V_3 variety, respectively. Under severe condition (25% light intensity), leaf number reduction is 19.3,17.8, 37.5%, respectively (Figure 3). Here, we observed the minimum reduction was found in case of V_2 (Snow White) and maximum reduction occurs in V_3 variety (Indian crown).

In this experiment, we also find the similar result in 7, 9 and 11 weeks after transplanting (WAT) (Figure 3 and 4). There the minimum reduction is found in V_2 variety (Snow White) at 75% light intensity and maximum reduction is found in V_3 variety (Indian Crown) at 25% light level.

Similar findings were also recorded by Amin *et al.* (2014) reported that plant leaf number is maximum under 20% reduced sunlight compared with 40% reduced sunlight. Hossain *et al*. (2017) observed that in low light environment, plants consume higher energy for body development in comparison with plants developed in open field condition. On the other hands, Anusiya and Sivachandiran (2019) experimented that lettuce leaves number was significantly reduced by the 50% shade level. Haque *et al.* (2009) also reported that the number of leaves per plant reduced due to the low light intensity in various plants.

4.1.3 Leaf Length

Leaves are the vital part of plants. Leaves consume direct sun light and produce food for plant by photosynthetic reaction. So, sun light is very necessary element for plant life. If plant get low sun light that is not sufficient to plant then the size of the leaves reduced seriously specially leaf length.

Leaf length was counted five times at 3, 5,7,9 and 11 weeks after transplanting (WAT). Leaf length at 3 WAT was found 6.1, 5.8, 5.6 and 4.9 cm under 100%, 75%, 50% and 25% light intensity, respectively for Chandi variety (V_1). Again, under 100%, 75%, 50%, and 25% light intensity condition the leaf length was found 5.6, 5.2, 5 and 4.7 cm, respectively, for Snow white variety (V_2). On the other hands,6.7, 6.2, 5.4 and 5.2 cm leaves length were recorded under 100%, 75%, 50%, and 25% light intensity, respectively, Indian crown variety (V_3). In this experiment, in contrast to control (100% light intensity), at 3 WAT, 75% light intensity (S_1) decreased leaf length by 5.95, 5.99 and 7.42% in V_1 (Chandi), V_2 (Snow white) and V_3 (Indian crown), respectively. In 50% light intensity, leaf length was decreased by 9.72, 10.18 and 19.79% in V_1, V_2 and V_3, respectively. Finally severe stress (25% light level, S_3) reduced leaf length by 21.08, 15.57 and 22.77% in V_1, V_2 and V_3, respectively (Figure 5). This result shows that minimum leaf length reduction is 5.95% at 75% light level in Chandi variety and maximum reduction is 22.77% at 25% light level in Indian crown variety

Leaf length at 5 WAT was found 8.9, 8.5, 7.7 and 6.7 cm under 100%, 75%, 50%, and 25% light intensity, respectively for Chandi variety (V_1). Again, under 100%, 75%, 50%, and 25% light intensity condition the leaf length was found 8.2, 7.6, 6.9 and 6.8 cm, respectively, for Snow white variety (V_2). On the other hands, 9.5, 9.1, 8.2and 7.7 cm leaves length were recorded under 100%, 75%, 50%, and 25% light intensity, respectively, in Indian crown variety (V_3). Under 75% light treatment, the reduction of leaves length is slight but under 50% and 25% light treatment, leaves length decreased significantly in all varieties. In contrast to controlled condition (100% light intensity), at 5 WAT, the reduction of leaves length is 5.2, 6.94 and 4.55% in V_1, V_2 and V_3 variety, respectively at 75% light treatment. On the other hand, at 50% light treatment, the leaves length reduction is 14.5, 15.1 and 13.29% in V_1, V_2 and V_3 variety, respectively. Under severe condition (25% light treatment), leaf length reduction is 25.65, 16.33 and 19.23% respectively, (Figure 5). This result shows that minimum leaf length reduction is 4.55% at 75% light treatment in Indian crown and maximum reduction is 25.65% at 25% light treatment in Chandi variety. In this experiment, we also find the similar result in 7, 9 and 11WAT. There the minimum reduction is found at 75% light intensity and maximum reduction is found at 25% light intensity (Figure 5 and 6)).

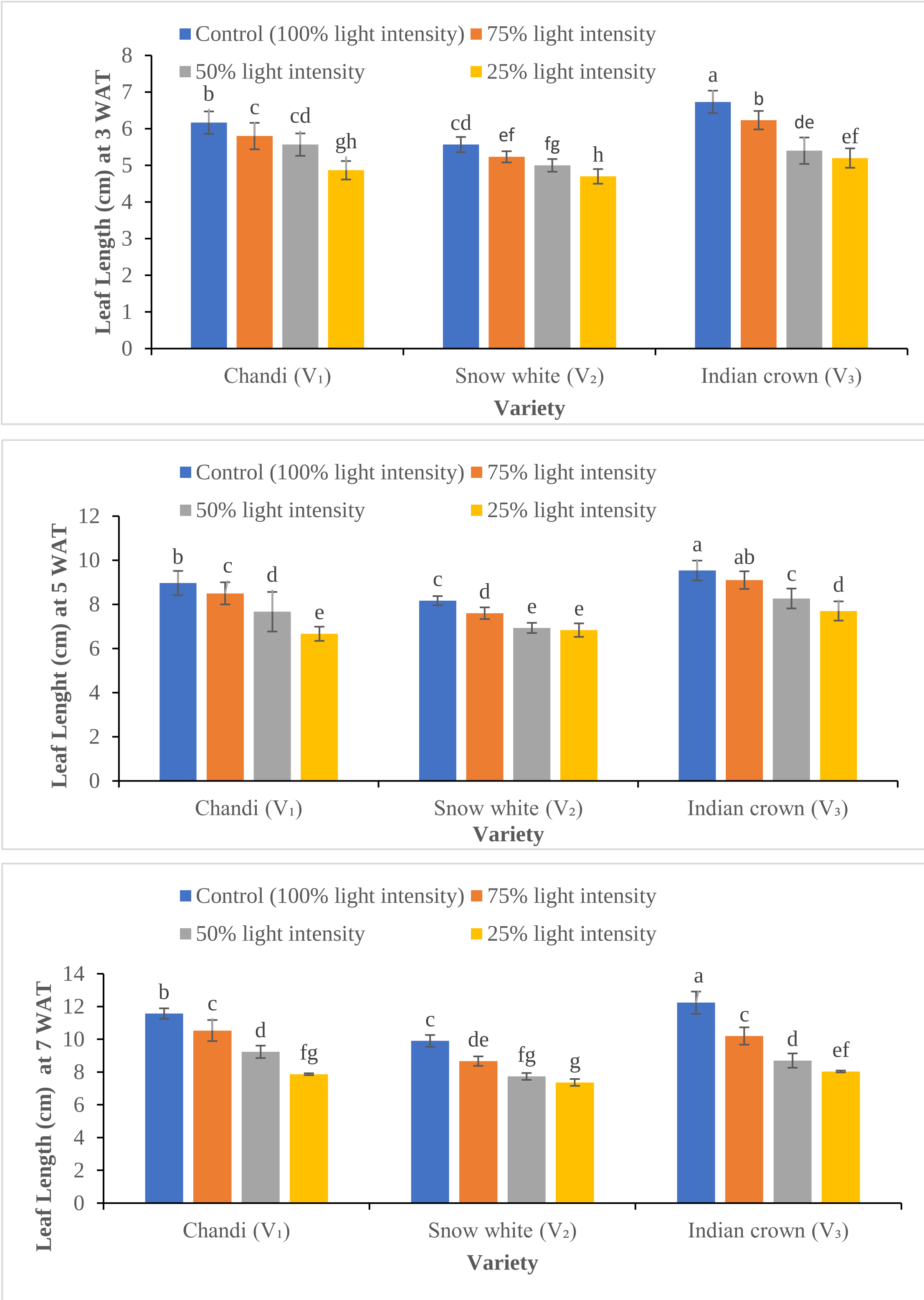
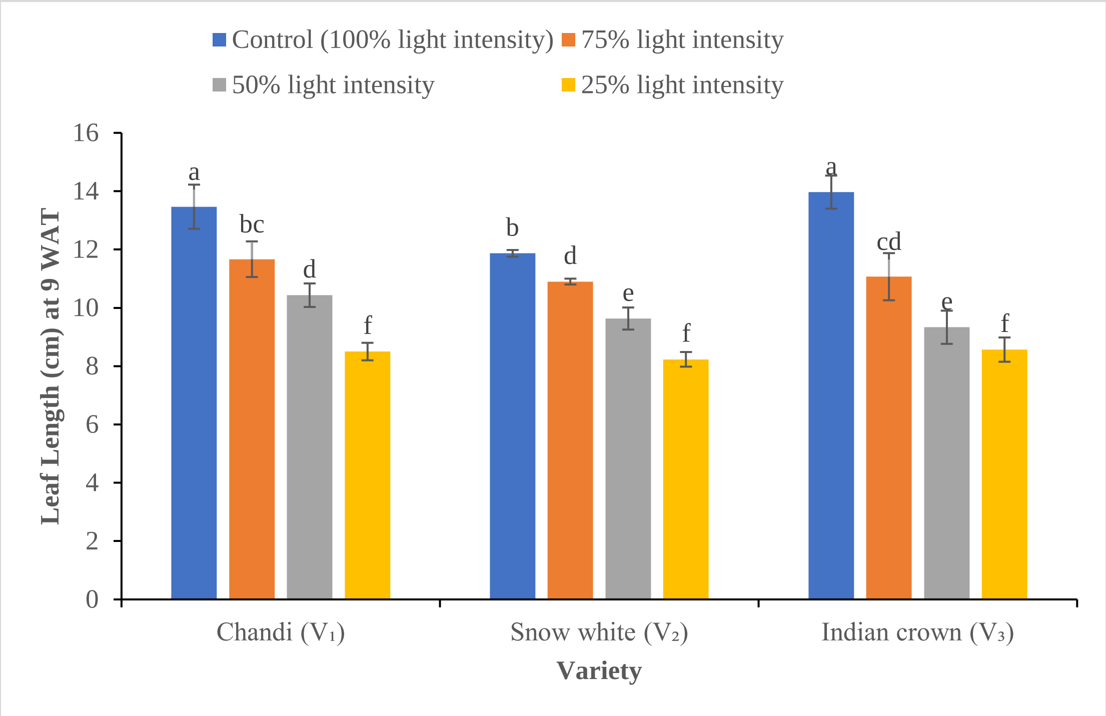


Figure 5. Effect of different low light stress on leaf length at 3, 5 and 7 weeks after transplanting (WAT) of different cauliflower varieties. Control, Shade-1 (S_1), Shade-2 (S_2) and Shade-3 (S_3) indicate 100%, 75%, 50% and 25% light intensity, respectively. Means (±SD) were calculated from three replications (n = 3) for each treatment. Bars with different letters are significantly different at P≤0.05 applying Fisher's LSD test.



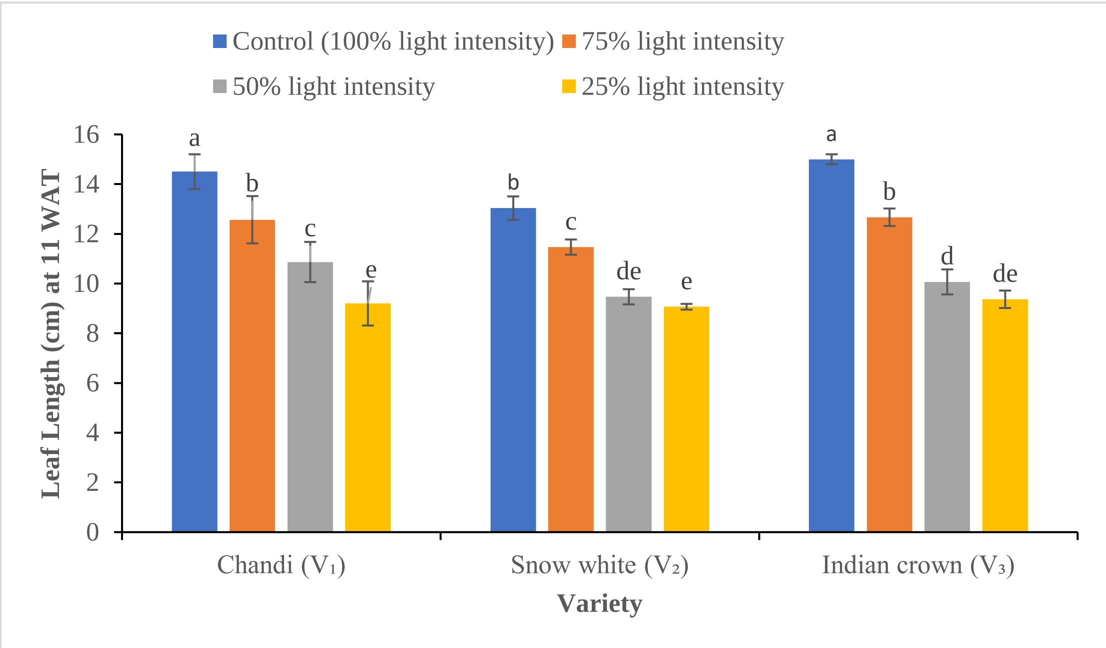


Figure 6. Effect of different low light stress on leaf length at 9 and 11 weeks after transplanting (WAT) of different cauliflower varieties. Control, Shade-1 (S_1), Shade-2 (S_2) and Shade-3 (S_3) indicate 100%, 75%, 50% and 25% light intensity, respectively. Means (±SD) were calculated from three replications (n = 3) for each treatment. Bars with different letters are significantly different at P≤0.05 applying Fisher's LSD test.

The findings are also supported by Rodriguez *et al*. (2015) who ensure that low light intensity negatively hamper the leaf length of *Brassica oleracea* species. He showed that at 50% light treatment and 20°C leaf length was 9.8 cm but at 75% light intensity and 32°C it was 11.2 cm. Similar results were also obtained by Kim *et al*. (2020) in *Peucedanum japonicum* Thunb. he showed that at 50% light intensity leaf length is 3.6 cm and at 75% light intensity it was 4.9 cm.

4.1.4 Leaf Width

Leaves are the main source of energy. Leaves width are seriously hampered by low sun light effect. This study indicates that leaves width significantly reduced due to low light intensity. Leaf width of Chandi variety (V_1) was found 4.5, 3.9, 3.5 and 2.9 cm under 100%, 75%, 50%, and 25% light intensity, respectively, at 3 WAT. Again, under 100%, 75%, 50%, and 25% light treatment the leaf width was found 4, 3.6, 3.2 and 2.9 cm, respectively, for Snow white variety (V_2). On the other hands, 4.5, 3.8, 2.9 and 2.3 cm leaves width were recorded under 100%, 75%, 50%, and 25% light intensity, respectively, in Indian crown variety (V_3). In this experiment, in contrast to control (100% light intensity), at 3 WAT, 75% light intensity (S_1) decreased leaf width by 13.23, 11.48 and 16.9 % in V_1 (Chandi), V_2 (Snow white) and V_3 (Indian crown), respectively. In 50% light intensity, leaf width was decreased by 23.26, 23.1 and 26.6 % in V_1, V_2 and V_3, respectively. Finally severe stress (25% light intensity, S_3) reduced leaf width by 36.76, 29.5 and 48.5 % in V_1, V_2 and V_3, respectively. This result shows that minimum leaf width reduction is 11.48 % at 75% light intensity in Snow white (V2) variety and maximum reduction is 48.5% at 25% light intensity in Indian crown variety. For showing this result, bars are marked with different letters because the difference of the reduction percentage is significant at $P \leq 0.05$ applying Fisher's LSD test (Figure 7).

Leaf width at 5 WAT was found 8.5, 5.1, 4.6 and 3.8 cm under 100%, 75%, 50%, and 25% light intensity, respectively for Chandi variety (V_1). Again, under 100%, 75%, 50%, and 25% light level the leaf width was found 5, 4.6, 3.9 and 3.7 cm, respectively, for Snow white variety (V_2). On the other hands, 6.2, 5.1, 4.6 and 4.1 cm leaves width were recorded under 100%, 75%, 50%, and 25% light intensity, respectively, in Indian crown variety (V_3). Under 75% light treatment, the reduction of leaves width is slight but under 50% and 25% light treatment, leaves width decreased significantly in all varieties (Figure 7).

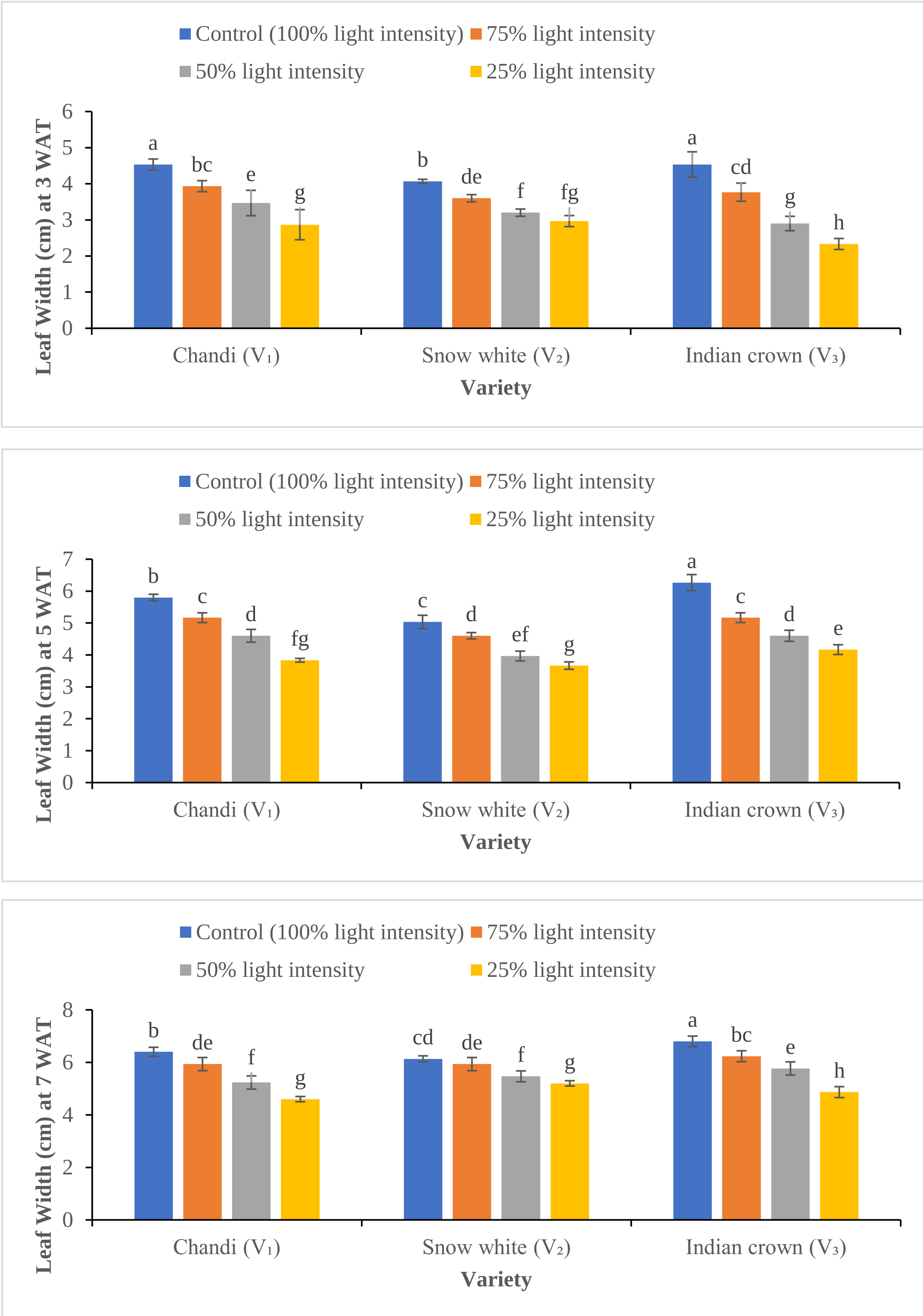
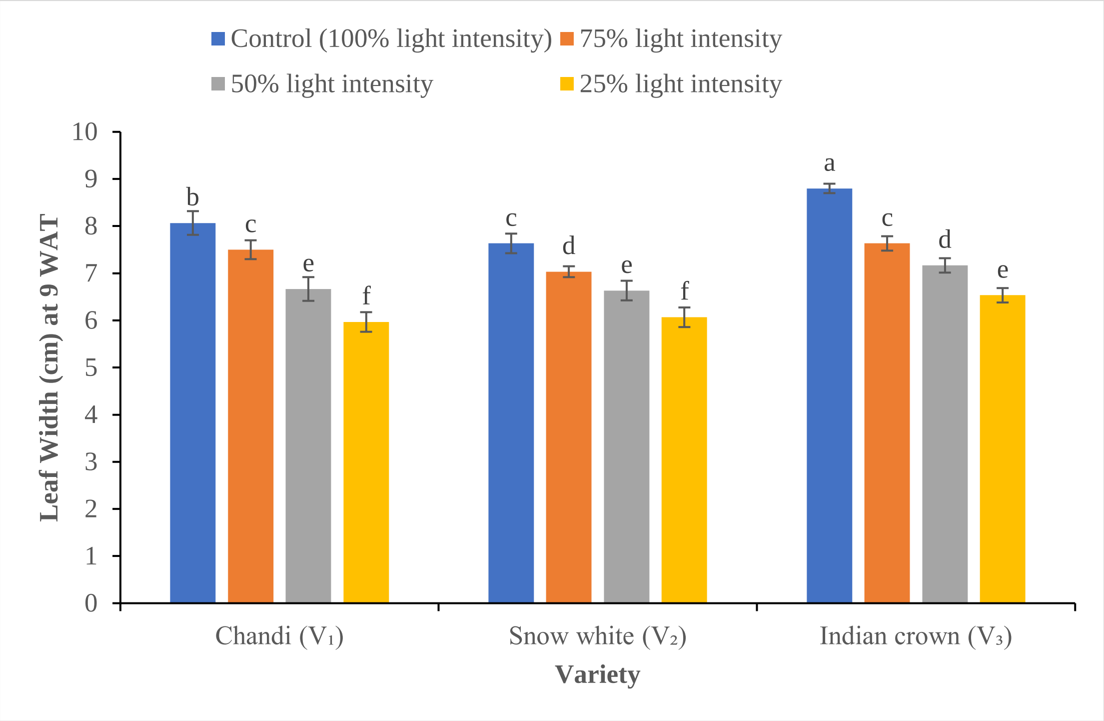


Figure 7. Effect of different low light stress on leaf width at 3, 5 and 7 weeks after transplanting (WAT) of different cauliflower varieties. Control, Shade-1 (S_1), Shade-2 (S_2) and Shade-3 (S_3) indicate 100%, 75%, 50% and 25% light intensity, respectively. Means (±SD) were calculated from three replications (n = 3) for each treatment. Bars with different letters are significantly different at P≤0.05 applying Fisher's LSD test.



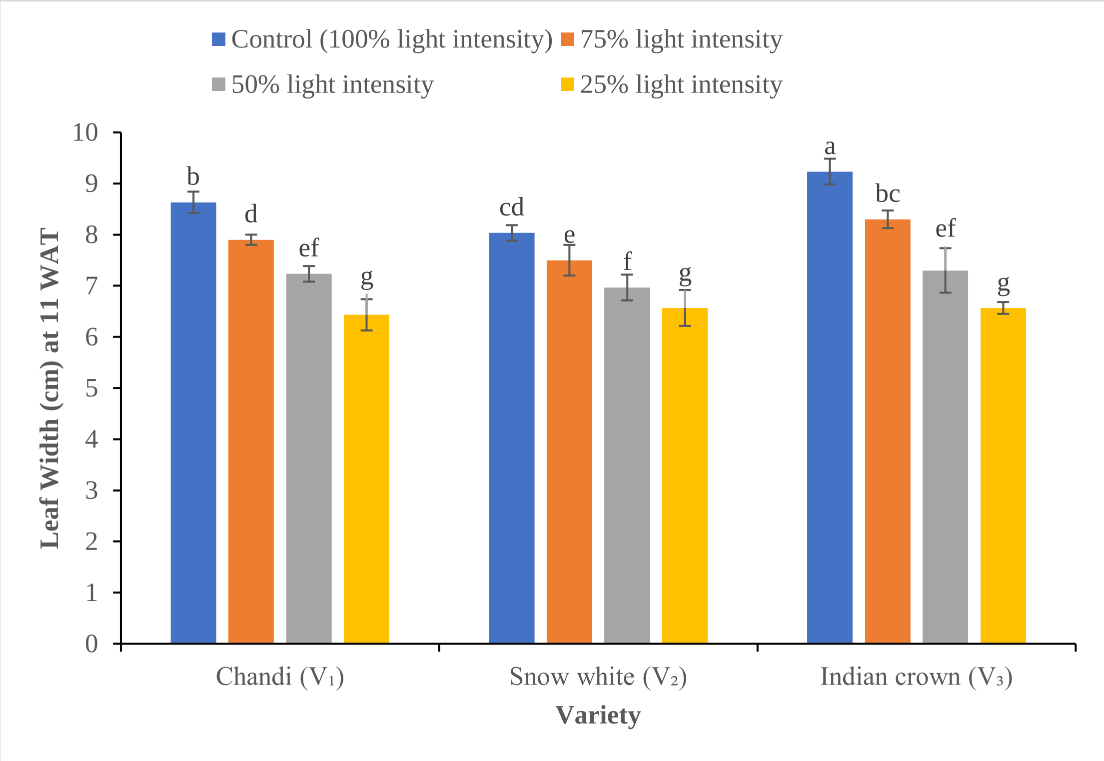


Figure 8. Effect of different low light stress on leaf width at 9 and 11 weeks after transplanting (WAT) of different cauliflower varieties. Control, Shade-1 (S_1), Shade-2 (S_2) and Shade-3 (S_3) indicate 100%, 75%, 50% and 25% light intensity, respectively. Means (±SD) were calculated from three replications (n = 3) for each treatment. Bars with different letters are significantly different at $P \leq 0.05$ applying Fisher's LSD test.

In contrast to controlled condition (100% light intensity), at 5 WAT, the reduction of leaves width is 10.9, 8.6 and 17.55% in V_1, V_2 and V_3 variety, respectively at 75% light intensity level. On the other hand, at 50% light intensity, the leaves width reduction is 20.69, 21.19 and 26.59% in V_1, V_2 and V_3 variety, respectively. Under severe condition (25% light intensity), leaf width reduction is 33.9, 27.15 and 33.5% respectively (Figure 4). This result shows that minimum leaf width reduction is 8.6% at 75% light intensity in Snow white and maximum reduction is 33.9% at 25% light intensity in Chandi variety. In this experiment, we also find the similar result in 7, 9 and 111 weeks after transplanting (WAT). There the minimum reduction is found at 75% light intensity level and maximum reduction is found at 25% light intensity level (Figure 8).

The findings are also supported by Rodriguez *et al.* (2015) who ensure that low light intensity hampered the leaf width of *Brassica oleracea* species. He showed that at 50% light intensity and 20°C leaf width was 5.4 cm but at 75% light intensity and 32°C it was 6.6 cm. Similar results were also obtained by Kim *et al*. (2020) in *Peucedanum japonicum Thunb*. he showed that at 50% light intensity leaf width is 2.2 cm and at 75% light intensity it was 2.8 cm.

4.1.5 Fresh Shoot Weight

Plant fresh shoot weight is an important parameter that is severely hampered by any sort of stress. In this study, 75% shade stress reduced plant fresh shoot weight slightly but under 50% and 25% shade stress decreased fresh shoot weight significantly in all varieties. The amount of fresh shoot weight under control condition was 306, 273 and 319.33 g in V_1, V_2 and V_3, respectively. The 75% light intensity treatment the amount of fresh weight decreased which were 271, 246 and 278.33 g in V_1, V_2 and V_3, respectively. Under 50% light intensity, the amount of fresh shoot weight further decreased and it became 257, 230, 244.67 g in V_1, V_2 and V_3, respectively. Lastly, in severe shade stress (S_3) amount of fresh shoot weight were recorded as 218.67, 207, 206.67 g in V_1, V_2 and V_3, respectively.

In comparison with the control (100% light intensity) treatment, 75% light intensity (S_1) decreased the fresh shoot weight by 11.5, 9.9 and 12.8% in V_1, V_2 and V_3 variety, respectively. At 50% light intensity, fresh shoot weight decreased by 16, 17.9 and 23.4% respectively, in contrast to the control treatment. Lastly under severe stress (S_3), the fresh shoot weight reduction in the cauliflower plant was 28.5, 24 and 35.3% in V_1, V_2 and V_3, respectively (Figure 9).

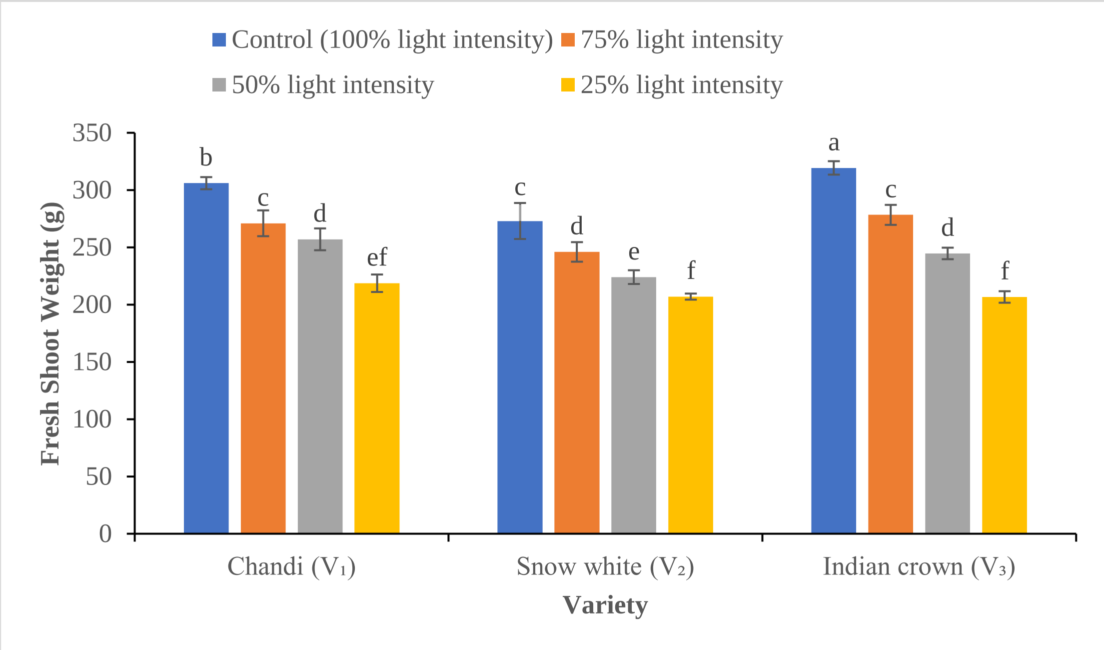


Figure 9. Effect of different low light stress on fresh shoot weight of different cauliflower varieties. Control, Shade-1 (S_1), Shade-2 (S_2) and Shade-3 (S_3) indicate 100%, 75%, 50% and 25% light intensity, respectively. Means (±SD) were calculated from three replications (n = 3) for each treatment. Bars with different letters are significantly different at $P \leq 0.05$ applying Fisher's LSD test.

So, it is clear that maximum reduction was 35.2% in Indian crown variety, was recorded under 25% light intensity and minimum reduction was documented 9.9% under 75% light intensity in Snow white variety. Also, Snow white variety is more tolerant to shade stress and showed minimum reduction percentage than the Chandi and Indian crown variety. Decrease of plant fresh shoot weight under shade stress condition indicates the loss towards growth of cauliflower plant which are supported by others findings (Haque *et al.*, 2009; Dong *et al.*, 2014).

4.1.6 Fresh Root Weight

Like plant fresh shoot weight, plant fresh root weight also followed harmonious model under low light stress situation. Under control condition, the quantity of fresh root weight was 11.7, 10.33 and 9.83 g in V_1, V_2 and V_3, respectively. The 75% low light treatment the amount of fresh root weight decreased which were 10.67, 9.77 and 8.4 g in V_1, V_2 and V_3, respectively. Under 50% low light treatment, the amount of fresh root weight further decreased and it became 9.27, 8.73 and 7.73 g in V_1, V_2 and V_3, respectively. Lastly, in severe stress (25% low light treatment) amount of fresh root weight were recorded as 8.63, 7.93 and 6.77 g in V_1, V_2 and V_3, respectively (Figure 10).

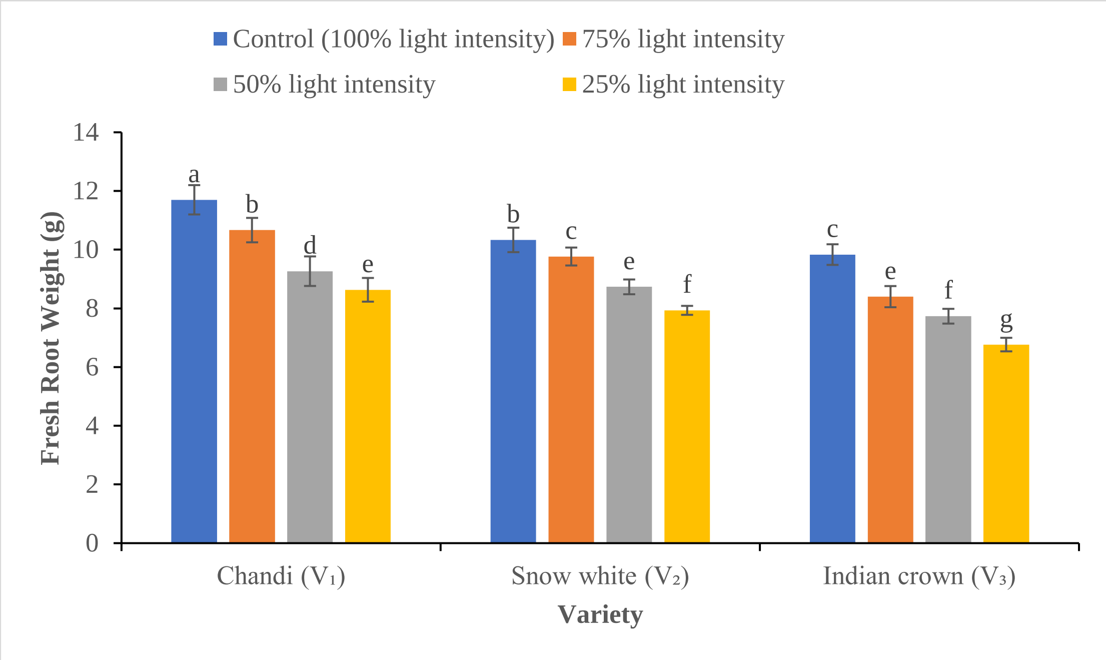


Figure 10. Effect of different low light stress on fresh root weight of different cauliflower varieties. Control, Shade-1 (S_1), Shade-2 (S_2) and Shade-3 (S_3) indicate 100%, 75%, 50% and 25%light intensity, respectively. Means (±SD) were calculated from three replications (n = 3) for each treatment. Bars with different letters are significantly different at $P \leq 0.05$ applying Fisher's LSD test.

In comparison with the control (100% light intensity) treatment, 75% light intensity(S_1) decreased the fresh root weight by 8.8, 5.5 and 14.6% in V_1, V_2 and V_3 variety respectively. At 50% light intensity, fresh root weight decreased by 20.8, 15.5 and 21.4%, respectively, in contrast to the control treatment. Lastly under severe stress (S_3), the fresh root weight reduction in the cauliflower plant was 26.2, 23.2 and 31.2% in V_1, V_2 and V_3, respectively. Result showed that maximum fresh root weight was decreased in Indian crown variety at 25% light intensity and that was 31.2%. On the other hands, minimum result found in Snow white variety at 75% light intensity and that was 5.5%.

Thakur *et al.* (2019) also found similar growth reduction in damask rose (*Rosa damascena* Mill.). Dong *et al.* (2014) found similar result in wheat plant. Saito *et al.* (1994) also got similar result, they shown that root growth is hampered under severe light stress condition.

4.1.7 Dry Matter Weight

Dry matter weight of cauliflower plants is also followed the same pattern under shade stress condition. The amount of dry matter weight under control condition (S_0) was 29.33, 30 and 33.67 g in V_1, V_2 and V_3, respectively. In 75% light intensity (S_1) treatment, the amount of dry weight decreased which were 26.67, 27.33 and 29.67 g in V_1, V_2 and V_3, respectively. Under 50% light intensity (S_2) treatment, the amount of dry weight further decreased and it became 24.33, 25 and 27.67 g in V_1, V_2 and V_3, respectively. Lastly, in severe stress condition at 25% light intensity (S_3) amount of dry weight were recorded as 21, 22.67 and 22.33 g in V_1, V_2 and V_3, respectively. In comparison with 100% light intensity (S_0), a gradual reduction was observed in 75%, 50%, and 25% light intensity in terms of dry weight of all three tested varieties. Though dry weight was reduced by 9, 7.9 and 11.9% at 75% light intensity; 11, 15.7 and 17.8% at 50% light treatment in V_1, V_2 and V_3, respectively, but 28.4, 23.6 and 33.7% reduction were observed at 25% light level in V_1, V_2 and V_3, respectively, (Figure 11).

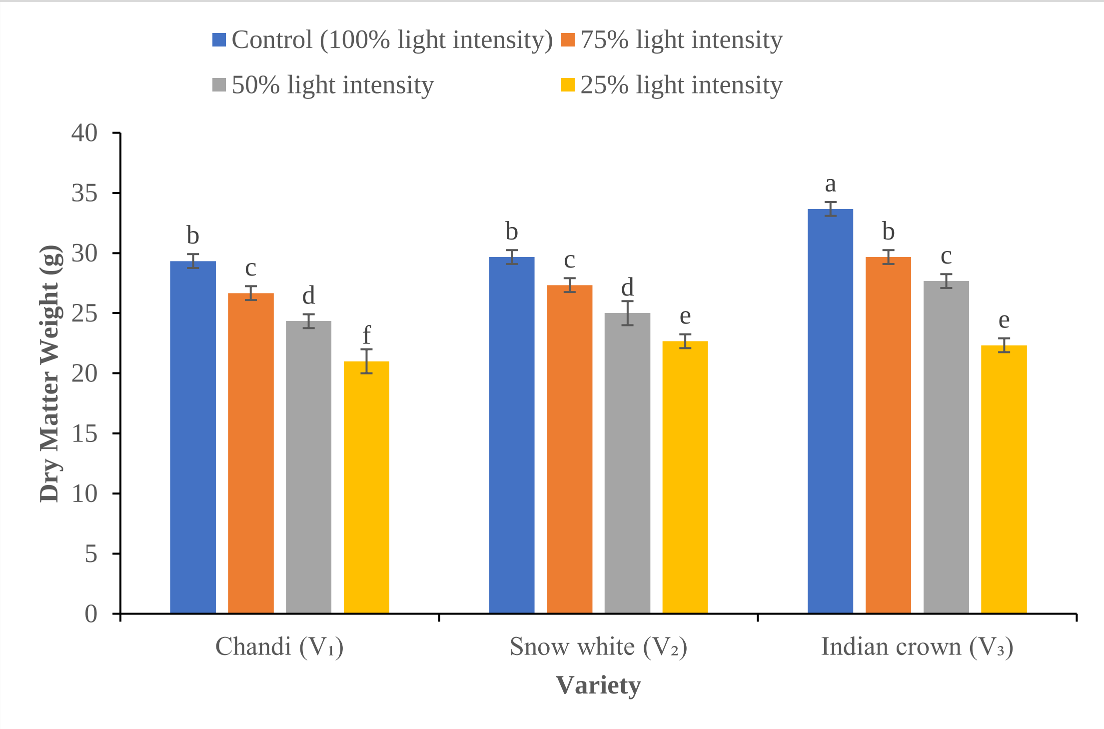


Figure 11. Effect of different low light stress on dry matter weight of different cauliflower varieties. Control, Shade-1 (S_1), Shade-2 (S_2) and Shade-3 (S_3) indicate 100%, 75%, 50% and 25%light intensity, respectively. Means (±SD) were calculated from three replications (n = 3) for each treatment. Bars with different letters are significantly different at P≤0.05 applying Fisher's LSD test.

This result justified by Zervoudakis *et al.* (2012). In his experimented he showed that in comparison with control (100% light intensity) condition, different levels of low light (75, 50 and 25% light intensity) significantly reduced weight of the dry matter of Sage (*Salvia officinalis L.*). This experiment findings were also in agreement with studies on other plants (Yang *et al.*, 2007; Wang *et al.*, 2009) which resemblance weight of the dry matter severely reduced under shade condition (Taiz and Zeiger, 2002)

4.1.8 Stem Diameter

Stem diameter of cauliflower is also a vital parameter to judge growth pattern during shade stress condition. Current study showed that shade stress highly reduced the stem diameter. The diameter of main stem was 3.1, 2.7, 2.5 and 2.3 cmunder 100% (S_0), 75% (S_1), 50% (S_2), and 25% (S_3) light intensity, respectively for Chandi variety (V_1). In addition, for Snow white variety (V_2), the stem diameter was 2.8, 2.6, 2.5 and 2.4 cm under S_0, S_1, S_2, and S_3 treatment, respectively. Under same treatment,3.3, 2.8, 2.5 and 2.3 cm stem diameter were found in Indian crown (V_3) variety.

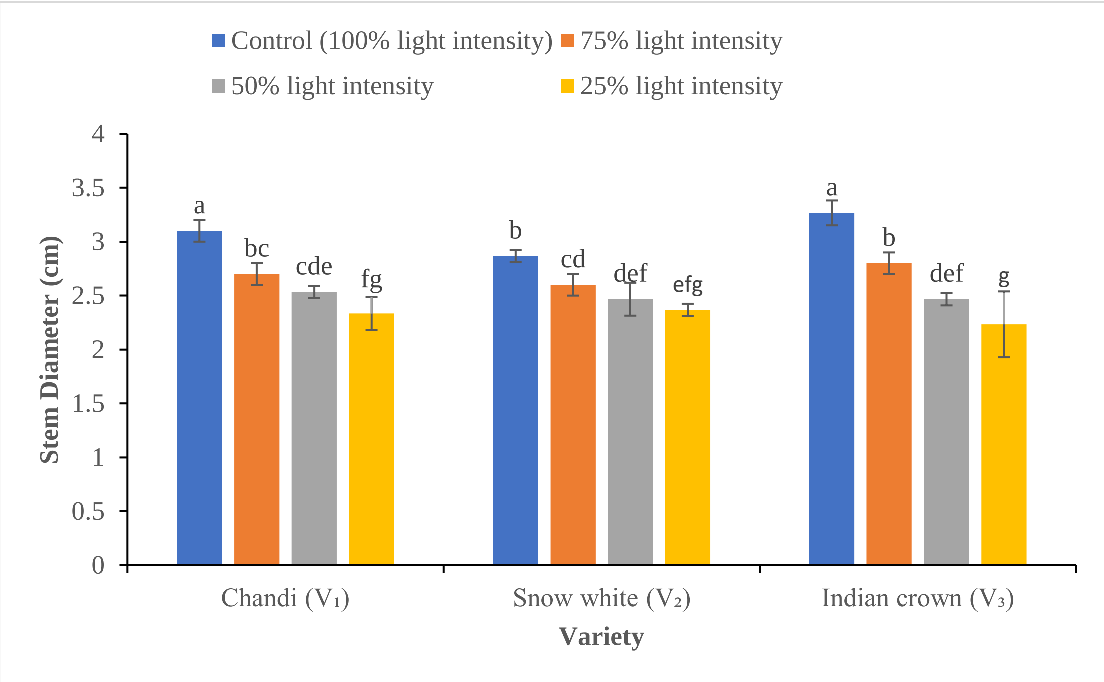


Figure 12. Effect of different low light stress on main stem diameter of different cauliflower varieties. Control, Shade-1 (S_1), Shade-2 (S_2) and Shade-3 (S_3) indicate 100%, 75%, 50% and 25%light intensity, respectively. Means (±SD) were calculated from three replications (n = 3) for each treatment. Bars with different letters are significantly different at P≤0.05 applying Fisher's LSD test.

Compare with control (100% light intensity) treatment, 75% light level (S_1) decreased main stem girth by 12.9, 9.3 and 14.29 % in V_1, V_2 and V_3 respectively. In 50% light intensity, stem diameter was decreased by 18.28, 13.95 and 17.8 % in V_1, V_2 and V_3 respectively. Lastly, in severe stress (25% light intensity) condition, declined the stem diameter by 24.73, 17.44 and 31.63 % in V_1, V_2 and V_3 respectively (Figure 12). This result was supported by Haque *et al.* (2009). He experimented that in comparison with control (100% light intensity) condition, different levels of low light (75, 50 and 25% light intensity) slightly or severely reduced the diameter of the main stem of bottle gourd.

4.1.9 SPAD Value

SPAD value supports a concept about photosynthetic performance of different plants. In current study low light stress significantly reduced SPAD value of leaves. The SPAD value of Chandi variety (V_1) was recorded at 66, 64, 60 and 53 under 100% (S_0), 75% (S_1), 50% (S_2), and 25% (S_3) light intensity, respectively. For Snow white variety (V_2), the SPAD value was 64, 62, 58 and 53.3% under 100% (S_0), 75% (S_1), 50% (S_2) and 25% (S_3) light intensity, respectively. In addition, the SPAD value of Indian crown variety (V_3) leaf was 67.3, 62.3, 56 and 49% under S_0, S_1, S_2, and S_3, respectively (Figure 13).

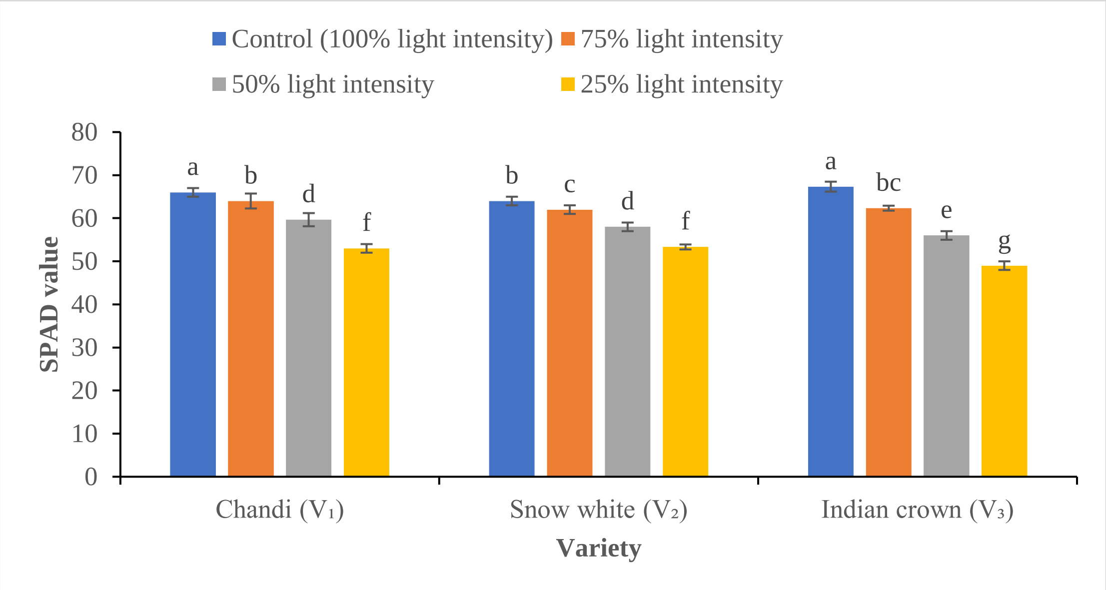


Figure 13. Effect of different low light stress on SPAD value of leaves of different cauliflower varieties. Control, Shade-1 (S_1), Shade-2 (S_2) and Shade-3 (S_3) indicate 100%, 75%, 50% and 25%light intensity, respectively. Means (±SD) were calculated from three replications (n = 3) for each treatment. Bars with different letters are significantly different at P≤0.05 applying Fisher's LSD test.

In comparison with control (100% light intensity) treatment, 75% light condition (S_1) decreased SPAD value by 3.03, 3.125 and 7.425% in V_1, V_2 and V_3, respectively. In 50% light treatment (S_2), SPAD value of leaves were decreased by 9.6, 9.38, 16. 83% in V_1, V_2 and V_3, respectively. Lastly severe stress (S_3) declined SPAD value by 19.7, 16.67 and 27.23% in V_1, V_2 and V_3, respectively. So, it clear that low light stress in this experiment significantly reduced photosynthetic activity of cauliflower as SPAD value indicate the concentration of chlorophyll content of leaves. This experiment is also supported by Rezai*et al.* (2018) in sage (*Salvia officinalis L.)* plant under severe low light environment.

4.1.10 Flowering Dates

Flowering, the fundamental step of sexual reproduction which is very essential in agricultural sector for fruit and seed production. It is a photoperiodic phenomenon, that is, a response which is controlled by the duration and quantity of light. For flowering, winter season crops need a maximum photoperiodism length. AS, cauliflower is a winter crop, so it needs a maximum photoperiodism length. In winter season, it is very hard to get maximum photoperiodism length. So, plants that get 75% light intensity, need a minimum time for flowering and that get 25% light intensity, need maximum time for flowering.

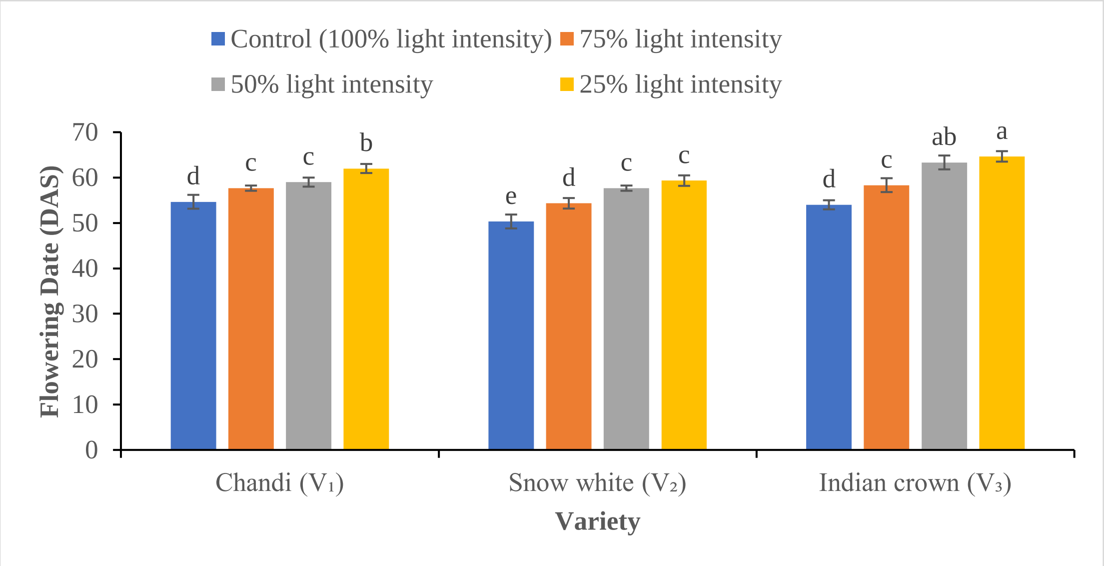


Figure 14. Effect of different low light stress on flowering dates of different cauliflower varieties. Control, Shade-1 (S_1), Shade-2 (S_2) and Shade-3 (S_3) indicate 100%, 75%, 50% and 25% light intensity, respectively. Means (±SD) were calculated from three replications (n = 3) for each treatment. Bars with different letters are significantly different at P≤0.05 applying Fisher's LSD test.

The time of first flowering for control treatment was 54.67, 50.33 and 54 days in V1, V2 and V3, respectively. In case of 75%light intensity, it was 57.67, 54.33 and 58.33 days, respectively. On the other hands, at 50%light intensity, it was 59, 58 and 63.33 days in V1, V2 and V3 species, respectively. But in severe condition, at 25% light intensity (S3) they were 62,60 and 64.67 days in V1, V2 and V3, respectively (Figure 14).

Compare with control (100% light intensity) treatment, 75% light intensity(S_1) increased flowering dates by 5.5, 7.9 and 8% in V_1, V_2 and V_3, respectively. In 50% light treatment, flowering times was increased by 7.9,14.6 and 17.3% in V_1, V_2 and V_3, respectively. Lastly, in severe stress (25% light intensity) condition, enhanced flowering dates by 13.4, 17.9 and 19.8% in V_1, V_2 and V_3, respectively that was a significant difference from control condition. This result also supported by Ghosh *et al.* (2016), showed that result at 25% light level has significant difference from 75% light level in case of flowering.

CHAPTER 5

SUMMARY AND CONCLUSION

Summary

In agroforestry system, low light stress/ shade stress is one of the most significant limiting factors for crop varieties. Cauliflower (*Brassica Oleracea Var. botrytis L.*) belongs to the family of Brassicaceae originated from Europe and Africa. Cauliflower plant has slight tolerance capacity to low light stress/ shade stress when they are growing in agroforestry system but severe low light tolerance level is depended upon cauliflower genotype sensitivity (Yasoda *et al*., 2018). Evaluation according to screening method is simple to estimate low light tolerant species.

A pot experiment was examined to find out the effect of light intensity on growth of 3speciesand to find out the shade stress preferable species of cauliflower. The study was experimented at the net house of Agroforestry and Environmental Science, Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh, during the months of October 2020 to March 2021. Factorial experiment including 3 cauliflower varieties viz. V_1 (Chandi), V_2 (Snow White) and V_3 (Indian Crown), with 3 low light/ shade treatments, S_0 (control), S_1(75% light intensity), S_2 (50% light intensity) and S_3 (25% light intensity).

Several parameters were collected and statistically analyzed for the evaluation best cauliflower varieties under different low light stress to achieve the objectives of the study.

Plant height of all cauliflower varieties reduced significantly under 50% light intensity (S_2) and 25% light intensity (S_3) level at all3, 5,7,9 and 11weeks after transplanting (WAT). During 3 WAT, in case of plant height, in low stress condition (75% light intensity), plant height reduced mostly in Chandi and Indian crown variety (7.87 and 6.68%, respectively) and minimum reduction occurred in Snow white variety (V_2) (3.24%) compared to control. Again, in severe stress condition (25% light intensity), plant height reduction occurred mostly in Indian crown and Chandi variety (19.5 and 17.17%, respectively) and lowest reduction occurred in Snow white (9.45%) compared to control. Similar result was also found at 5, 7, 9 and 11 WAT in case of leaf length. In case of leaf number data, at 3 WAT, data is not significant because there was no significant difference at Fishers LSD test. At 5 WAT, in control condition, maximum leaf number was recorded in Indian Crown (V_3) variety and minimum leaf number was found in Snow white variety. Here, leaf number was reduced in every variety with the increase of light stress condition. Similar result was observed 7, 9 and 11WAT.

In case of leaf length at 3 WAT, at 75% light intensity, Snow White (V_2) showed minimum reduction (6%) and Indian crown variety (V_2) showed maximum reduction (7.42%). At 50% light intensity, Chandi (V_1) had minimum reduction rate (5.2%) and maximum reduction was Indian crown (V_2) (19.8%). At 25% light intensity, minimum reduction was in Snow white (15.57%) and maximum was in Indian crown (22.8%), that all reduction results are significant. Similar result was also found at 5, 7, 9 and 11 WAT in case of leaf length. In case of leaf width, during 3 WAT, at 75% light intensity, Snow White (V_2) showed minimum reduction (11.47%) and Indian crown variety (V_2) showed maximum reduction (16.9%). At 50% light intensity, Snow white (V_2) showed minimum reduction rate (21.3%) and maximum reduction was Indian crown (V_2) (36.03%). At 25% light intensity, minimum reduction was in Snow white (29.5%) and maximum was in Indian crown (48.5%), that all reduction results are significant. Similar result was also found at 5, 7, 9 and 11 WAT in case of leaf width.

In case of grith of the main stem, in low stress condition (75% light intensity), stem girth reduced mostly in Chandi (V_1) and Indian crown (V_3) variety (12.9 and 14.28%, respectively) and minimum reduction occurred in Snow white variety (V_2) (9.3%) compared to control. Again, in severe stress condition (25% light intensity), stem diameter reduction occurred mostly in Indian crown (V_3) variety (31.6%), medium reduction occurred in V_1 variety (24.7%) and least reduction occurred in V_2 variety (17.45%) compared to control. In case of SPAD value of leaf, in low stress condition (75% light intensity), SPAD value of leaf reduced mostly inV_3 variety (7.425%) and least reduction occurred in V_1 and V_2 variety (3%) compared to control. Again, in severe stress condition (25% light intensity), SPAD value of leaf reduced mostly in V_3 variety (27.23%) and least reduction occurred in V_1 and V_2 variety (19.7 and 16.67%) compared to control. In case of first flowering date, in low stress condition (75% light intensity), first flowering time reduced most in V_3 variety (8%) and least reduction occurred in V_1 variety (5%) compared to control. Again, in severe stress condition (25% light intensity), first flowering date reduced most in V_3 variety (19.75%) and minimum reduction occurred in V_1 variety.

In case of fresh shoot weight, in low stress condition (75% light intensity), fresh shoot weight reduced mostly in Chandi (V_1) and Indian crown (V_3) variety (11.44 and 12.84%, respectively) and minimum reduction occurred in Snow white variety (V_2) (9.9%) compared to control. Again, in severe stress condition (25% light intensity), fresh shoot weight reduction occurred mostly in Indian crown (V_3) variety (35.28%), medium reduction occurred in V_1 variety (28.54%) and lowest reduction occurred in V_2 variety (24.17%) compared to control. In case of fresh root weight, in low stress condition (75% light intensity), fresh root weight reduced mostly in Indian crown variety(V_3) (14.57%), medium reduction occurred in Chandi variety (V_1) (8.83%) and minimum reduction occurred in Snow white variety (V_2) (5.48%) compared to control. Again, in severe stress condition (25% light intensity), fresh root weight reduction occurred mostly in Indian crown (V_3) variety (31.18%), medium reduction occurred in Chandi variety (V_1) (26.2%) and lowest reduction occurred in Snow white variety (V_2) (24.17%) compared to control. In case of dry matter weight, in low stress condition (75% light intensity), dry matter weight reduced mostly in Indian crown variety (V_3) (11.88%), medium reduction occurred in Chandi variety (V_1) (9.09%) and minimum reduction occurred in Snow white variety (V_2) (7.9%) compared to control. Again, in severe stress condition (25% light intensity), dry matter weight reduction occurred mostly in Indian crown (V_3) variety (33.67%) and lowest reduction occurred in V_1 and V_2 (28.4 and 23.6%, respectively) compared to control.

Conclusion

In agroforestry system, light stress is one of the world's most serious environmental stress because of combination of tree and crop either sequentially or simultaneously, reducing crop growth and yield. Cauliflower (*Brassica Oleracea Var. botrytis L.*), a member of the Brassicaceae family, is one of Bangladesh's most famous vegetable crops that is highly susceptible to low light stress. So, shade-tolerant cauliflower varieties must be chosen to combat in agroforestry system.

Taking into consideration the overall performance, Snow white variety showed less negative performance than the other varieties under shaded condition. The reduction of SPAD value as well as number of leaves and leaf size were lower in these varieties under shaded condition. As a result, total biomass reduction under shaded condition was not so high in Snow white variety. Therefore, among the tested cauliflower varieties Snow white is suitable for shaded condition with low light intensities.

Drawback

Due to massive rat attack we could not take the data of curd yield of cauliflower.

Recommendations

- For getting more accurate results, need more growth and yield based researches on this topic in future.
- There should be more research in the physiological, biochemical and molecular level of low light stress tolerance.
- Researches on other abiotic stresses and its relation with cauliflower should be done in future.
- Before recommendation the variety for agroforestry system, this experiment need to be justified in different agro-climatic zone in Bangladesh and need to add more new released variety for such type of varietal screening research.

REFERENCES

Ajithkumar, B., Karthika, V. P. and Rao, V. U. M. (2014). Crop weather relationships in Cauliflower (*Brassica oleraceavar. Botrytis* L.) in the Central zone of Kerala. AICRP on Agrometeorology, Department of Agricultural Meteorology College of Horticulture, Kerala Agricultural University. Vellanikkara, Thrissur, Kerala, India. pp 90-110.

Amin, M.R., Shemu, S.A., Shiam, I.H., Mehraj, H. and Uddin, A.F.M.J. (2014). Growth and yield of summer tomato as influenced by reduced light intensity. *J. Exp. Biosci.* **5(**2): 31–34.

Angmo, P., Dolma, T., Katiyar, A. and Chaurasia, O. P. (2020). Growing cauliflower in winter under passive solar greenhouse in Trans Himalayan Ladakh, India. *Def. Life Sci. J.* **5**(3):192-197.

Anonymous. (1988). Crop Status Report. Christian Reformed Worlds Relief Committee, Bogra. pp. 124-127.

Ansaril, M.I. and Chen, S.G. (2011). Leaf senescence. An overview. *Int. J. Recent Trends Sci. Technol.* **1**(3): 110-114.

Anusiya, M. and Sivachandiran, S. (2019). Effect of different shade levels on growth and yield performance of lettuce. *Int. J. For. Hortic.* **5**(3): 1–4.

Arenas-Corraliza, M.G., Rolo, V., López-Díaz, M.L and Moreno G. (2019). Wheat and barley can increase grain yield in shade through acclimation of physiological and morphological traits in Mediterranean conditions. Organic and Mountain Agriculture Research Center, Plasencia, Spain. Sci. Rep. 9, Art. No. 9547.

Argade, M. B., Kadam, J. H., Garande, V. K., Patgaonkar, D. R., Patil, V. S., and Sonawane, P. N. (2018). Effect of different shading intensities on growth and yield of cherry tomato. *Int. J. Appl. Nat. Sci.***10**(1): 352–357.

Assmann, S.M. (1992). Effects of light quantity and quality during development on the morphology and stomatal physiology of *Commelina communis*. *Oecologia*. **92**(6): 188–195.

Baharuddin, R., Chozin, M.A. and Syukur, M. (2014). Shade tolerance of 20 genotypes of tomato (*Lycopersicon esculentum Mill*.). *Indones. J. Agric. Sci.* **42**(2): 130-135.

Bazzaz, F.A. and Carlson R.W. (1982) Photosynthetic acclimation to variability in the light environment of early and late successional plants. *Oecologia.* **54**(8):313–316.

Beggs, C. J., Schneider-Ziebert, U. and Wellman, E. (1986). In-B radiation and adaptive mechanisms in plants. **In:** Statispheric ozone reduction, solar ultraviolet radiation and plant life. Worrest, R. C. and Caldwell, M. M. (ed.). Berlin, pp 25-57.

Bewley J.D. and Black M. (1983). Physiology of development and germination. *J. Exp. Bot*. **35**(158): 156-189.

Bjorkman., O. and Holmgren, P. (1963). Adaptability of the photosynthetic apparatus to light intensity in ecotypes from exposed and shaded habitats. *Physiol. Plant*. **16**(2):889–914.

Boardman, N.K. (1977). Comparative photosynthesis of sun and shade plants. *Annu. Rev. Plant Physiol.* **28**(9):355–377.

Bowes, G., Ogren, W.L., Hageman, R.H., (1971). Light saturation, photosynthesis rate, RuDP carboxylase activity and specific leaf weight in soybeans grown under different light intensities. *Proc. Am. Soc. Agron*. **1**(2): 77–79.

Brouwer, B., Ziolkowska, A., BAGARD, M., Keech, O. and Gardestrom, P. (2012). The impact of light intensity on shade-induced leaf senescence. *Plant Cell Environ*. 35(6): 1084-1098.

Burt, H., Hegnay, M., and GraUe, H. (1989). Cauliflower growing in the South West. Western Australian Department of Agriculture. *Int. J. Recent Trends Sci. Technol*. **12**(2):87-110.

Cantwell, M. and Kasmire, F.R., (2002). Postharvest handling systems: flower, leafy and stem vegetables. **In:** Postharvest technology of horticultural crops. (ed. a. kader), university of california agriculture and natural resources. Pub.3311, pp. 423-433.

Čekey, N., Šlosar, M., Uher, A., Balogh, Z., Valšikova, M. and Lošak, T. (2011). The effect of nitrogen and sulphur fertilization on the yield and content of sulforaphane and nitrates in cauliflower. *Acta Univ. Agric. et Silvic. Mendelianae Brun.* **59** (5):17-22.

Cervera, S. S., Olarte, C., Echávarri, J. F. and Ayala, F. (2007). Influence of exposure to light on the sensorial quality of minimally processed cauliflower. *J. Food Sci.* **72**(1):12-18.

Chatterjee, R. and Mahanta, S. (2013). Performance of off-season cauliflower (*Brassica oleracea var. botrytis* L.) under agro shade net as influenced by planting dates and nutrient source. *Int. J. Adv. Agric. Sci. Technol*. **1** (1): 56-62.

Chen, H., Li, Q.P., Zeng, Y.L., Deng, F. and Ren. W-J (2019). Effect of different shading materials on grain yield and quality of rice. *Sci. Rep*. **9**(3): 92-99.

Coohill, T. P. (1989). Ultraviolet action spectra (280 nm to 380 nm) and solar effectiveness spectra for higher plants. *J. Photochem. Photobiol.* **50**(4): 451-457.

Cregg, B. M., Teskey, R. O. and Dougherty, P. M. (1993). Effect of shade stress on growth, morphology, and carbon dynamics of loblolly pine branches. *J. Tree Sci.* **7**(4):208–213.

Crisp, P. and Angell, S. M. (1985). Genetic control of green curd color in cauliflower. *Ann. Appl. Biol.* **107(3)**: 601-603.

Crisp, P., Jewell, P. A. and Gray, A. R. (1975). Improved selection against the purple color defect of cauliflower curds. *Euphytica*. **24**(9): 177-180.

Demotes-Mainard, S., Péron, T., Corot, A., Bertheloot, J., Le Gourrierec, J., Pelleschi-Travier, S., et al. (2016). Plant responses to red and far-red lights, applications in horticulture. *J. Environ. Exp. Bot*. **121**(6): 4–21.

Dhatt, A.S. and Kaler H.S. (2009). Effect of shade net and growing media on nursery raising of cauliflower in sub-tropical area. *J. Adv. Hortic. Sci*. **23**(2): 118-122.

Dickson, M. H., Lee, C. Y. and Bramble, A. E. (1988). Orange curd high carotene cauliflower inbreeds, NY 156, NY 163 and NY 165. *J. Hortic. Sci.* **23**(4): 778-779

Dong, C., Fu, Y., Liu, G. and Liu, H. (2014). Low light intensity effects on the growth, photosynthetic characteristics, antioxidant capacity, yield and quality of wheat (*Triticum aestivum* L.) at different growth stages in BLSS. *Adv. Space Res.* **53**(11): 1557–1566.

D'Souza, C., Yuk, H. G., Khoo, G. H. and Zhou, W. (2015). Application of light-emitting diodes in food production, postharvest preservation, and microbiological food safety. *Compr. Rev. Food Sci. Food Saf*. **14** (6): 719–740.

Frederick, J. E. (1993). Ultraviolet sunlight reaching the Earth's surface. A review of recent research. *Photochem. Photobiol.***57**(1): 175-178.

Gao, J., Zhang, J., He, C. and Wang, Q. (2021a). Effects of light spectra and 15N pulses on growth, leaf morphology, physiology, and internal nitrogen cycling in Quercus variabilis Blume seedlings. *PLOS ONE*. **16**(7): 98-107.

Gao, M., He, R., Shi, R., Zhang, Y., Song, S., Su, W. and Liu, H. (2021b). Differential effects of low light intensity on broccoli microgreens growth and phytochemicals. *J. Agron.* **11**(3): p. 537.

Ghosh, A., Dey, K., Das, S. and Dutta, P. (2016). Effect of light on flowering of fruit crops. *Int. J. Adv. Life Sci*. **5**(7): 2597-2603.

Giri, H.N., Sharma, M. D., Thapa, R. B., Pande, K. R. and Khatri, B. B. (2020). Growth status, curd yield and crop duration of late season cauliflower varieties. *J. Agric. Nat. Resour.* **3**(2): 118-126.

Givnish, T.J., Montgomery, R.A. and Goldstein, G. (2004). Adaptive radiation of photosynthetic physiology in the Hawaiian lobeliads: light regimes, static light responses and whole-plant compensation points. *Am. J. Bot*. **91**(2): 228-46.

Graamans, L., Baeza, E., Van Den Dobbelsteen, A., Tsafaras, I. and Stanghellini, C. (2018). Plant factories versus greenhouses: comparison of resource use efficiency. *Agric. Syst*. **160** (94): 31–43.

Hampson, C.R., Azarenko, A.N. and Potter, J.R. (1996). Photosynthetic rate, flowering, and yield component alteration in hazelnut in response to different light environments. *J. Am. Soc. Hortic. Sci.* **121**(6): 1103–1111.

Haque, M. M., Hasanuzzaman M. and Rahman. M. L. (2009). Effect of light intensity on the morpho-physiology and yield of bottle gourd (*Lagenaria vulgar* L.). *J. Plant Sci.* **2**(3): 158-161.

Hogewoning, S. W., Douwstra, P., Trouwborst, G., Van Ieperen, W. and Harbinson, J. (2010a). An artificial solar spectrum substantially alters plant development compared with usual climate room irradiance spectra. *J. Exp. Bot.* **61**(1): 1267–1276.

Hogewoning, S.W., Trouwborst, G., Maljaars, H., Poorter, H., Ieperen, W.V. and Harbinson, J., (2010b). Blue light dose-responses of leaf photosynthesis, morphology, and chemical composition of Cucumis sativus grown under different combinations of red and blue light. *J. Exp. Bot*. **61**(11): 3107–3117.

Hossain, M.A., Hasan, M.A., Sikder, S. and Chowdhury, A. K. M. M. B. (2017). Leaf characteristics and yield performance of mungbean (*Vigna radiata L*.) varieties under different levels of shading. *The Agriculturists*. **15**(2): 40-51.

Islam, M. S., Nayeem, A. K. and Huda, S. N. (2020). an economic analysis of cauliflower production in selected areas of Mymensingh district of Bangladesh. *Int. Cent. Res. Develop.* **29**(2): 1-10.

Ismail, M.R. and Ann, L.J. (2004). Effect of root cooling and shading on growth and yield of tropical Cauliflower (*Brassica oleraceae var. botrytis*) in coconut coir dust culture. *Acta Hortic*. **36**(644): 269-274.

Jeong, K.Y., Pasian, C.C., McMahon, M. and Tay, D. (2009). Growth of six Begonia species under shading. *J. Open Hortic.* **7**(2):22–28.

Johkan, M., Shoji, K., Goto, F., Hahida, S. and Yoshihara, T. (2012). Effect of green light wavelength and intensity on photomorphogenesis and photosynthesis in *Lactuca sativa*. *J. Environ. Exp. Bot*. **75**(2): 128–133.

Johnson C. B. and Hilton J. (1978). Effects of light on phytochrome in cauliflower curd. *Planta.***144**(1): 13–17.

Kasemir, H. (1983). Light control of chlorophyll accumulation in higher plants. **In**: Encyclopedia of plant physiology. H. Mohr (ed.). Berlin. pp 507-560.

Katsoulas, N. and Kittas C. (2008). Impact of greenhouse microclimate on plant growth and development with special reference to the Solanaceae. *Eur. J. Plant Sci. Biotechnol.* **2**(1): 31–44.

Kengere, A., Daniel, K. A., Mbuvi, S. M. and Muindi, E. M. (2022). Effects of black shade net on yield of *Brassica rapa* and *Brassica oleracea* Cabbages in Kilifi County. *J. Agric. Ecol. Res. Int*. **23**(4): 12-21.

Khatib, K.A. and Paulsen, G.M. (1989). Enhancement of thermal injury to photosynthesis in wheat plants and thylakoids by high light intensity. *J. Plant Physiol.* **90**(3): 1041–1048.

Kim, J. K., Kang, H. M., Jang, D. C., Na, J. K. and Choi, K. Y. (2020). Effect of light intensity and temperature on the growth and functional compounds in the baby leaf vegetable plant *Peucedanum japonicum* Thunb. *Int. J. Hortic. Sci. Technol.* **38(6):** 822-829.

Kim, S.J., Hahn, E.J., Heo, J.W. and Paek, K.Y. (2004). Effects of LEDs on net photosynthetic rate, growth and leaf stomata of Chrysanthemum plantlets in vitro**.** *Sci. Hortic.***101**(1-2): 143–151.

Kopsell, D. A. (2008). Genetic and environmental factors affecting plant lutein/zeaxanthin. *Agro. Food Ind. Hi Tech*. **19**(2): 44-46.

Kulkarni, M. G., Sparg, S. G., and Van Staden, J. (2005). Temperature and light requirements for seed germination and seedling growth of two medicinal Hyacinthaceae species. *S. Afr. J. Bot.* **71**(3–4): 349–353.

Kumar, A., Kumar, M., Singh, B., Singh, M. K., Singh, S., Singh, R. and Kumar, R. (2020). Growth, yield and quality of cauliflower as influenced by different sources of nutrients and mulching in Indo-Gangatic Plains of Western Uttar Pradesh. *Int. Res. J. Pure Appl. Chem.* **21**(24): 300-307.

Leyla, B., Mostafa, A., Sasan, A., Mehdi, S., Oksana, L. and Tao L. (2018). Effects of growth under different light spectra on the subsequent high light tolerance in rose plants. *AoB PLANTS,* **10** (5): 634-647.

Lian, M.L., Murthy, H.N. and Paek, K.Y. (2002). Effect of light emitting diodes (LEDs) on the in vitro induction and growth of bulblets of Lilium oriental hybrid 'Pesaro'. *Int. J. Hortic. Sci*. **94**(12): 365–370.

Lin, K.H, Chen, L.F.O, Li, S.D. and Lo, H.F. (2015). Comparative proteomic analysis of cauliflower under high temperature and flooding stresses. *Sci. Hortic.* **183**(95): 118-129.

Liu, X.Y., Guo, S.R., Xu, Z.G., Jiao, X.L. and Takafumi, T. (2011). Regulation of chloroplast ultrastructure, cross-section anatomy of leaves and morphology of stomata of cherry tomato by different light irradiations of LEDs. *J. Hortic. Sci.* **46**(2): 217–221.

Long, S.P., Humphries, S. and Falkowski, P.G. (1994). Photoinhibition of photosynthesisin nature. *J. Annu. Rev. Plant Physiol. Plant Mol. Biol.* **45**(1): 633–662.

Lopez-Marin, J., Galvez, A. and Gonzalez, A. (2011). Effect of shade on quality of green-house peppers. *Acta Hortic.***893**(8932): 895–900.

Lopez-Marin, J., Galvez, A., Gonzalez, A., Egea-Gilabert, C. and Fernandez, J.A. (2012). Effect of shade on yield, quality, and photosynthesis-related parameters of sweet pepper plants. *Acta Hortic.* **956**(65): 545–552.

Mancinelli, A. L. (1985). Light dependent anthocyanin synthesis: a model system for the study of plant photomorphogenesis. *Bot. Rev.* **51**(1): 107-157.

Manolopoulou E. and Varzakas T. (2016). Effect of temperature in color changes of green vegetables. *Curr. Res. Nutr. Food Sci.* **45**(1): 10-17.

Markovic, V., Lazic, B., Djurovka, M. and Ilin, Z. (1996). Influence of nitrogen on yield, nitrate (NO3) and nitrite (NO2) content in vegetables. *Int. J. Adv. Res. Rev.* **3**(25): 475-480.

Marquez, U.M.L. and Sinnecker, P. (2007). Chlorophylls: Properties, biosynthesis, degradation and functions. In: Food colorants chemical and functional properties. C. Socaciu (ed.). Florida, USA. pp. 5-49.

Masabni J., Sun, Y., Niu G. and Valle P. D. (2016). Shade effect on growth and productivity of tomato and chili pepper. *Hortic. Technol.* **26**(3): 344-350.

Matos, F.S., Wolfgramm, R., Cavatte, P.C., Villela, F.G., Ventrella, M.C. and DaMatta, F.M. (2009). Phenotypic plasticity in response to light in the coffee tree. *J. Environ. Exp. Bot.* **67**(2): 421–427.

Mayer, A.M. and Poljakoff-Mayber, A. (1989) The Germination of Seeds. 4th Ed. Pergamon Press plc, Headington Hill Hall, Oxford OX3 OBW, England. pp. 52-56.

Miller, D. H. and Machlis, L. (1968). Effects of light on the growth and development of the liverwort, *Sphaerocarpos donnellii* Aust. *Plant Physiol*. **43**(5):714–722.

Mo, Z., Li, W., Pan, S., Fitzgerald, T. L., Xiao, F., Tang, Y., Wang, Y., Duan, M., Tian H. and Tang, X. (2015). Shading during the grain filling period increases 2-acetyl-1-pyrroline content in fragrant rice. *J. Rice.* **8**(9): 3-10.

Morais, H., Medri, M.E., Marur, C.J., Caramori, P.H., Ribeiro, A.M. and Gomes, J.C. (2004). Modifications on leaf anatomy of *Coffea arabica* caused by shade of Pigeon pea (*Cajanus cajan*). *Braz. Arch. Biol. Technol. J.* **47**(6): 863–871.

Murcia, M.A., LóPEZ-Ayerra, B., Martinez-Tomé, M. and Garcia-Carmona, F. (2000). Effect of industrial processing on chlorophyll content of broccoli. *J. Sci. Food Agric*. **80**(10): 1447-1451.

Nguyen N. H., Sng B. J. R., Yeo H. C. and Jang I. C. (2021). Comparative phenotypic and transcriptomic analyses unravel conserved and distinct mechanisms underlying shade avoidance syndrome in Brassicaceae vegetables. *BMC Genom*. **22**(1): 760-767.

Nhut, D.T., Takamura, T., Watanabe, H., Watanabe, H., Okamoto, K. and Tanaka, M. (2003). Responses of strawberry plantlets cultured in vitro under superbright red and blue light-emitting diodes (LEDs). *Plant Cell, Tissue Organ Cult.* **73**(1): 43–52.

Nowbuth, R.D. and Pearson, S. (1998). The effect of temperature and shade on curd initiation in temperate and tropical Cauliflower. *Acta Hortic.* **459**(7): 79-88

O'Connell, S. and Tate, R. (2017). Winter broccoli and cauliflower under organic high tunnels in a humid, subtropical climate. *Hort. Sci*. **52**(17): 1511-1517.

Ohadi, S., Mashhadi H. R., Tavakkol-Afshari, R. and Mesgaran, M.B. (2010). Modelling the effect of light intensity and duration of exposure on seed germination of *Phalaris minor* and *Poa annua*. *Weed Res. J.* **50**(3):209–217.

Onyekwelu, J.C., Stimm, B., Mosandl, R. M. and Olusola, J. A. (2012). Effects of Light Intensities on Seed Germination and Early Growth of *Chrysophyllum albidum* and *Irvingia gabonensis* Seedlings. *J. Sci. Food Agric.***18**(1):23-29.

Paik, I., and Huq, E. (2019). Plant photoreceptors: Multifunctional sensory proteins and their signaling networks. *Semin. Cell Dev. Biol.* **92**(6):114–121.

Paradiso, R. and Proietti, S. (2021). Light-quality manipulation to control plant growth and photomorphogenesis in greenhouse horticulture: the state of the art and the opportunities of modern led systems. *J. Plant Growth Regul*. **21**(67): 1–39.

Paul, R. (2019). Influence of hardening off period and temperature on cauliflower yield. *Plant Arch.* **19**(2): 3181-3184.

Perez-Balibrea, S., Moreno, D. A. and Viguera, C. G. (2008). Influence of light on health promoting phytochemicals of broccoli sprouts. *J. Sci. Food Agric*. **88**(5): 904–910.

Pierson, E.A., Mack, R.N. and Black, R.A. (1990). The effect of shading on photosynthesis, growth, and regrowth following defoliation for *Bromus tectorum*. *Oecologia.* **84**(9): 534–543.

Pogson, B. J. and Morris, S.C. (1997). Consequences of cool storage of broccoli on physiological and biochemical changes and subsequent senescence at 20°C. *J. Am. Soc. Hortic. Sci.* **122**(4): 553-558.

Ptushenko, O.S., Ptushenko, V.V. and Solovchenko, A.E. (2020). Spectrum of light as a determinant of plant functioning. *J. Agron. Sci.* **10**(3): 25-36.

Quiro´s, R., Villalba, G., Gabarrell, X. and Munoz, P. (2015). Life cycle assessment of organic and mineral fertilizers in a crop sequence of cauliflower and tomato. *Int. J. Environ. Sci. Technol.* **12**(56): 3299-3316.

Rahman, H.U., Hadley, P, Pearson, S. and Dennett, M.D. (2006). Effect of incident radiation integral on cauliflower growth and development after curd initiation. *J. Plant Growth Regul.* **51**(1): 41–52.

Rakhmawati, S. U. and Rahmadiyanto A. N. (2015). The Effects of Light Color on Seed Germination of *Markhamia stipulata* (Wall.). International Conference on Biological Science ICBS, pp. 233-240.

Rezai, S., Etemadi, N., Nikbakht, A., Yousefi, M. and Majidi, M. M. (2018). Effect of light intensity on leaf morphology, photosynthetic capacity, and chlorophyll content in sage (*Salvia officinalis* L.). *Int. J. Hortic. Sci. Technol.***36**(1): 46–57.

Robberecht, R., (1989). Environmental photobiology. **In**: The Science of the Photobiology. Smith, K. C. (Ed.). Plenum Press, New York. pp. 135-154.

Rodriguez, V. M., Soengas, P., Alonso-Villaverde, V. and Sotelo, T. (2015). Effect of temperature stress on the early vegetative development of *Brassica oleracea L. BMC Plant Biol.* **15**(1):145.

Rupasena, L.P. (1999). Production and marketing of vegetables, research study No. 102, HARTI, Colombo. pp. 1 –26.

Saito, M., Kato, T. and Saito, M. (1994). Effects of low temperature and shade on relationships between nodulation, vesicular-arbuscular mycorrhizal infection, and shoot growth of soybeans. *Biol. Fertil. Soils*. **17**(1): 206–211.

Sen J., Das S. P.and Ghosh G.K. (2017). Nutrient content of cauliflower (*Brassica oleracea L.var. botrytis*) as influenced by lime, boron and farmyard manure in acid soil of North Central Plateau Zone of India. *Biosci. Trends.***10**(1): 240-245.

Shanmugavelu, K.G. (1989). Production technology of vegetable crops. Oxford & IBH Publishing, New Delhi-110001, 661.

Shao, Q., Wang, H., Guo, H., Zhou, A., Huang, Y. and Sun, Y. (2014). Effects of shade treatments on photosynthetic characteristics, chloroplast ultrastructure, and physiology of *Anoectochilus roxburghii. PLOS ONE***.** **9**(2):1–10.

Sharmin, S., Mitra, S. and Rashid, M. H. (2018). Production, yield and area growth of major winter vegetables of Bangladesh. *J. Bangladesh Agric. Univ.***16**(3): 492–502.

Shewfelt, R.L. (2000). Fruit and vegetable quality. **In:** Fruit and vegetable quality: An integrated view. R.L. Shewfelt and B. Brückner (eds.). Lancaster, UK: Technomic Press. pp. 144-157.

Shih, P.Y, Shih, J.C, Chang, L.C and Lo, H.F. (2013). Physiological index for tolerance to high temperature and waterlogging in cauliflower. *Taiwan J. Soc. Hortic. Sci.* **59**(12): 191-204.

Shikata, K., Matsushita, Y., Nawata, E. and Sakuratani. T. (2003). Effect of intereropping with maize on the growth and light environment of cowpea, Japanese. *J. Trop. Agric.* **47**(1): 17-26.

Sims, D.A., Pearcy, R.W. (1994). Scaling sun and shade photosynthetic acclimation of *Alocasia macrorrhiza* (Araceae) to a transfer from low to high light. *Am. J. Bot.* **79**(8): 449–455.

Smith H. (1982). Light quality, photo perception, and plant strategy. *Annu. Rev. Plant Physiol.* **33**(1): 481–518.

Šrot, R. (2005). Zelenina – Rady pěstitelům (Vegetables - Counsels for Growers). 1st ed. Praha: Aventinum., 197 p., ISBN 80-7151-248-6.

Steinger, T., Roy, B.A. and Stanton, M.L. (2003). Evolution in stressful environments II: adaptive value and costs of plasticity in response to low light in Sinapis arvensis. *J. Evol. Biol.* 16(2): 313–323.

Taiz, L. and Zeiger, E. (2002). Plant Physiology. 3rd (ed.). Sunderland: Sinauer Associates, Inc. Publishers, Sunderland, MA, USA. pp. 67-86.

Terashima, I., Fujita, T., Inoue, T., Chow, W.S. and Oguchi, R. (2009). Green light drives leaf photosynthesis more efficiently than red light in strong white light: revisiting the enigmatic question of why leaves are green. *J. Plant Cell Physiol*. **50**(4): 684–697.

Thakur, M., Bhatt, V. and Kumar, R. (2019). Effect of shade level and mulch type on growth, yield and essential oil composition of damask rose (*Rosa damascena Mill.*) under mid hill conditions of Western Himalayas. *PLOS ONE*. **14**(4): 21-46.

Theofanoudis, S., Petropoulos, S. and Antoniadis, A. (2015). The effect of manure, zeolite and mineral fertilizer on the yield and mineral composition of cauliflower. **In:** Agrosym 2015, Sixth International Scientific Agricultural Symposium. Jahorina, pp. 1058-1062.

Thomas, D. S., Turner, D.W. and Tan, S.C. (1992). Covering cauliflower curds during growth reduces floret flavonoid sand improves quality. *N. Z. J. Crop Hortic. Sci.* **20**(2): 147-151.

Uher, A., Mezeyova, I., Hegedusova, A. and Šlosár, M. (2017). Impact of nutrition on the quality and quantity of cauliflower florets. *Potravinarstvo*. **11**(12): 113-127.

Uher, A., Šlosár, M. and Valšíková, M. (2013). Fertilisation impact on the content of selected bioactive compounds in cauliflower. *J. Cent. Eur. Agric.*,**14** (1): 261-269.

Veloso, A. C. R., Silva, P. S., Siqueira, W. K., Duarte, K. L. R., Gomes, I. L. V., Santos, H. T. and Fagundes, M. (2017). Intraspecific variation in seed size and light intensity affect seed germination and initial seedling growth of a tropical shrub. *Acta Bot. Bras*. 31(4): 736–741.

Vendrame, W., Moore, K.K., and Broschat, T.K. (2004). Interaction of light intensity and controlled release fertilization rate on growth and flowering often New Guinea impatiens cultivars. *Hortic. Technol*. **14**(4):491–495.

Venkateswarlu, B., Prasad, V.V.S.S. and Rao, A.V. (1977) Effects of low light intensity on different growth phases in rice (*Oryza sativa* L.). *Plant Soil*. **47**(3): 37–47.

Wang, W. J., Sun, X. T., Wang, G. C., Xu, P., Wang, X. Y. and Lin, Z. L. (2010). Effect of blue light on indoor seedling culture of *Saccharina japonica* (Phaeophyta*). J. Appl. Phycol.***22**(6): 737–744.

Wang, Y., Guo, Q. and Jin, M. (2009). Effects of light intensity on growth and photosynthetic characteristics of *Chrysanthemum morifolium*. *Chin. J. Chin. Mat. Med*. **34**(13): 1633-1635.

Wentworth M., Murchie E.H., Gray J.E., Villegas, D., Pastenes C., Pinto M. and Horton, P. (2006). Differential adaptation of two varieties of common bean to abiotic stress. *J. Exp. Bot.* **57**(3): 699–709.

Wheeler, R.M., Mackowiak, C.L. and Sager, J.C., (1991). Soybean stem growth under high pressure sodium with supplemental blue lighting. *J. Agron*. **83**(5): 903–906.

Wiebe, H.J. and Krug, H. (1974). Physiological problems of experiments with cauliflower in growth chambers. *Acta Hortic*. **39**(9): 105-114.

Wurr, D.C.E, Fellows, J.R and Phelps K. (1996). Investigating trends in vegetable crop response to increasing temperature associated with climate change. *Sci. Hortic.* **66**(3-4): 255-263.

Xie, Y., Kristensen, H. L. (2016). Overwintering grass-clover as intercrop and moderately reduced nitrogen fertilization maintain yield and reduce the risk of nitrate leaching in an organic cauliflower (*Brassica oleracea L. var. botrytis*) agroecosystem. *Sci. Hortic*. **206**(3): 71-79.

Yan, Q.Y., Liu, H.C., Chen, R.Y., Song, S.W. and Sun, G.W. (2011). Effect of different shading net on growth and quality of flowering of chinese cabbage. *Acta Hortic*. **907**(29): 199-203.

Yang, X.Y., Ye, X.F., Liu, G.S., Wei, H.Q. and Wang Y. (2007). Effects of light intensity on morphological and physiological characteristics of tobacco seedlings. *Chin. J. Appl. Ecol.* 18: 2642-2645.

Yasoda, P. G. C, Pradheeban, L, Nishanthan K. and Sivachandiran S. (2018). Effect of different shade levels on growth and yield performances of cauliflower. *Int. J. Environ. Agric. Biotech.***3**(3): 948-955.

Yavari, N., Tripathi, R., Wu, B.S., MacPherson, S., Singh, J. and Lefsrud, M. (2021). The effect of light quality on plant physiology, photosynthetic, and stress response in Arabidopsis thaliana leaves. *PLOS ONE*. **16**(3):267-273.

Yi-bo, W., Rui-dong, H. and Yu-fei, Z. (2021). Effects of shading stress during the reproductive stages on photosynthetic physiology and yield characteristics of peanut (*Arachis hypogaea Linn*.). *J. Integr. Agric*. **20**(5): 1250–1265.

Yoldas, F., Ceylan, S., Yagmur, B. and Mordoğan, S. N. (2008). Effects of nitrogen fertilizer on yield quality and nutrient content in broccoli. *J. Plant Nutr.* **31**(10):1333-1343.

Yuan, L., Liu, J., Cai, Z., Wang, H., Fu, J., Zhang, H., Zhang, Y., Zhu, S., Wu, W., Yan, H., Zhang, H., Li, T., Zhang, L. and Yuan, M. (2022). Shade stress on maize seedlings biomass production and photosynthetic traits. *Ciênc. Rural.* **52**(3): 34-45.

Zervoudakis, G., Salahas, G., Kaspiris G. and Konstantopoulou E. (2012). Influence of Light Intensity on Growth and Physiological Characteristics of Common Sage (*Salvia officinalis* L.) *Braz. Arch. Biol. Technol.* **55**(1): 89-95.

Zheng, L. (2010). The influence of light and temperature on the germination of *Brassica oleracea* Seed. *Plant Sci. J.* **169**(4):753-759.

Zheng, L. and Labeke, M.V. (2017). Long-term effects of red- and blue-light emitting diodes on leaf anatomy and photosynthetic efficiency of three ornamental pot plants. *Front. Plant Sci.* **8**(1):917-923.

PLATES

Plate 1: Seedling transplanting

Plate 2: Seedlings after transplanting

Plate 3: Providing shade by different layer of net on cauliflower

Plate 4: After providing shade to the cauliflower

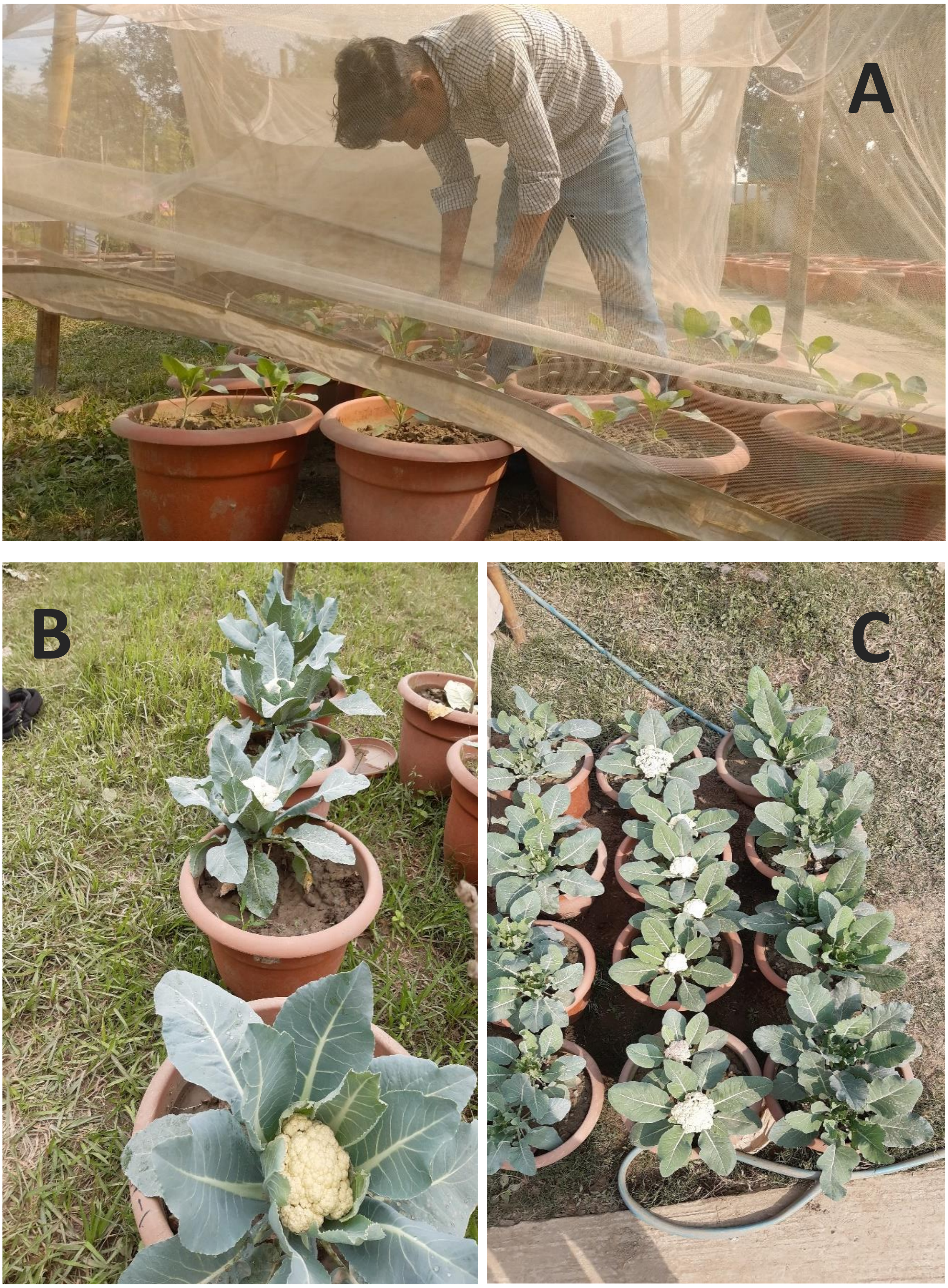


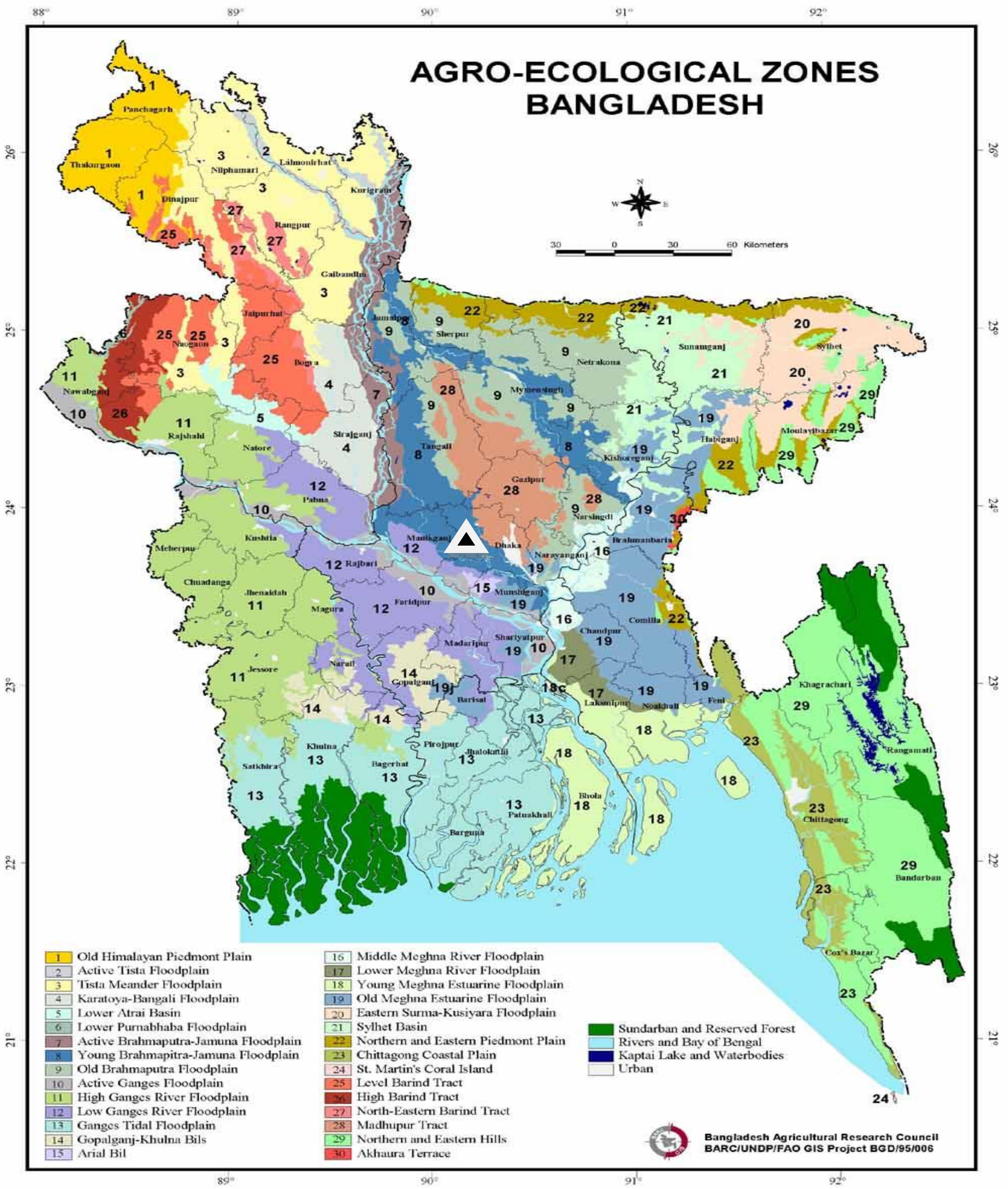
Plate 5: Intercultural operations; weeding (A) and after irrigation (B and C).

Plate 6: Measuring parameter. inside net (A); outside net (B and C)

Plate 7: Some pictures of cauliflower

APPENDICES

Appendix I. Map showing the experimental site of the study



▲ The experimental site under

Appendix II. Monthly records of air temperature, relative humidity, rainfall and sunshine hours during the period from October 2020 to March 2021.

Month	Year	Monthly average air temperature (°C)			Average relative humidity (%)	Total rainfall (mm)	Total sunshine (hours)
		Maximum	Minimum	Mean			
Oct.	2020	36	21	28	69	Trace	219
Nov.	2020	31	18	24	63	Trace	216
Dec.	2020	28	16	22	61	Trace	212
Jan.	2021	27	13	20	57	Trace	198
Feb.	2021	29	18	23	70	3	225
Mar.	2021	32	22	25	73	4	231

Source: Bangladesh Meteorological Department (Climate division), Agargaon Dhaka-1212.

Appendix III. The mechanical and chemical characteristics of soil of the experimental site as observed prior to experimentation (0 -15 cm depth).

Mechanical composition:

Particle size	**Constitution**
Texture	Loamy
Sand	40%
Silt	40%
Clay	20%

Chemical composition:

Soil characters	**Value**
Organic matter	1.44 %
Potassium	0.15 meq/100 g soil
Calcium	1.00 meq/100 g soil
Magnesium	1.00 meq/100 g soil
Total nitrogen	0.072
Phosphorus	22.08 μg/g soil
Sulphur	25.98 μg/g soil
Boron	0.48 μg/g soi
Copper	3.54 μg/g soil
Iron	262.6 μg/g soil
Manganese	164 μg/g soil
Zinc	3.32 μg/g soil

Source: Soil Resources Development Institute (SRDI), Khamarbari, Dhaka

Appendix IV. All values of different growth and yield contributing characters of three cauliflower varieties under control and low light stress treatment with mean and SD

Plant height 3 WAT

	Mean	**SD**
V_1S_0	14.73	0.31
V_1S_1	13.57	0.40
V_1S_2	12.97	0.25
V_1S_3	12.20	0.46
V_2S_0	14.50	0.36
V_2S_1	14.03	0.15
V_2S_2	13.57	0.21
V_2S_3	13.13	0.15
V_3S_0	15.57	0.32
V_3S_1	14.53	0.40
V_3S_2	13.57	0.35
V_3S_3	12.53	0.35

S_0: Control; S_1: 75% light intensity; S_2: 50% light intensity; S_3: 25% light intensity

Plant height 5 WAT

	Mean	**SD**
V_1S_0	21.4	0.35
V_1S_1	19.6	0.45
V_1S_2	18.4	0.45
V_1S_3	17.4	0.56
V_2S_0	20.4	0.75
V_2S_1	20.2	0.50
V_2S_2	19.4	0.60
V_2S_3	18.8	0.53
V_3S_0	24.5	0.75
V_3S_1	21.8	0.50
V_3S_2	20.6	0.60
V_3S_3	18.5	0.53

S_0: Control; S_1: 75% light intensity; S_2: 50% light intensity; S_3: 25% light intensity

Plant height 7 WAT

	Mean	SD
V_1S_0	24.57	1.00
V_1S_1	23.87	1.19
V_1S_2	23.07	0.57
V_1S_3	22.63	0.72
V_2S_0	23.70	0.72
V_2S_1	23.60	0.87
V_2S_2	23.20	0.56
V_2S_3	23.03	0.50
V_3S_0	25.47	0.35
V_3S_1	23.83	1.02
V_3S_2	22.70	1.35
V_3S_3	22.17	0.95

S_0: Control; S_1: 75% light intensity; S_2: 50% light intensity; S_3: 25% light intensity

Plant height 9 WAT

	Mean	SD
V_1S_0	28.20	1.28
V_1S_1	26.57	1.11
V_1S_2	25.30	1.01
V_1S_3	24.73	0.80
V_2S_0	26.60	0.50
V_2S_1	25.63	0.76
V_2S_2	24.90	0.70
V_2S_3	23.80	0.10
V_3S_0	29.30	0.36
V_3S_1	27.53	1.15
V_3S_2	26.83	1.52
V_3S_3	24.63	1.12

S_0: Control; S_1: 75% light intensity; S_2: 50% light intensity; S_3: 25% light intensity

Plant height 11 WAT

	Mean	SD
V_1S_0	31.40	1.01
V_1S_1	28.60	1.71
V_1S_2	27.20	1.32
V_1S_3	25.67	1.03
V_2S_0	29.43	1.42
V_2S_1	28.40	0.66
V_2S_2	27.50	0.61
V_2S_3	26.20	0.56
V_3S_0	35.43	0.93
V_3S_1	30.83	0.60
V_3S_2	28.40	1.42
V_3S_3	27.17	1.24

S_0: Control; S_1: 75% light intensity; S_2: 50% light intensity; S_3: 25% light intensity

Leaf Number 3 WAT

	Mean	SD
V_1S_0	6.67	0.58
V_1S_1	6.00	0.00
V_1S_2	5.33	0.58
V_1S_3	4.67	0.58
V_2S_0	6.33	0.58
V_2S_1	6.00	0.00
V_2S_2	5.67	0.58
V_2S_3	5.00	0.00
V_3S_0	7.33	0.58
V_3S_1	6.33	0.58
V_3S_2	5.33	0.58
V_3S_3	5.00	0.00

S_0: Control; S_1: 75% light intensity; S_2: 50% light intensity; S_3: 25% light intensity

Leaf Number 5 WAT

	Mean	SD
V_1S_0	10.33	0.58
V_1S_1	9.33	0.58
V_1S_2	8.67	0.58
V_1S_3	8.33	0.58
V_2S_0	9.33	0.58
V_2S_1	8.67	0.58
V_2S_2	8.33	0.58
V_2S_3	7.67	0.58
V_3S_0	10.67	0.58
V_3S_1	9.67	0.58
V_3S_2	8.33	0.58
V_3S_3	6.67	0.58

S_0: Control; S_1: 75% light intensity; S_2: 50% light intensity; S_3: 25% light intensity

Leaf Number 7 WAT

	Mean	SD
V_1S_0	12.67	0.58
V_1S_1	11.33	0.58
V_1S_2	10.33	0.58
V_1S_3	9.33	0.58
V_2S_0	11.67	0.58
V_2S_1	10.67	0.58
V_2S_2	9.67	0.58
V_2S_3	9.33	0.58
V_3S_0	13.33	0.58
V_3S_1	11.33	0.58
V_3S_2	9.67	0.58
V_3S_3	8.67	0.58

S_0: Control; S_1: 75% light intensity; S_2: 50% light intensity; S_3: 25% light intensity

Leaf Number 9 WAT

	Mean	SD
V_1S_0	15.00	1.00
V_1S_1	13.00	1.00
V_1S_2	11.33	0.58
V_1S_3	9.33	0.58
V_2S_0	13.33	0.58
V_2S_1	12.00	1.00
V_2S_2	10.67	0.58
V_2S_3	9.33	0.58
V_3S_0	15.67	0.58
V_3S_1	13.00	1.00
V_3S_2	10.67	0.58
V_3S_3	9.67	0.58

S_0: Control; S_1: 75% light intensity; S_2: 50% light intensity; S_3: 25% light intensity

Leaf Number 11 WAT

	Mean	SD
V_1S_0	17.67	0.58
V_1S_1	14.67	0.58
V_1S_2	13.33	0.58
V_1S_3	9.33	0.58
V_2S_0	15.67	0.58
V_2S_1	13.67	0.58
V_2S_2	11.67	0.58
V_2S_3	9.67	0.58
V_3S_0	18.67	0.58
V_3S_1	15.33	0.58
V_3S_2	12.33	0.58
V_3S_3	9.67	0.58

S_0: Control; S_1: 75% light intensity; S_2: 50% light intensity; S_3: 25% light intensity

Leaf Length 3 WAT

	Mean	SD
V_1S_0	6.17	0.31
V_1S_1	5.80	0.36
V_1S_2	5.57	0.31
V_1S_3	4.87	0.25
V_2S_0	5.57	0.21
V_2S_1	5.23	0.15
V_2S_2	5.00	0.17
V_2S_3	4.70	0.20
V_3S_0	6.73	0.31
V_3S_1	6.23	0.25
V_3S_2	5.40	0.36
V_3S_3	5.20	0.26

S_0: Control; S_1: 75% light intensity; S_2: 50% light intensity; S_3: 25% light intensity

Leaf Length 5 WAT

	Mean	SD
V_1S_0	8.97	0.55
V_1S_1	8.50	0.50
V_1S_2	7.67	0.90
V_1S_3	6.67	0.32
V_2S_0	8.17	0.21
V_2S_1	7.60	0.26
V_2S_2	6.93	0.23
V_2S_3	6.83	0.31
V_3S_0	9.53	0.45
V_3S_1	9.10	0.40
V_3S_2	8.27	0.45
V_3S_3	7.70	0.44

S_0: Control; S_1: 75% light intensity; S_2: 50% light intensity; S_3: 25% light intensity

Leaf Length 7 WAT

	Mean	SD
V_1S_0	11.57	0.32
V_1S_1	10.53	0.64
V_1S_2	9.23	0.38
V_1S_3	7.87	0.06
V_2S_0	9.90	0.36
V_2S_1	8.67	0.29
V_2S_2	7.73	0.21
V_2S_3	7.37	0.21
V_3S_0	12.23	0.68
V_3S_1	10.20	0.53
V_3S_2	8.70	0.44
V_3S_3	8.03	0.06

S_0: Control; S_1: 75% light intensity; S_2: 50% light intensity; S_3: 25% light intensity

Leaf Length 9 WAT

	Mean	SD
V_1S_0	13.47	0.76
V_1S_1	11.67	0.61
V_1S_2	10.43	0.40
V_1S_3	8.50	0.30
V_2S_0	11.87	0.12
V_2S_1	10.90	0.10
V_2S_2	9.63	0.38
V_2S_3	8.23	0.25
V_3S_0	13.97	0.57
V_3S_1	11.07	0.81
V_3S_2	9.33	0.57
V_3S_3	8.57	0.42

S_0: Control; S_1: 75% light intensity; S_2: 50% light intensity; S_3: 25% light intensity

Leaf Length 11 WAT

	Mean	SD
V_1S_0	14.50	0.70
V_1S_1	12.57	0.95
V_1S_2	10.87	0.81
V_1S_3	9.20	0.89
V_2S_0	13.03	0.47
V_2S_1	11.47	0.31
V_2S_2	9.47	0.31
V_2S_3	9.07	0.12
V_3S_0	15.00	0.20
V_3S_1	12.67	0.35
V_3S_2	10.07	0.50
V_3S_3	9.37	0.35

S_0: Control; S_1: 75% light intensity; S_2: 50% light intensity; S_3: 25% light intensity

Leaf Width 3 WAT

	Mean	SD
V_1S_0	4.37	0.15
V_1S_1	3.93	0.15
V_1S_2	3.47	0.35
V_1S_3	2.87	0.42
V_2S_0	4.07	0.06
V_2S_1	3.60	0.10
V_2S_2	3.20	0.10
V_2S_3	2.97	0.15
V_3S_0	4.53	0.35
V_3S_1	3.77	0.25
V_3S_2	2.90	0.20
V_3S_3	2.33	0.15

S_0: Control; S_1: 75% light intensity; S_2: 50% light intensity; S_3: 25% light intensity

Leaf Width 5 WAT

	Mean	SD
V_1S_0	5.80	0.10
V_1S_1	5.17	0.15
V_1S_2	4.60	0.20
V_1S_3	3.83	0.06
V_2S_0	5.03	0.21
V_2S_1	4.60	0.10
V_2S_2	3.97	0.15
V_2S_3	3.67	0.12
V_3S_0	6.27	0.25
V_3S_1	5.17	0.15
V_3S_2	4.60	0.17
V_3S_3	4.17	0.15

S_0: Control; S_1: 75% light intensity; S_2: 50% light intensity; S_3: 25% light intensity

Leaf Width 7 WAT

	Mean	SD
V_1S_0	6.40	0.17
V_1S_1	5.93	0.25
V_1S_2	5.23	0.25
V_1S_3	4.60	0.10
V_2S_0	6.13	0.12
V_2S_1	5.93	0.25
V_2S_2	5.47	0.21
V_2S_3	5.20	0.10
V_3S_0	6.80	0.20
V_3S_1	6.23	0.21
V_3S_2	5.77	0.25
V_3S_3	4.87	0.21

S_0: Control; S_1: 75% light intensity; S_2: 50% light intensity; S_3: 25% light intensity

Leaf Width 9 WAT

	Mean	SD
V_1S_0	8.07	0.25
V_1S_1	7.50	0.20
V_1S_2	6.67	0.25
V_1S_3	5.97	0.21
V_2S_0	7.63	0.21
V_2S_1	7.03	0.12
V_2S_2	6.63	0.21
V_2S_3	6.07	0.21
V_3S_0	8.80	0.10
V_3S_1	7.63	0.15
V_3S_2	7.17	0.15
V_3S_3	6.53	0.15

S_0: Control; S_1: 75% light intensity; S_2: 50% light intensity; S_3: 25% light intensity

Leaf Width 11 WAT

	Mean	SD
V_1S_0	8.63	0.21
V_1S_1	7.90	0.10
V_1S_2	7.23	0.15
V_1S_3	6.43	0.31
V_2S_0	8.03	0.15
V_2S_1	7.50	0.30
V_2S_2	6.97	0.25
V_2S_3	6.57	0.35
V_3S_0	9.23	0.25
V_3S_1	8.30	0.17
V_3S_2	7.30	0.44
V_3S_3	6.57	0.12

S_0: Control; S_1: 75% light intensity; S_2: 50% light intensity; S_3: 25% light intensity

Girth of the Main Stem

	Mean	SD
V_1S_0	3.10	0.10
V_1S_1	2.70	0.10
V_1S_2	2.53	0.06
V_1S_3	2.33	0.15
V_2S_0	2.87	0.06
V_2S_1	2.60	0.10
V_2S_2	2.47	0.15
V_2S_3	2.37	0.06
V_3S_0	3.27	0.12
V_3S_1	2.80	0.10
V_3S_2	2.47	0.06
V_3S_3	2.23	0.31

S_0: Control; S_1: 75% light intensity; S_2: 50% light intensity; S_3: 25% light intensity

Dry Matter Weight (g)

	Mean	SD
V_1S_0	29.33	0.58
V_1S_1	26.67	0.58
V_1S_2	24.33	0.58
V_1S_3	21.00	1.00
V_2S_0	29.67	0.58
V_2S_1	27.33	0.58
V_2S_2	25.00	1.00
V_2S_3	22.67	0.58
V_3S_0	33.67	0.58
V_3S_1	29.67	0.58
V_3S_2	27.67	0.58
V_3S_3	22.33	0.58

S_0: Control; S_1: 75% light intensity; S_2: 50% light intensity; S_3: 25% light intensity

Flowering Dates (DAS)

	Mean	SD
V_1S_0	54.67	1.53
V_1S_1	57.67	0.58
V_1S_2	59.00	1.00
V_1S_3	62.00	1.00
V_2S_0	50.33	1.53
V_2S_1	54.33	1.15
V_2S_2	57.67	0.58
V_2S_3	59.33	1.15
V_3S_0	54.00	1.00
V_3S_1	58.33	1.53
V_3S_2	63.33	1.53
V_3S_3	64.67	1.15

S_0: Control; S_1: 75% light intensity; S_2: 50% light intensity; S_3: 25% light intensity

Fresh Shoot Weight (g)

	Mean	SD
V_1S_0	306.00	5.29
V_1S_1	271.00	11.27
V_1S_2	257.00	9.54
V_1S_3	218.67	7.64
V_2S_0	273.00	15.72
V_2S_1	246.00	8.54
V_2S_2	224.00	6.00
V_2S_3	207.00	2.65
V_3S_0	319.33	5.86
V_3S_1	278.33	8.74
V_3S_2	244.67	5.03
V_3S_3	206.67	5.03

S_0: Control; S_1: 75% light intensity; S_2: 50% light intensity; S_3: 25% light intensity

Fresh Root Weight (g)

	Mean	SD
V_1S_0	11.70	0.50
V_1S_1	10.67	0.42
V_1S_2	9.27	0.50
V_1S_3	8.63	0.40
V_2S_0	10.33	0.42
V_2S_1	9.77	0.31
V_2S_2	8.73	0.25
V_2S_3	7.93	0.15
V_3S_0	9.83	0.35
V_3S_1	8.40	0.36
V_3S_2	7.73	0.25
V_3S_3	6.77	0.23

S_0: Control; S_1: 75% light intensity; S_2: 50% light intensity; S_3: 25% light intensity

SPAD Value

	Mean	SD
V_1S_0	66.00	1.00
V_1S_1	64.00	1.73
V_1S_2	59.67	1.53
V_1S_3	53.00	1.00
V_2S_0	64.00	1.00
V_2S_1	62.00	1.00
V_2S_2	58.00	1.00
V_2S_3	53.33	0.58
V_3S_0	67.33	1.15
V_3S_1	62.33	0.58
V_3S_2	56.00	1.00
V_3S_3	49.00	1.00

S_0: Control; S_1: 75% light intensity; S_2: 50% light intensity; S_3: 25% light intensity

Appendix V. Anova for all values of three cauliflower varieties under control and low light stress treatment.

Factorial ANOVA Table for Plant height at 3 WAT

Source	DF	SS	MS	F	P
Replication	2	0.2717	0.13583		
Variety	2	2.8817	1.44083	14.06	0.0001
Treatment	3	26.1497	8.71657	85.04	0.0000
Variety*Treatment	6	2.4694	0.41157	4.02	0.0073
Error	22	2.2550	0.10250		
Total	35	34.0275			

Grand Mean: 13.742

CV: 2.33

Factorial ANOVA Table for Plant height at 5 WAT

Source	DF	SS	MS	F	P
Replication	2	4.901	2.4503		
Variety	2	28.764	14.3819	59.56	0.0000
Treatment	3	85.603	28.5344	118.18	0.0000
Variety*Treatment	6	12.429	2.0716	8.58	0.0001
Error	22	5.313	0.2415		
Total	35	137.010			

Grand Mean: 19.953

CV: 2.46

Factorial ANOVA Table for Plant height at 7 WAT

Source	DF	SS	MS	F	P
Replication	2	10.5839	5.29194		
Variety	2	0.1906	0.09528	0.28	0.7557
Treatment	3	20.5497	6.84991	20.39	0.0000
Variety*Treatment	6	6.1494	1.02491	3.05	0.0251
Error	22	7.3894	0.33588		
Total	35	44.8631			

Grand Mean: 23.486

CV: 2.47

Factorial ANOVA Table for Plant height at 9 WAT

Source	DF	SS	MS	F	P
Replication	2	6.167	3.0833		
Variety	2	6.167	3.0833	9.47	0.0011
Treatment	3	137.639	45.8796	140.84	0.0000
Variety*Treatment	6	5.611	0.9352	2.87	0.0321
Error	22	7.167	0.3258		
Total	35	162.750			

Grand Mean: 11.917

CV: 4.79

Factorial ANOVA Table for Plant height at 11 WAT

Source	DF	SS	MS	F	P
Replication	2	19.091	9.5453		
Variety	2	17.067	23.5336	50.55	0.0000
Treatment	3	164.463	54.8210	117.75	0.0000
Variety*Treatment	6	25.826	4.3044	9.25	0.0000
Error	22	10.243	0.4656		
Total	35	266.690			

Grand Mean: 28.853

CV: 2.36

Factorial ANOVA Table for Leaf Number at 3 WAT

Source	DF	SS	MS	F	P
Replication	2	0.8889	0.44444		
Variety	2	0.7222	0.36111	1.79	0.1908
Treatment	3	18.0833	6.02778	29.84	0.0000
Variety*Treatment	6	1.5000	0.25000	1.24	0.3256
Error	22	4.4444	0.20202		
Total	35	25.6389			

Grand Mean: 5.8056

CV: 7.74

Factorial ANOVA Table for Leaf Number at 5 WAT

Source	DF	SS	MS	F	P
Replication	2	2.0000	1.0000		
Variety	2	2.6667	1.3333	4.89	0.0175
Treatment	3	32.1111	10.7037	39.35	0.0000
Variety*Treatment	6	6.2222	1.0370	3.80	0.0095
Error	22	6.0000	0.2727		
Total	35	49.0000			

Grand Mean: 8.8333

CV: 5.91

Factorial ANOVA Table for Leaf Number at 7 WAT

Source	DF	SS	MS	F	P
Replication	2	2.0000	1.0000		
Variety	2	2.1667	1.0833	3.97	0.0337
Treatment	3	61.1111	20.3704	74.69	0.0000
Variety*Treatment	6	4.7222	0.7870	2.89	0.0314
Error	22	6.0000	0.2727		
Total	35	76.0000			

Grand Mean: 10.667

CV: 4.90

Factorial ANOVA Table for Leaf Number at 9 WAT

Source	DF	SS	MS	F	P
Replication	2	6.167	3.0833		
Variety	2	6.167	3.0833	9.47	0.0011
Treatment	3	137.639	45.8796	140.84	0.0000
Variety*Treatment	6	5.611	0.9352	2.87	0.0321
Error	22	7.167	0.3258		
Total	35	162.750			

Grand Mean: 11.917

CV: 4.79

Factorial ANOVA Table for Leaf Number at 11 WAT

Source	DF	SS	MS	F	P
Replication	2	1.056	0.5278		
Variety	2	12.056	6.0278	19.10	0.0000
Treatment	3	292.306	97.4352	308.67	0.0000
Variety*Treatment	6	10.611	1.7685	5.60	0.0012
Error	22	6.944	0.3157		
Total	35	322.972			

Grand Mean: 13.472

CV: 4.17

Factorial ANOVA Table for Leaf Length at 3 WAT

Source	DF	SS	MS	F	P
Replication	2	1.2772	0.63861		
Variety	2	3.5939	1.79694	84.21	0.0000
Treatment	3	7.6900	2.56333	120.13	0.0000
Variety*Treatment	6	0.8550	0.14250	6.68	0.0004
Error	22	0.4694	0.02134		
Total	35	13.8856			

Grand Mean: 5.5389

CV: 2.64

Factorial ANOVA Table for Leaf Length at 5 WAT

Source	DF	SS	MS	F	P
Replication	2	3.4539	1.72694		
Variety	2	9.6622	4.83111	70.88	0.0000
Treatment	3	17.6744	5.89148	86.44	0.0000
Variety*Treatment	6	1.1089	0.18481	2.71	0.0399
Error	22	1.4994	0.06816		
Total	35	33.3989			

Grand Mean: 7.9944

CV: 3.27

Factorial ANOVA Table for Leaf Length at 7 WAT

Source	DF	SS	MS	F	P
Replication	2	0.7039	0.3519		
Variety	2	15.2172	7.6086	54.06	0.0000
Treatment	3	62.2986	20.7662	147.56	0.0000
Variety*Treatment	6	3.5872	0.5979	4.25	0.0055
Error	22	3.0961	0.1407		
Total	35	84.9031			

Grand Mean: 9.3361

CV: 4.02

Factorial ANOVA Table for Leaf Length at 9 WAT

Source	DF	SS	MS	F	P
Replication	2	2.147	1.0869		
Variety	2	4.591	2.2953	13.90	0.0001
Treatment	3	107.574	35.8581	217.16	0.0000
Variety*Treatment	6	5.732	0.9553	5.79	0.0000
Error	22	3.633	0.1651		
Total	35	123.703			

Grand Mean: 10.636

CV: 3.82

Factorial ANOVA Table for Leaf Length at 11 WAT

Source	DF	SS	MS	F	P
Replication	2	3.777	1.8886		
Variety	2	8.337	4.1686	23.99	0.0000
Treatment	3	133.201	44.4004	255.52	0.0000
Variety*Treatment	6	3.687	0.6145	3.54	0.0133
Error	22	3.823	0.1738		
Total	35	152.826			

Grand Mean: 11.439

CV: 3.64

Factorial ANOVA Table for Leaf Width at 3 WAT

Source	DF	SS	MS	F	P
Replication	2	0.8150	0.40750		
Variety	2	0.4850	0.24250	11.47	0.0004
Treatment	3	13.0400	4.34667	205.65	0.0000
Variety*Treatment	6	1.1950	0.19917	9.42	0.0000
Error	22	0.4650	0.02114		
Total	35	0.02114			

Grand Mean: 3.5000

CV: 4.15

Factorial ANOVA Table for Leaf Width at 5 WAT

Source	DF	SS	MS	F	P
Replication	2	0.1089	0.05444		
Variety	2	3.4489	1.72444	75.21	0.0000
Treatment	3	16.4322	5.47741	238.88	0.0000
Variety*Treatment	6	0.7111	0.11852	5.71	0.0019
Error	22	0.5044	0.02293		
Total	35	21.2056			

Grand Mean: 4.7389

CV: 3.20

Factorial ANOVA Table for Leaf Width at 7 WAT

Source	DF	SS	MS	F	P
Replication	2	0.5772	0.28861		
Variety	2	0.8606	0.43028	23.90	0.0000
Treatment	3	12.3031	4.10102	227.77	0.0000
Variety*Treatment	6	0.9661	0.16102	8.94	0.0001
Error	22	0.3961	0.01801		
Total	35	15.1031			

Grand Mean: 5.7139

CV: 2.35

Factorial ANOVA Table for Leaf Width at 9 WAT

Source	DF	SS	MS	F	P
Replication	2	0.1667	0.08333		
Variety	2	3.0217	1.51083	47.48	0.0000
Treatment	3	19.0942	6.36472	200.03	0.0000
Variety*Treatment	6	0.7450	0.12417	3.90	0.0083
Error	22	0.7000	0.03182		
Total	35	23.7275			

Grand Mean: 7.1417

CV: 2.50

Factorial ANOVA Table for Leaf Width at 11 WAT

Source	DF	SS	MS	F	P
Replication	2	0.6156	0.30778		
Variety	2	2.0422	1.02111	24.48	0.0000
Treatment	3	22.4933	7.49778	179.73	0.0000
Variety*Treatment	6	1.3000	0.21667	5.19	0.0018
Error	22	0.9178	0.04172		
Total	35	27.3689			

Grand Mean: 7.5556

CV: 2.70

Factorial ANOVA Table for Fresh Shoot Weight

Source	DF	SS	MS	F	P
Replication	2	368.2	184.1		
Variety	2	5088.7	2544.4	43.42	0.0000
Treatment	3	37828.1	12609.4	215.19	0.0000
Variety*Treatment	6	1997.5	332.9	5.68	0.0011
Error	22	1289.1	58.6		
Total	35	46571.6			

Grand Mean: 254.31

CV: 3.01

Factorial ANOVA Table for Fresh Root Weight

Source	DF	SS	MS	F	P
Replication	2	1.8939	0.9469		
Variety	2	21.3172	10.6586	190.21	0.0000
Treatment	3	41.3142	13.7714	245.76	0.0000
Variety*Treatment	6	1.0717	0.1786	3.19	0.0209
Error	22	1.2328	0.0560		
Total	35	66.8297			

Grand Mean: 9.1472

CV: 2.59

Factorial ANOVA Table for Dry Matter Weight

Source	DF	SS	MS	F	P
Replication	2	2.722	1.361		
Variety	2	57.556	28.778	79.69	0.0000
Treatment	3	378.778	126.259	349.64	0.0000
Variety*Treatment	6	15.556	2.593	7.18	0.0002
Error	22	7.944	0.361		
Total	35	462.556			

Grand Mean: 26.611

CV: 2.26

Factorial ANOVA Table for Stem Diameter

Source	DF	SS	MS	F	P
Replication	2	0.16222	0.08111		
Variety	2	0.09056	0.04528	3.97	0.0338
Treatment	3	2.93556	0.97852	85.73	0.0000
Variety*Treatment	6	0.24944	0.04157	3.68	0.0116
Error	22	0.25111	0.01141		
Total	35	3.68889			

Grand Mean: 2.6444

CV: 4.04

Factorial ANOVA Table for SPAD Value

Source	DF	SS	MS	F	P
Replication	2	0.72	0.361		
Variety	2	24.89	12.444	9.80	0.0009
Treatment	3	1011.33	337.111	265.40	0.0000
Variety*Treatment	6	54.00	9.000	7.90	0.0003
Error	22	27.94	1.270		
Total	35	1118.89			

Grand Mean: 59.556

CV: 1.89

Factorial ANOVA Table for Flowering Dates

Source	DF	SS	MS	F	P
Replication	2	7.389	3.694		
Variety	2	133.389	66.694	55.14	0.0000
Treatment	3	418.333	139.444	115.28	0.0000
Variety*Treatment	6	22.167	3.694	3.05	0.0250
Error	22	26.611	1.210		
Total	35	607.889			

Grand Mean: 57.944

CV: 1.90