REPRODUCTIVE FITNESS AND PHENOLOGY RESPONSES OF SAU PERILLA-1 TO GROWING DEGREE DAYS OBSERVED ON DIFFERENT TRANSPLANTING DATES

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A THESIS

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CERTIFICATE

*This is to certify that thesis paper entitled "***REPRODUCTIVE FITNESS AND PHENOLOGY RESPONSES OF SAU PERILLA-1 TO GROWING DEGREE DAYS OBSERVED ON DIFFERENT TRANSPLANTING DATES"** *submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University (SAU), Dhaka in partial fulfillment of the requirements for the degree of* ***MASTER OF SCIENCE IN AGRONOMY****, embodies the result of a piece of bona fide research work carried out by* ***JANNATUL FEROUS KATHA*** *Registration no****. 20-11080*** *under my supervision and guidance. No part of the dissertation has been submitted for any other degree or diploma.*

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

Dated: June, 2022
Dhaka, Bangladesh

(Prof. Dr. H.M.M. Tariq Hossain)
Supervisor

Dedicated To Beloved My Parents And Respected Teachers Whose Prayers, Efforts, And Wishes Are an Inspiration

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REPRODUCTIVE FITNESS AND PHENOLOGY RESPONSES OF SAU PERILLA-1 TO GROWING DEGREE DAYS OBSERVED ON DIFFERENT TRANSPLANTING DATES

Abstract

SAU Perilla-1 (Golden Perilla BD) is a latest oil crop variety enriched with Omega-3 fatty acid, which is introduced by Sher-e-Bangla Agricultural University in 2021. The seed contains ~40% edible oil and is recommended for growing in *Kharif-2* season when no oil crop is grown in Bangladesh. However, for *Robi* seasonal trail, the crop was sown on 21 November (D_1), 28 November (D_2), 05 December (D_3), and 12 December (D_4) with 40 cm × 40 cm (S_1), 40 cm × 30 cm (S_2), and 40 cm × 20cm (S_3) planting configurations maintained in each of the dates. The research was aimed mainly on thermal effects on phenological parameters (germination, flowering and biological yields) as evaluated by the Growing Degree Days (GDD) and Heat Use Efficiency (HUE) over stover yield and grain yield of SAU Perilla-1. The results revealed that sowing dates had significant effect on the yield variations as evaluated by the studied parameters of the crop. However, D_2 showed the uppermost level of seed weight per plant. The highest seed weight per plant was recorded due to the effect of S_3 and that of the value touched at the bottom for S_2. The maximum seed weight was recorded in D_2S_3 and that of the lowest was found in D_4S_3. The GDD values increased with increasing days to germination of seeds. Sowing date strongly influenced the GDD requirement for germination of SAU Perilla-1. When the crop was sown on D_1, 75 days were needed accumulating 1670.4 °F for flowering of the crop. The GDD requirement was highest (1802°F**)** in D_4 sowing treatment, when 82 days were required to initiate flowering. The GDD requirement declined as sown on D_2 and D_3 dates. The results indicated that the variation in temperature prevailed under different dates of sowing. HUE was higher in producing stover plant when sown on 21st November (D_1) with second highest grain production (4.10 mg/plant//°F/Day). Contrary to that the highest HUE for grain (8.13 mg/plant//°F/Day) was yielded in D_2 sowing date although the stover production was reduced from that of D_1 treatment found. When sowing is delayed, either of grain and stover synthesis were lowered down as found in D_3 and D_4 treatments.

Key words: SAU Perilla-1, Sowing dates, Spacing, GDD and HUE

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LIST OF ABBREVIATIONS

AEZ	Agro-Ecological Zone
AIS	Agriculture Information Service
Anon.	Anonymous
BARC	Bangladesh Agricultural Research Council
BARI	Bangladesh Agricultural Research Institute
BBS	Bangladesh Bureau of Statistics
BINA	Bangladesh Institute of Nuclear Agriculture
BNNC	Bangladesh National Nutrition Council
CV %	Percent of Coefficient of Variance
cv.	Cultivar (s)
DAS	Days After Sowing
eds.	Editors
et al.	et alii (and others)
etc.	et cetera (and other similar things)
FAO	Food and Agriculture Organization
GDD	Growing Degree days
HI	Harvest Index
LSD	Least Significant Difference
MOP	Muriate of Potash
NPTs	New Plant Types
SAU	Sher-e-Bangla Agricultural University
SRDI	Soil Resources and Development Institute
TDM	Total Dry Matter
TSP	Triple Super Phosphate
UNDP	United Nations Development Programme
var.	Variety
viz.	Namely

CHAPTER I

INTRODUCTION

SAU Perilla-1 (Golden Perilla BD) (*Perilla frutescens*) has been Bangladesh's newly introduced oil crop variety since 2020. The crop is photosensitive and is recommended as an annual oil-yielding crop in Bangladesh. Although this variety is native to the Republic of Korea, it is also widely distributed and cultivated in Southeast and East Asia (Makino, 1961; Asif, 2011), the USA, and the European Nations (Nitta et al., 2003) of the globe. However, the crop is suitable for cultivation in Kharif 2 seasons (Mid- July to Mid-November) and can be cultivated as a year-round crop in Bangladesh. The crop shows its blooming during the last week of September to the first week of October. The matured seeds worth 1.00-1.50 t ha^{-1} could easily be harvested by (100-110) days prior to starting preparation for upcoming winter cropping provided the seedlings (30 days old) are transplanted by the middle of August. Perilla is a short-statured plant with slow vegetative growth following the induction of flowers at the end of September in Bangladesh. Wada and Totsuka (1982) also reported that the perilla becomes photosensitive at the fourth leaf pair stage and starts 18-20 days after starting long nights.

However, the crop sown on different sowing dates exposed to a variety of weather conditions affects phonological stages with growth rate and yield. Among them, the temperature is one of the important weather parameters influencing the phenology and yield of crops (Bishnoi et al., 1995). Generally, plants require a specific amount of heat to maintain their different stages of a life cycle, such as from seedling to the four-leaf stage. The warm days advance plant and insect growth rapidly. Due to the very close relationship between temperature and plant development, agro-meteorological indices like growing degree-days (GDD) and heat use deficiency (HUE) are frequently used as indicators for crop development evaluation and was found to be useful as an input in crop growth studies (Rao *et al*., 1999; Hari Ram *et al*.,2012). Growing degree days is a way of assigning a heat value to each day.

The values are added together to estimate the amount of seasonal growth of plants resulting in ‘’ Thermal time” more consistently predicting when a certain plant stage will occur.

These thermal times are sometimes referred to as a “Thermal Calendar”. However, calendar days can be misleading, due to climatic variations, especially in early crop growth stages. For example, a cool environment delays a plant reaching the four-leaf stage, which affects optimal weed control tactics. Research has shown that measuring the heat accumulated over time provides a more accurate count of calendar days. As such, it is an urgent need to investigate the impact of temperature, particularly of GDD on reproductive fitness and phenology responses of SAU perilla-1. Therefore, the cropping duration would be optimized as per the performance of the physiological parameters generated through the replicated trials on different sowing times during the stipulated period of SAU perilla-1 induces flowers during long nights. Early August is the best time for planting perilla as it can be harvest by the end of October, after which the land can be used for producing winter and summer crops. Through this experiment we want to explore that how the yield of perilla response at late sowing of November and December.

The objectives may be considered under study-

1. To study the GDD effects on flowering and fruiting fitness and phenology responses of SAU Perilla - 1.
2. To optimize the sowing time for yield maximization of SAU Perilla - 1 on the basis of heat use efficiency (HUE) and the GDD levels accumulated within the stipulated season in Bangladesh.

CHAPTER II

REVIEW OF LITERATURE

This chapter deals with the review of past researchers related to this investigation. In spite of the sincere effort, adequate numbers of directly related works of literature were not that much available for this study. The literature was arranged in a section wise. However, the kinds of literature of available studies have been briefly discussed in this chapter followed by a conceptual framework of the study.

2.1 General study on Perilla

Dhyani *et al*., (2019) found that *Perilla frutescens* is an annual herb belonging to the mint family (Lamiaceae) which is majorly produced in countries like China, Japan, India, Thailand, and Korea.

Meng *et al*., (2008) revealed that various cultivars of *Perilla frutescens* were easily differentiated on the basis of their foliage color which varied from red to green.

Yu *et al*., (2017) stated that *Perilla frutescens* a worldwide distributed plant that is an important economic crop and the plant of Perilla is also traditionally used as a medicinal herb such as an anti-microbial, anti-allergic, anti-inflammatory, antioxidant, anticancer, anti-microbial, anti-depressive and anti-cough effect.

Ahmed *et al*., (2018) narrated that Perilla has traditionally been prescribed to treat depression-related disease, anxiety, asthma, chest stuffiness, vomiting, coughs, colds, flues, phlegm, tumors, allergies, intoxication, fever, headache, stuffy nose, constipation, abdominal pain, and indigestion.

Ahmed *et al*., (2018) revealed that 271 natural molecules have been identified in perilla organs including phenolic acids, flavonoids, essential oils, triterpenes, carotenoids, phytosterols, fatty acids, tocopherols, and policosanols. Individual compounds like rosmarinic acid, perillaldehyde, luteolin, apigenin, tormentic acids have attracted researchers' interest for their pharmacological properties.

Makino *et al*., (2003) informed that the leaves of *Perilla frutescens* are one of the most popular garnishes in Japan, used as an antidote for fish and crab meat allergies or as a food colorant. Perilla and rosmarinic acid are potentially promising agents for the treatment of allergic diseases.

2.2 Oil quality of Perilla

Longvah *et al*.,(1991) explored that *Perilla frutescens*, an edible oilseed of Northeast India, was evaluated for its' nutrient composition and protein quality which was found to be a rich source of protein (17%) and fat (51.7%). The fatty acid profile indicated that perilla oil is rich in polyunsaturated fatty acids, such as linolenic acid (56.8%) and linoleic acid (17.6%).

Bondioli *et al*., (2020) found that the analysis of fatty acid composition has highlighted a very high amount of Alpha-linolenic acid (ALA), more than 60%, higher than other ALA-rich oils such as linseed and similar to chia oil. So, it is possible to obtain high-quality oils even in the presence of high alpha-linolenic acid concentrations.

Tunit *et al*., (2022) stated that *Perilla frutescens* seed oil and *M. oleifera* consist of fatty acids that are beneficial for the skin. Mixing of these oils at a 1:1 ratio has been shown to increase the antioxidant activity of oils.

Asif *et al*., (2010) narrated that *Perilla frutescens* seeds contain fixed oil which is a useful edible oil and also an alternative source of unsaturated fatty acids (linolenic acid is omega-3 fatty acids), phenolic compounds (rosemarinic acid, luteolin chrysoeriol, quercetin, and apigenin. Perilla seed oil produced a laxative effect and increased gastric motility in constipated rats.

Ahmed *et al*., (2018) showed that the leaves, seeds, and stems of *Perilla frutescens* are used for various therapeutic applications in folk medicine. Also, it is an annual herbal medicinal, aromatic, functional food and ornamental plant that belongs to the mint family (Lamiaceae).

Shin *et al*., (1994) reported that the lipids contents of five perilla seed cultivars ranged from 38.6% to 47.8% on a dry weight basis. The lipid consisted of 91.2%-93.9% neutral lipids, 3.9% -5.8% glycolipids, and 2.0% -3.0% phospholipids.

Dhyani *et al*., (2019) revealed that perilla oil showed anticancer, anti-diabetic, antiasthma, antimicrobial, anti-inflammatory, antioxidant, and cardioprotective effects and perilla plant is getting more attention because of its medicinal benefits and phytochemical contents.

Li *et al*., (2015) found that Perilla had high iodine and low acid and peroxide values, indicating that the seed oil has the good qualities of edible oil and can be stored for a long period of time without deterioration.

2.3 Yield response of Perilla:

Wu *et al*., (2020) explored that the growth and nutraceutical quality of perilla sprouts is strongly dependent on planting density which has the Influence on growth, photosynthetic parameters, antioxidant capacity, Min Secondary metabolites, and soluble protein contents of ready-to-eat sprouts.

Rouphael *et al*., (2019) stated that *Perilla frutescens* is a potential specialty for consumption and therapeutic uses with high contents of phenolic and volatile compounds. Plant growth, mineral composition, polyphenol profile, and aroma volatile components of two perilla genotypes in response to salinity were assessed where salinity suppressed growth and yield of both genotypes where red pigmented was less sensitive than green pigmented one.

Li *et al*., (2015) revealed that extraction time had a great significant effect on oil yield. Based on Response Surface Methodology (RSM) results, the optimum conditions included an extraction time of 17.11 min and a liquid-to-solid ratio of 7.02: 1, under these conditions, the maximum oil yield was 36.27%.

Zhu *et al*., (2012) investigated the quantitative effects of ultrasonic power, extraction time, and the ratio of liquid-solid and extraction temperature on the yield of perilla seed meal proteins using RSM. The optimal extraction process of perilla meal proteins was that extraction temperature of 40®C, power of 61 W, extraction time of 12 min, and the ratio of liquid to solid of 40 ml g^{-1}, and under these conditions, the extracted contents of the perilla meal proteins was 10.77%.

2.4 Response of Perilla to Agrometeorological Indices:

Lin *et al*., (2020) investigated the growth, photochemical reflectance, and antioxidant properties of Perilla frutescens species in response to temperature and water stress conditions. Additionally, red perilla plants exhibited better temperature and drought tolerance than green plants due to their higher soil-plant analysis development values under the same temperature treatments.

Zhang *et al*., (2012) revealed the effect of salt stress on perilla plant growth by investigating the response of three perilla plant varieties which showed different salt tolerance after three weeks of salt stress. Among the three varieties, Suyin 1 is more salt tolerant than Ziye 7 and Ziye 10 and Ziye 10 is the most sensitive to salt stress.

Sharma *et al.*, (2022) showed the morphological and physiological response of Perilla to the change in climatic and edaphic factors with altitude and environmental factors that promote the growth of Perilla. Morphological and physiological traits of perilla differed in their response at different altitudes. Perilla showed better performance at higher altitudes as an emerging industrial crop.

Ling *et al*., (2011) stated that high cadmium concentration destructed protective enzyme balance which restrained the growth of *Periila frutescens.*

(Zeevaart, 1969). reported that growing of Perilla, later than the optimum time, appears short statured plants with slow vegetative growth following induction of flowers due to the advent of long nights.

Mossati *et al.*, (2021) found that by Soaking the seeds of perilla overnight before sowing, it helps to accelerate germination and sowing 1mm deep in spring when temperatures reach 20^{o}C or above as they need some heat to germination

2.5 Effect of Planting Density on Perilla Yield:

Shen *et al.*, (2014) showed the variation tendency of agronomic characteristics with the changing of planting density. Among them, the plant height, main-stem nods, first effective branch length, spikes per plant and yield per plant were negatively related to planting density. On the other hand, main spike length and main spike grains were positively related to the planting density.

Wu *et al.*, (2020**)** explored the influence of planting density on growth, photosynthetic parameters, antioxidant capacity, main secondary metabolites, soluble sugar and soluble protein contents of ready-to-eat sprouts and also found that Growth and nutraceutical quality of perilla sprouts is strongly dependent on planting density.

Kim *et al*., (1995) studied about the distance from stem-base to nutrient solution, and the planting density for the growth of *Perilla frutescens* by deep flow culture in the winter season. In an experiment for the distance from stem-base to nutrient solution, leaf numbers and leaf mineral contents were not affected by the distance, but yields, root weights, stem-base circumferences, and shoot heights gave the best results in the high distance. In the planting density experiment, leaf emergence rates and shoot heights were not affected by the density. The yields per plant were much lower in 20 x 10 cm treatment, but the yields per unit area were much higher. So the cultivation brings a lot of advantage in the high density up to 20 x 10 cm.

Wu *et al.*, (2020) explored that the growth and nutraceutical quality of perilla sprouts is strongly dependent on planting density which has the Influence on growth, photosynthetic parameters, antioxidant capacity, Min Secondary metabolites, and soluble protein contents of ready-to-eat sprouts.

Zheng *et al*.,(2018) conducted field experiments to evaluate the effect of planting density on growth and yield of *Perilla frutescens.* Planting density has significant effects on thousand grain weight, total yield and field yield of the plant but less effects on the plant height, stem diameter, root length, effective spike number and branch number of *Perilla frutescens.*

Wu *et al*., (2020) revealed that optimizing planting density will not only improve sprouts yield and quality but also reduce input cost by reducing seed rate and fertilizer usage without reducing yield.

2.6 Optimum sowing time for Perilla:

Majumdar *et al*., (2019) showed that Perilla is a short-day annual crop in Kharif-2 or summer season with 1.3-1.5 t/ha yield potentials. Successful introduction of the crop in the Kharif-2 season (mid-July-Mid-November) could have been served not only for oil seed production but also for saving money for importing oils in Bangladesh.

Kwak *et al*., (2018) carried out an experiment to determine the optimum sowing time of Perilla to minimize the seed loss at harvesting time. They used two different types of perilla and the sowing time was June 15, June 30, July 15 and August 1. As the sowing time is late, days of growth from sowing to flowering were shortened, the stem length and culm diameter were shortened and the number of effective branches were 82%, 61% and 56% as compared with June 15. Kawk *et al*., (2018) also found that the cluster height was shorter or below than average because of late sowing time.

2.7 No of Branches per plant

Yao *et al.*, (2020) revealed that with the planting density increased, the leaves appeared narrow, plants small, the deciduous leaves increased, and the leaf yield per plant was low, but the leaf yield per Mu increases significantly with the planting density.

Kim *et al.*, (1995) studied about the distance from stem-base to nutrient solution, and the planting density for the growth of *Perilla frutescens* by deep flow culture in the winter season. In an experiment for the distance from stem-base to nutrient solution, leaf numbers and leaf mineral contents were not affected by the distance, but yields, root weights, stem-base circumferences, and shoot heights gave the best results in the high distance. In the planting density experiment, leaf emergence rates and shoot heights were not affected by the density. The yields per plant were much lower in 20 x 10 cm treatment, but the yields per unit area were much higher. So the cultivation brings a lot of advantage in the high density up to 20 x 10 cm.

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2.8 No of fruits per branch

Zhang *et al*., (2017) experimented The morphological traits of 55 Chinese Perilla fruit samples (size, 100 grains weight, color, hardness, surface ridge height which can be divided into 6 categories by cluster analysis, namely: I, big grain (diameter 1.5 mm above and 100 grains weight above 0.16 g), low ridge, hard; II, big grain, low ridge, soft; III, big grain, high ridge, soft, fruit; IV, big grain. high ridge, gray brown or dark brown; V, small grain (diameter 1.5 mm below and 100-grain weight 0.16 g below), low ridge, hard, dark brown; VI, small grain, low ridge, hard, yellow brown.) and also found that the fruits with white pericarp are mainly from P. frutescens var. frutescens with purple leaves.

2.9 No of seeds per main spike

Wu *et al.,* (2020**)** explored the influence of planting density on growth, photosynthetic parameters, antioxidant capacity, main secondary metabolites, soluble sugar and soluble protein contents of ready-to-eat sprouts and also found that Growth and nutraceutical quality of perilla sprouts is strongly dependent on planting density.

Wu *et al.,* (2020) also revealed that planting at a density of 1450 plants m^{-2} significantly increased yield, improved the activities of antioxidant enzymes SOD and CAT, enhanced the generation of reactive oxygen species, increased the content of total chlorophyll and net photosynthetic rate, and decreased the content of MDA in perilla sprouts.

Shen *et al.,* (2014) showed the variation tendency of agronomic characteristics with the changing of planting density. Among them, the plant height, main-stem nods, first effective branch length, spikes per plant and yield per plant were negatively related to planting density. On the other hand, main spike length and main spike grains were positively related to the planting density.

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2.10. Seed weight per plant (g)

Shen *et al.,* (2014) showed the variation tendency of agronomic characteristics with the changing of planting density. Among them, the plant height, main-stem nods, first effective branch length, spikes per plant and yield per plant were negatively related to planting density. On the other hand, main spike length and main spike grains were positively related to the planting density.

Shen *et al.,* (2014) also found that the effect of planting density on kilo grain weight were not significant. The yield of experimented two cultivars all increased first and then decreased gradually with the increased of planting density.

Zheng *et al.,* (2018) conducted field experiments to evaluate the effect of planting density on growth and yield of *Perilla frutescens.* Planting density has significant effects on thousand grain weight, total yield and field yield of the plant but less effects on the plant height, stem diameter, root length, effective spike number and branch number of *Perilla frutescens.*

2.11 Stover weight per plant (g)

Shen *et al*., (2014) showed the variation tendency of agronomic characteristics with the changing of planting density. Among them, the plant height, main-stem nods, first effective branch length, spikes per plant and yield per plant were negatively related to planting density. On the other hand, main spike length and main spike grains were positively related to the planting density.

Zheng *et al*., (2018) conducted field experiments to evaluate the effect of planting density on growth and yield of *Perilla frutescens.* Planting density has significant effects on thousand grain weight, total yield and field yield of the plant but less effects on the plant height, stem diameter, root length, effective spike number and branch number of *Perilla frutescens.*

Wu *et al*., (2020**)** explored the influence of planting density on growth, photosynthetic parameters, antioxidant capacity, main secondary metabolites, soluble sugar and soluble protein contents of ready-to-eat sprouts and also found that Growth and nutraceutical quality of perilla sprouts is strongly dependent on planting density.

2.12 GDD for germination & flowering

Wada and Totsuka (1982) also reported that perilla becomes photosensitive at the fourth leaf pair stage and flowering starts by 18-20 days after starting of long nights.

Lee and Yang (2006) found that the later the transplanting time the shorter the plant height and the smaller the leaf area and plant weights

Nath *et al*., (1999) discovered that the GDD indicates the thermal environment of a particular crop.

Chakraborty *et al*., (1994) revealed that onset of different phenophases is initiated when a specific temperature regime is available (Chakraborty *et al*., 1994).

(Jacobs 1982). Said that *Perilla frutescens L. Britt.* is an obligatory short-day plant.

(Zeevaart, 1969). reported that growing of Perilla, later than the optimum time, appears short statured plants with slow vegetative growth following induction of flowers due to the advent of long nights.

Mossati *et al.,* (2021) found that by Soaking the seeds of perilla overnight before sowing, it helps to accelerate germination and sowing 1mm deep in spring when temperatures reach 20^{o}C or above as they need some heat to germinate.

Lin *et al.,* (2020) investigated the growth, photochemical reflectance, and antioxidant properties of *Perilla frutescens* species in response to temperature and water stress conditions. Additionally, red perilla plants exhibited better temperature and drought tolerance than green plants due to their higher soil-plant analysis development values under the same temperature treatments.

2.13 Heat Use Efficiency (HUE)

Lin *et al.,* (2020) investigated the growth, photochemical reflectance, and antioxidant properties of *Perilla frutescens* species in response to temperature and water stress conditions. Additionally, red perilla plants exhibited better temperature and drought tolerance than green plants due to their higher soil-plant analysis development values under the same temperature treatments.

(Zeevaart, 1969). reported that growing of Perilla, later than the optimum time, appears short statured plants with slow vegetative growth following induction of flowers due to the advent of long nights.

CHAPTER III

MATERIALS AND METHODS

This part presents a concise depiction of the duration of the experimental period, site description, climatic state of the area, harvest or planting materials that are being utilized in the test, treatments, design, crop growing procedure, intercultural activities, data collection and statistical analyses

3.1 Experimental period

The experiment was conducted during November 2021 to March 2022 at SAU farm. The materials used and the methods followed to set up the trial is stated as of the following headings below:

3.2 Site description

3.2.1 Geographical location

The experiment was directed at the Agronomy field of Sher-e-Bangla Agricultural University (SAU), Sher-e-Bangla Nagar Agargaon, Dhaka, Bangladesh. The experimental site is topographically situated at 23°77′ N scope and 90°33′ E longitude at an elevation of 8.6 meters above ocean level (Anon., 2004).

3.2.2 Agro-Ecological Zone

The experimental field belongs to the Agro-ecological zone (AEZ) of "The Madhupur Tract", AEZ-28 (Anon., 1988 a). This was a region of complex relief and soils developed over the Madhupur clay, where floodplain sediments buried the dissected edges of the Madhupur Tract leaving small hillocks of red soils as „islands" surrounded by floodplain (Anon., 1988 b). For better understanding about the experimental site has been shown in the Map of AEZ of Bangladesh in Appendix-I. (Banglapedia, 2014).

3.3 Climate & Soil

The climate of the experimental site was subtropical, characterized by the winter season from November to February and the pre-monsoon period or hot season from March to April and the monsoon period from May to October (Edris *et al.*, 1979). Meteorological data related to the temperature, relative humidity and rainfall during the experiment period of was collected from Bangladesh Meteorological Department (Climate division), Sher-e-Bangla Nagar, Dhaka and has been presented in Appendix- II.

The soil of the experimental pots belongs to the General soil type, Shallow Red Brown Terrace Soils under Tejgaon soil series. Soil pH ranges from 5.4–5.6 (Anon., 1989). The land was above flood level and sufficient sunshine was available during the experimental period. The morphological, physical and chemical characteristics of the experimental soil have been presented in Appendix-III. (Banglapedia, 2014 and Biswas *et al*., 2019).

3.4 Planting materials

In this research work, "SAU Perilla -1 (Golden Perilla BD)" genotype variety of Perilla seed was used as planting materials, which was collected from Department of Agronomy, Shere-Bangla Agricultural University, Dhaka-1207, Bangladesh. Basically, this variety is originated from South Korea.

3.5 Description of the variety

"SAU Perilla-1 (Golden Perilla BD) " genotype of Perilla seed used as planting material for the present study. These variety was recommended for Rabi and kharif season. The feature of this variety was presented below:

Identifying Characters:

Name of variety	SAU Perilla-1
Type	Short statured plant with slow vegetative growth
Height	
Crop Duration	100-110
Leaf color at maturity	Green to Brown color
Suitable areas	All over Bangladesh
Flowering	Starts by 18-20 days after starting of long nights
Grain color	Black
Yield	1.00-1.50 t/ha

Source: Personal Communication: Prof. Dr. H.M.M. Tariq Hossain, Dept. Of Agronomy, SAU, Dhaka.

3.6 Major Insect or Pest Management

3.6.1 Herbicide: No herbicide was used during the experimentation. Visible weeds were removed from experimental land was kept weed-free during the final land preparation. Nevertheless, during the successive growth of the crop, two hand weeding (one weeding at 40 DAS and the second weeding at 65 DAS) were done to control the weeds grown in the unit plots of the experiment.

3.6.2 Pesticide: Some caterpillars were found visible while damaging the leaves of the crop. So, Ripcord* 10EC was used @ 10ml/L to control the pest.

3.7 Experimental detailsLand preparation Date: The land was prepared on 14th November, 2021.

3.7.1 Seed Sowing Date: Seeds were sown on four different dates at 7 days of interval. The levels of sowing dates were designated D_1, D_2, D_3, and D_4 representing 21st November, 28th November, 05th December, and 12th December respectively.

3.7.2 Spacing: According to the treatment requirement the planting configurations were denoted by S_1, S_2, and S_3, for 40cm × 40cm, 40cm × 30cm, 40cm × 20cm presenting row to row and plant to plant distances, respectively.

3.7.3 Fertilizer apply Date: All the fertilizers were applied at before seed sowing during final land preparation except total urea.

3.7.4 Germination Date: First germination of $D_{1,}$ $D_{2,}$ $D_{3,}$ and D_4 plot were seen on 29^{th} November, 7^{th} December, 20^{th} December, and 29^{th} December respectively.

3.7.5 Flowering date: First flowering of D_1, D_2, $D_{3,}$ and D_4 plots were seen on 5^{th} February, 12^{th} February, 23^{rd} February and 6^{th} March respectively.

3.7.6 Harvesting Date: First harvesting of the D_1, D_2, D_3 and D_4 plot was done on 5^{th} April, 10^{th} April, 27^{th} April, and 30^{th} April respectively.

3.8 Experimental Treatment Details and Combinations:

3.8.1 Experimental Treatment Details:

The trial was done with two factors of which were I) Sowing dates and ii) Planting configuration. The levels of the factors were 04 and 03, respectively. The levels of sowing dates were designated D_1, D_2, D_3, and D_4 representing 21^{st} November, 28^{th} November, 05^{th} December, and 12^{th} December respectively. Similarly, the planting configurations were denoted by S_1, S_2, and S_3, for 40cm × 40cm, 40cm × 30cm, 40cm × 20cm presenting row to row and plant to plant distances, respectively.

$D_{1=}$ 21^{st} November

$D_{2=}$ 28^{th} November

$D_{3=}$ 5^{th} December

$D_{4=}$ 12^{th} December

$S_{1=}$40cm×40cm

S_2= 40cm×30cm

S_3=40cm×20cm

Factor A: Sowing Dates (Four levels)	**Factor B**: Planting configurations (Three levels)
D_1 : 21st November	**S_1**: 40 cm × 40 cm
D_2 : 28th November	**S_2**: 40 cm× 30 cm
D_3 : 5th December	**S_3**: 40 cm× 20 cm
D_4 : 12th December	

3.8.2 Treatment combinations

These two-factor experiments were included 12 treatment combinations.

D_1S_1, D_1S_2, D_1S_3, D_2S_1, D_2S_2, D_2S_3, D_3S_1, D_3S_2, D_3S_3, D_4S_1, D_4S_2, D_4S_3.

3.8.3 Experimental design

Land Size: North-South = 25m

East-West= 10m

Total = 25× 10m= 250m^2

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications**.** There were 36 unit plots each measuring 3m × 2m in size. Each replication and the unit plots were separated by 0.50m respectively.

3.9 Details of Experimental Preparation:

3.9.1 Preparation of experimental land

The land was opened with the help of a tractor drawn disc harrow on (19 October 2019) and then ploughed with a rotary plough twice followed by laddering to achieve a medium tilth required for the crop under consideration. All weeds and other plant residues of previous crop were removed from the field. Immediately after the final land preparation, the field layout was made on (19 October 2019) according to experimental specification. Individual plots were cleaned and finally the plots were prepared.

3.9.2 Fertilizer Application

Cow dung @ 3000kg/ha was added through well mixing into the soil while preparing the experimental land. Moreover, TSP, MOP, and Gypsum fertilizers were used @ 130, 40 and 100 kg/ha respectively as basal dose. The whole quantities of the said fertilizers were added into soil before the final preparation of the land. Urea fertilizer was added @ 125kg/ha, which was applied as top dress into two equal splits at 45 DAS (Days after seeding) and the rest amount was broadcasted 1 week before flowering of plants.

3.9.3 Seed Sowing

SAU Perilla – Seeds were sown on 21st November, 28th November, 05th December, and 12th December respectively as of the treatments in shallow depth rows (4-6 mm app.) made by a furrow opener pulling by hands. Immediately after sowing of seeds the furrows were covered by loose soil. The seeds were placed in rows with continuous line operated by hand. Before sowing the seeds were measured as needed to cover the unit plot @ 1kg /ha. After 05 to 07 days the seedlings were visible with two cotyledons flanked on hypocotyl over soil surface layer.

3.10 Maintaining Intercultural Operations

3.10.1 Thinning and gap filling:

Thinning was done at 10 DAS and 30 DAS manually. During the first thinning, seedlings were thinned at random places, where the seeds were germinated densely. However, at second thinning time, plant to plant spacing were tried to maintain finally as of the planting configuration assigned in each unit plot. In some cases, the crop line (s) were needed to fill the gaps, due to uneven germination of seeds, with healthy seedlings uprooted from the densely populated area of plots.

3.10.2 Making drains between plots

Shallow drains were made between the gaps of replication as well as unit plots. As the crop is very much sensitive to water logging conditions as low as 24 hours, these small furrow-like drains facilitated to drain out excess water after rain fall during the cropping season.

3.10.3 Weeding

The hand weeding was done as when necessary to keep the plot free from weeds. During plant growth period two weeding were on 25 DAS and 35 DAS of 4 different plots.

3.10.4 Application of irrigation water

Irrigation water was given as per plant's requirement on a regular basis.

3.10.5 Pest and disease control

As described in section 3.6.

3.10.6 General observations of the experimental site

Regular observations were made to see the growth stages of the crop. In general, the plot looked nice with normal green plants, which were vigorous and luxuriant.

3.10.7 Harvesting, threshing & cleaning

As the crop was sown in different dates, it was harvested as of maturity attained by 100 to 130 DAS. The maturity was detected by the yellowing coloration of the capsules. The seeds of tagged plants were threshed, cleaned and dried in sun for 3-4 consecutive days on a threshing yard. The seeds and Stover weights (g) per plant were measured with a digital balance.

3.10.8 Drying

The harvested products were taken on the threshing floor and it was dried for about 4– 5 days.

3.11 Crop sampling

During harvesting period 5 plants were cutting from the soil base from each plot which was selected for crop sampling for taking various parameters data of the plant.

3.12 Data collection

During harvesting of plants, 05 pre-tagged plants were isolated carefully for the data recorded on the following parameters:

i) No. of branches per plant
ii) No. of fruits per branch
iii) No. of fruits per main spike
iv) No. of seeds per main spike
v) No. of seeds per branch
vi) Stover weight per plant (g)

vii) Seed weight per plant (g)

viii) GDD for germination, flowering

ix) Heat use efficiency (HUE) and physiological maturity

3.13 Procedure of recording data

A brief outline on data recording procedure followed during the study is given below:

3.13.1 No. of branches per plant:

At different sowing interval and spacing of plants, the number of branches of five randomly selected plants from the inner rows per plot was measured by counting the number of branches of the plant and the mean value of the number of branches were recorded.

3.13.2 No. of fruits per branch:

The numbers of fruits per branch was measured from the base to tip of the branch collected from five randomly selected branches of each plot and finally average result was recorded.

3.13.3 No. of fruits per main spike:

The number of fruits per main spike was measured from the base to tip of the main spike collected from five randomly selected plants of each plot and finally average result was recorded.

3.13.4 No. of seeds per main spike:

Five main spikes from each plot were selected randomly and the number of seeds per main spike were counted. Then the average result was recorded.

3.13.5 No. of seeds per branch:

Five branches from each plot were selected randomly and the number of seeds per branch were counted. Then the average result was recorded.

3.13.6 Stover weight per plant (g)

After removing the seeds from capsule various parts of the plants without seed part was weighted and well dried Stover were collected from each plot were taken and converted into hectare and were expressed in t ha^{-1}The straw yield t ha^{-1} was measured by the following formula:

$$\text{Stover yield (t ha}^{-1}\text{)} = \frac{\text{Stover yield per plot (kg)} \times 10000}{\text{Area of plot in square meter} \times 1000}$$

3.13.7 Seed weight per plant (g)

Seed weight (Includes chaff, shell and total seed weight of a capsule) of five randomly selected plants from the five selected plants in each plot was taken in an electrical balance and the average weight was recorded in gram.

3.13.8 Calculation of growing degree days (GDD):

The GDD were calculated (Ottman, 2008) by determining the mean daily temperature and subtracting it from the base temperature needed for growth of the crop. The GDD value for one day was represented by the following equation:

$$GDD = \frac{(T_{max} + T_{min})}{2} - T_{base}$$

where, T_{max} = Daily Maximum Temperature; T_{min} = Daily Minimum Temperature and the T_b = Base Temperature [**For Perilla it was noted 10°C (50°F) below which the growth of the crop will stopped**].

3 .13. 9 Calculation of HUE

The heat use efficiency is the extent of above-ground dry matter formed per degree day (Ottman, 2008). It was intended by using the following formula:

$$\textbf{Heat Use Efficiency (g/m}^2\textbf{/°F day)} = \frac{\textbf{Dry matter yield g/m}^2}{\textbf{AGDD °F Day}}$$

Where, AGDD = Accumulated growing degree days (°F day)

3.14 Statistical analysis

The obtained data were analyzed statistically using Statistics 10 computer-based software. The mean separation tests were done by LSD test at 5% level of probability. The analyses of variances were done and tested the significant levels of individual treatment effect by the F-test (Gomez and Gomez, 19)

CHAPTER IV

RESULTS AND DISCUSSIONS

The data on different growth, yield contributing characters and yield were recorded to find out the effect of planting density and optimum sowing time to get maximum yield of Perilla. The results have been presented, discussed and possible explanation have been given under the following headings:

i) Effect of treatments on number of branches per plant

The line graph demonstrates the number of branches per plant at different spacing. Among the spacing levels, S_3 and S_2 treatments were shown up with the identical result on the said parameter. The no. of branch per plant was reduced statistically at S_1 level of the treatment (Figure 1).

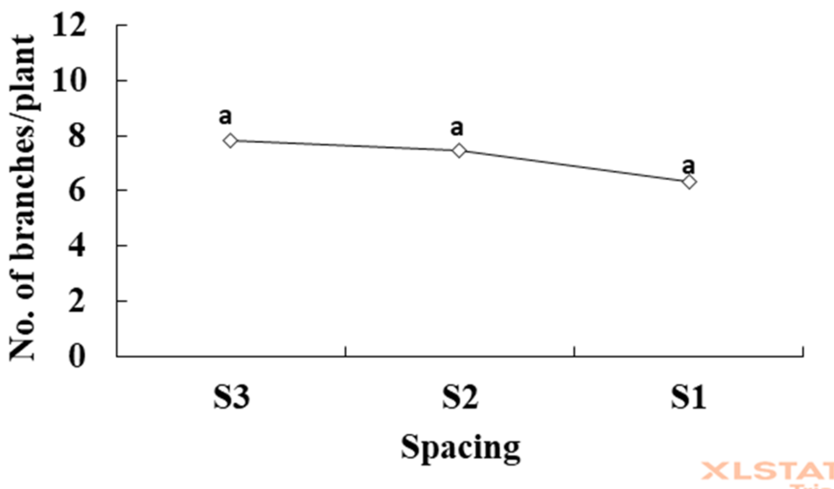

Figure 1: Spacing effects on no. of branches per plant of SAU Perilla-1 [Where S_1= 40cm × 40cm, S_2 = 40cm × 30cm, S_3 = 40cm × 20cm with $LSD_{5\%}$ = 0.86]

The line chart (Figure 2) demonstrates the number of branches per plant in respect of different days after seeding. The plants grew from the second sowing date (D_2) showed the highest number of branches but the lowest value was noted from the plots treated with D_4 treatment (Figure 2).

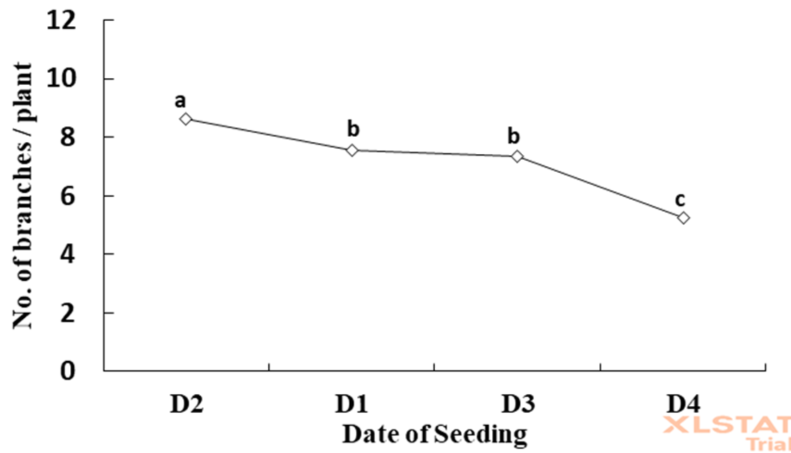

Figure 2: Generation of no. of branches per plant due to the effect of sowing dates of SAU Perilla-1
[Where D_1 = 21st November, D_2 = 28th November, D_3 = 05th December, and D_4 = 12th December and $LSD_{5\%}$ = 0.99]

The histogram above depicts the fruit number per branch in respect of combination of treatments (Date of seeding× Spacing). The highest number of branches per plant was recorded in D_2S_2 treated plot and that of the lowest was found in D_4S_3. However, among the combination of treatments, D_2 level of sowing date played best in every spacing level under study. Contrary to that the D_4 level of the treatments showed the lowest result in every case of spacings under study (Figure 3).Kim *et al*., (1995) also studied about the distance from stem-base to nutrient solution, and the planting density for the growth of *Perilla frutescens* by deep flow culture in the winter season. In an experiment for the distance from stem-base to nutrient solution, leaf numbers and leaf mineral contents were not affected by the distance, but yields, root weights, stem-base circumferences, and shoot heights gave the best results in the high distance. In the planting density experiment, leaf emergence rates and shoot heights were not affected by the density. The yields per plant were much lower in 20 x 10 cm treatment, but the yields per unit area were much higher. So, the cultivation brings a lot of advantage in the high density up to 20 x 10 cm.

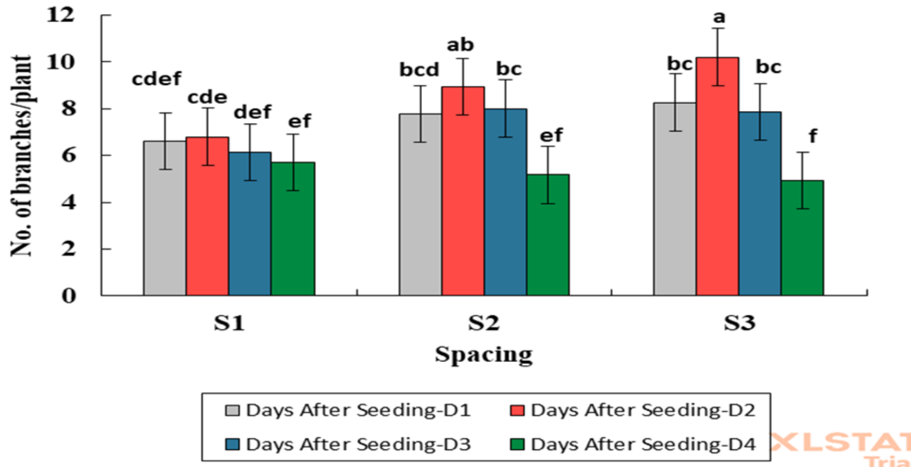

Figure 3: Cumulative effect of spacing and days after seeding of SAU Perilla-1 on the no. of branches plant

[Where D_1 = 21st November, D_2 = 28th November, D_3 = 05th December, D_4 = 12th December and S_1= 40cm × 40cm, S_2 = 40cm × 30cm, S_3 = 40cm × 20cm with $LSD_{5\%}$ = 1.72]

ii) Effect of treatments on fruit number per branch

The linear graph demonstrates fruit number per branch at different spacing. At all spacing, the said parameter showed similar result statistically, however, S_3 resulted with the highest no. of fruits among the treatments under study (Figure 4).

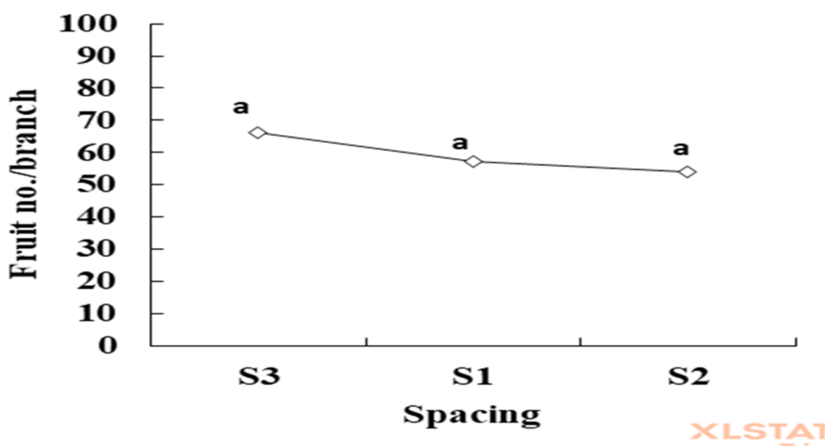

Figure 4: Effect of sowing distances on fruit no. per branch of SAU Perilla-1

[Where S_1= 40cm × 40cm, S_2 = 40cm × 30cm, and S_3 = 40cm × 20cm; $LSD_{5\%}$ = 22.41]

The line graph (Figure 5) below indicates the fruit number per branch due to the effect of different days after seeding. The treatment D_2 showed the best result and D_4 showed the lowest result. Here, D_2 was statistically similar with D_1; and D_4 was statistically similar with D_3; on the other hand, D_1 and D_3 showed similar result statistically (Figure 5). However, yield of fruits per branch decreased very sharply after D_2 treatment.

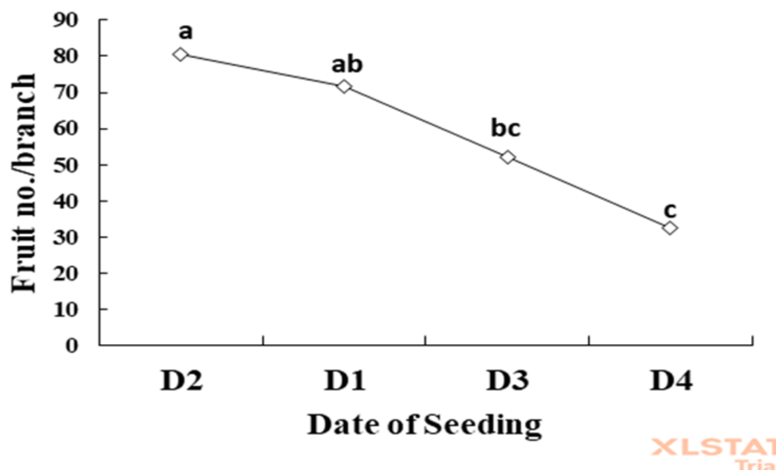

Figure 5: Impacts of sowing dates on production of fruits per branch (no.) of SAU Perilla-1
[Where D_1 = 21st November, D_2 = 28th November, D_3 = 05th December, and D_4 = 12th December and $LSD_{5\%}$ = 25.87]

The bar diagram (Figure 6) appears with a result on fruit number per branch in combination effects of treatments (Date of seeding× Spacing). The highest outcome was found in D_2S_3 combination and the lowest one was recorded in D_4S_3 association of treatments. However, in every sowing date, the S_3 treatment played the best performance on this parameter except D_4 sowing level of the study (Figure 6). Wu et al., (2020**)** also explored the influence of planting density on growth, photosynthetic parameters, antioxidant capacity, main secondary metabolites, soluble sugar and soluble protein contents of ready-to-eat sprouts and also found that Growth and nutraceutical quality of perilla sprouts is strongly dependent on planting density.

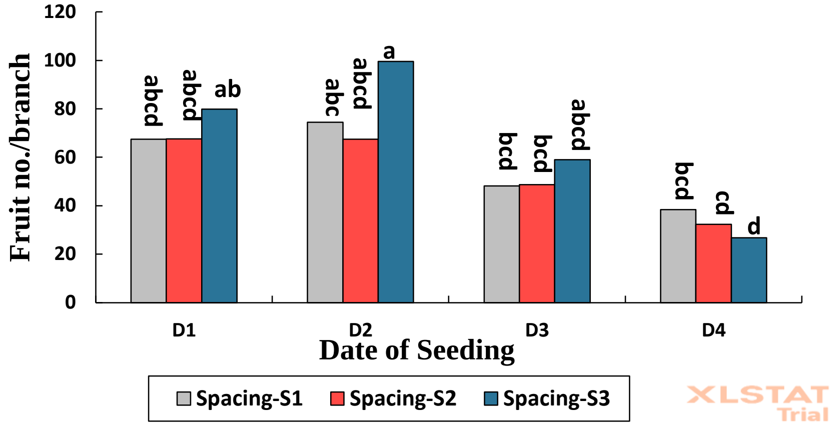

Figure 6: Fruit yield per branch as evaluated by combined effects of spacings and sowing dates in SAU Perilla-1

[Where D_1 = 21st November, D_2 = 28th November, D_3 = 05th December, D_4 = 12th December and S_1= 40cm × 40cm, S_2 = 40cm × 30cm, S_3 = 40cm × 20cm with $LSD_{5\%}$ = 44.82]

iii) Effect of treatments on fruit number per main spike

The line graph demonstrates the fruit numbers per main spike which were differentiated due to spacing treatments of our experiment. At all spacing levels, the fruit number per main spike showed up with no difference statistically although, the S_2 treatment appeared with the highest number on the studied parameter and that of the lowest in S_1 treatment (Figure 7).

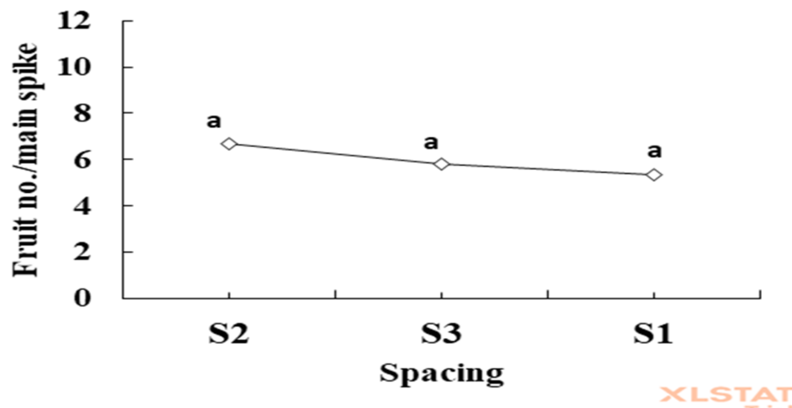

Figure 7: Effect of spacing on fruit no. per main spike of SAU Perilla-1
[Where S1= 40cm × 40cm, S2 = 40cm × 30cm, and S3 = 40cm × 20cm; $LSD_{5\%}$ = 11.09]

The graph presented (Figure 8) on fruit number per main spike in respect of different days after seeding. Here, D_1 exhibited the best result over the D_4 treatment, which showed the lowest value on the said parameter. In this case, D_1 was statistically similar with D_2 and D_3; and D_4 but similar with D_2 (Figure 8).

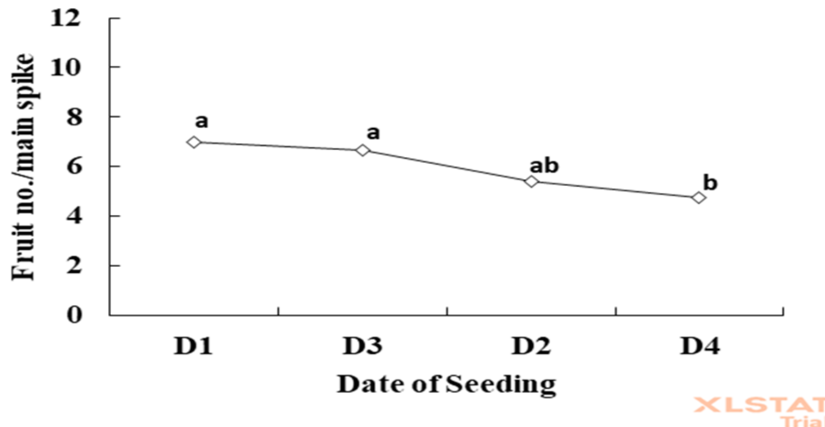

Figure 8: Individual effect of sowing dates on fruit no. / main spike of SAU Perilla-1

[Where D_1 = 21st November, D_2 = 28th November, D_3 = 05th December, and D_4 = 12th December and $LSD_{5\%}$ = 12.80]

The bar diagram (Figure 9) shows the output of fruit number per main spike due to combination effect of treatments (Date of seeding× Spacing). The highest no. of fruits was found in D_1S_2 and the that of the lowest recorded in D_4S_3 combination. It is noted that the S_2 treatment showed the best result when combined with D_1, D_2 and D_3 levels but the S_1 showed the highest result in combination with D_4 treatment only. However, the fruit no. was reduced gradually from S_1 to S_3 treatment at fourth sowing time (D_4) (Figure 9).

Shen et al., (2014) also found the variation tendency of agronomic characteristics with the changing of planting density. Among them, the plant height, main-stem nods, first effective branch length, spikes per plant and yield per plant were negatively related to planting density. On the other hand, main spike length and main spike grains were positively related to the planting density.

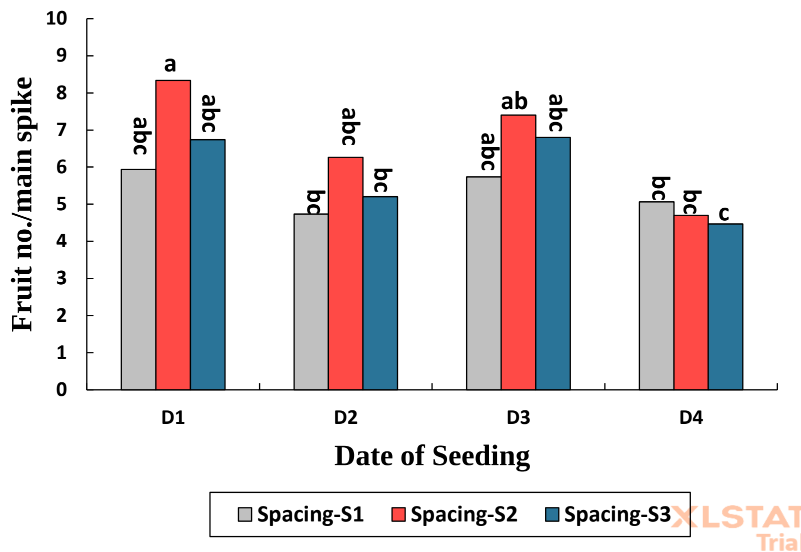

Figure 9: Combined effect of sowing dates and spacing on no. of fruits per main spike of SAU Perilla-1

[Where D_1 = 21st November, D_2 = 28th November, D_3 = 05th December, D_4 = 12th December and S_1= 40cm × 40cm, S_2 = 40cm × 30cm, S_3 = 40cm × 20cm with $LSD_{5\%}$ = 22.18]

A field experiment was conducted by Zheng et al.,(2018). to evaluate the effect of planting density on growth and yield of *Perilla frutescens*. He also found similar result that planting density has significant effects on thousand grain weight, total yield and field yield of the plant but less effects on the plant height, stem diameter, root length, effective spike number and branch number of *Perilla frutescens.*

iv) Effect of treatments on seed number per main spike

The line plot (Figure 10) below demonstrates the seed number per main spike at different plant to plant spacing. As an individual effect of spacing, the highest number of seeds were found in S_3 treatment. The results from the other two treatment levels (S_2 and S_1) were statistically similar but different from the S3 spacing level (Figure 10).

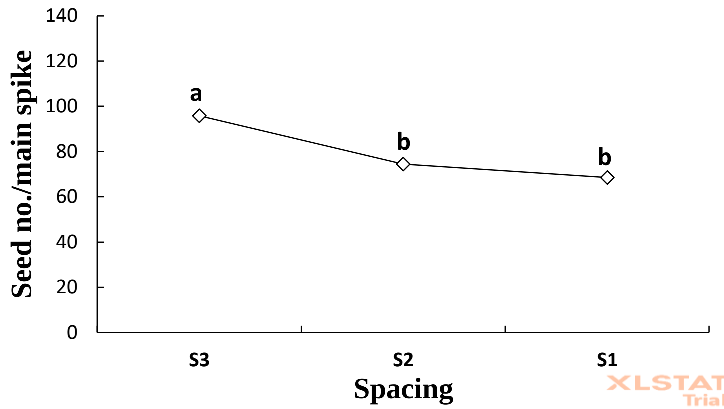

Figure 10: Production of seed per main spike due to spacing variation in SAU Perilla-1

[Where S_1= 40cm × 40cm, S_2 = 40cm × 30cm, S_3 = 40cm × 20cm and $LSD_{5\%}$ = 11.09]

The linear graph (Figure 11) shows on the variation of seed number per main spike due to different days after seeding. In this case the D_2 appeared with the best out come on the number of seeds and that of lowest was found in D_4 treatment. However, sowing date affected significantly on yielding the number of sees per main stem and gradual decrease was notable significantly in D_1, D_3, D_4 treatments (Figure 11).

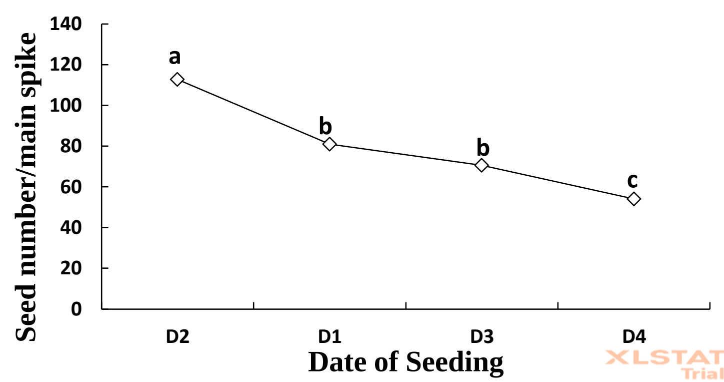

Figure 11: Seed yield per main branch as evaluated by the different seeding dates of SAU Perilla-1

[Where D_1 = 21st November, D_2 = 28th November, D_3 = 05th December, D_4 = 12th December and $LSD_{5\%}$ = 12.80]

The histogram (Figure 12) above is made on the data derived from the combination of treatments (Date of seeding× Spacing) to expose the yield effect on the seed number per main spike. The highest seed number was recorded in D_2S_3 and that of the lowest value was found in D_4S_3., The S_3 treatment in every sowing date; except D_4 (D_1, D_2 and D_3) showed the best result but S_2 showed the lowest result. However, at D_4, S_1 showed the highest result and S_3 revealed the lowest result although the differences among them were statistically non-significant (Figure 12).

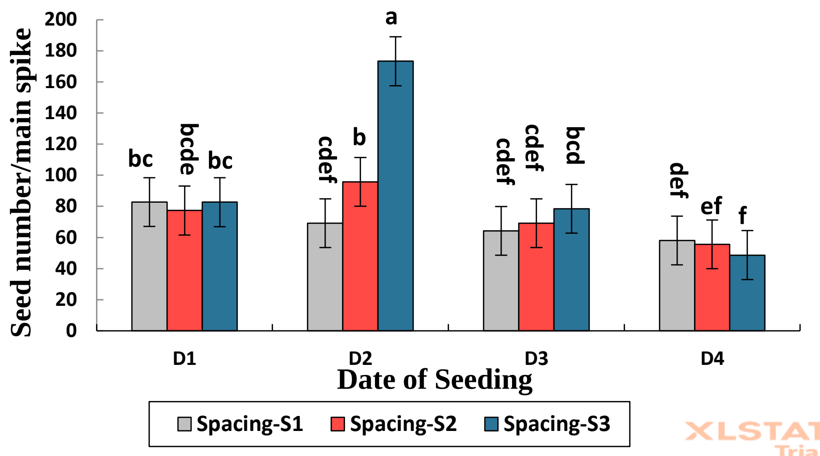

Figure 12: Seed number per main spike as produced due to the effect of seeding times and spacings in SAU Perilla-1

[Where D_1 = 21st November, D_2 = 28th November, D_3 = 05th December, D_4 = 12th December and S_1= 40cm × 40cm, S_2 = 40cm × 30cm, S_3 = 40cm × 20cm with $LSD_{5\%}$ = 22.18]

Zheng et al., (2018) conducted field experiments to evaluate the effect of planting density on growth and yield of *Perilla frutescens.* Planting density has significant effects on thousand grain weight, total yield and field yield of the plant but less effects on the plant height, stem diameter, root length, effective spike number and branch number of *Perilla frutescens.*

v) Effect of treatments on seed number per branch

The line plot (Figure 13) demonstrates the seed number per branch that changes due to different spacing. It showed that the S_3 and S_2 resulted with identical result and that was declined statistically due to the S_1 treatment. However, the highest numbers of seeds were recorded in the closest plant population (S_3) and that of the lowest was found in thinnest plant population (S_1) treatment (Figure 13).

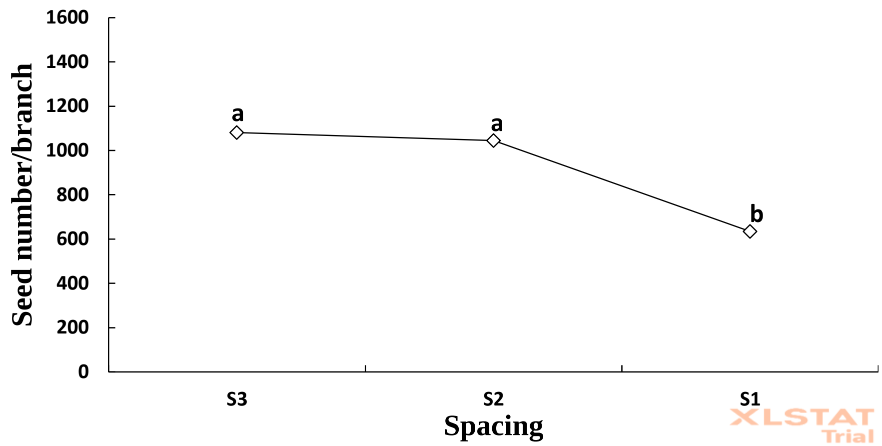

Figure 13: Effects of spacing on number of seeds per branch of SAU Perilla-1 [Where S_1= 40cm × 40cm, S_2 = 40cm × 30cm, S_3 = 40cm × 20cm with $LSD_{5\%}$ = 113.62]

The linear plot (Figure 14) is represented on the seed number per branch and that varied due to different days after seeding. In this case D_1 and D_2 levels of sowing intervals showed identical results statistically but the number of seeds decreased as of the sowing dates delayed after D_2 (D_3, and D_4). It is interesting to note that declining of seed number per plant was statistically significant among the D_2, D_3 and D_4 treatments under study (Figure 14).

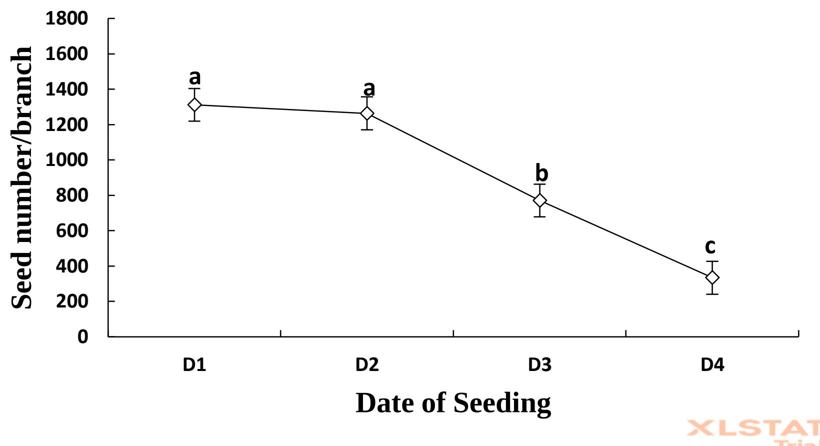

Figure 14: Evaluation of different days after seeding on production of seeds (no.) per branch of SAU Perilla-1

[Where D_1 = 21st November, D_2 = 28th November, D_3 = 05th December, D_4 = 12th December and $LSD_{5\%}$ = 131.22]

The histogram (Figure 15) above is depicted with seed number per branch that changed due to the combination effect of treatments (Date of seeding× Spacing) (Figure 15). The highest value on the parameter was found in D_1S_2 and that of the lowest was noted from plots assigned with D_4S_3 combination of treatments. D_2S_3 treated plots also showed up with second highest number of seeds per branch but the difference from D_1S_2 was non-significant. However, gradual decrease in seeds yield were observed with combinations of dates of sowing in S_1 and S_2 levels of spacing under study. Similar trend of downing on seed numbers per branch was observed in S_3 level of spacing with an exception of D_1S_3 combination of treatment (Figure 15). Kim et al., (1995) also studied about the distance from stem-base to nutrient solution, and the planting density for the growth of *Perilla frutescens* by deep flow culture in the winter season. In an experiment for the distance from stem-base to nutrient solution, leaf numbers and leaf mineral contents were not affected by the distance, but yields, root weights, stem-base circumferences, and shoot heights gave the best results in the high distance. In the planting density experiment, leaf emergence rates and shoot heights were not affected by the density. The yields per plant were much lower in 20 x 10 cm treatment, but the yields per unit area were much higher. So, the cultivation brings a lot of advantage in the high density up to 20 x 10 cm.

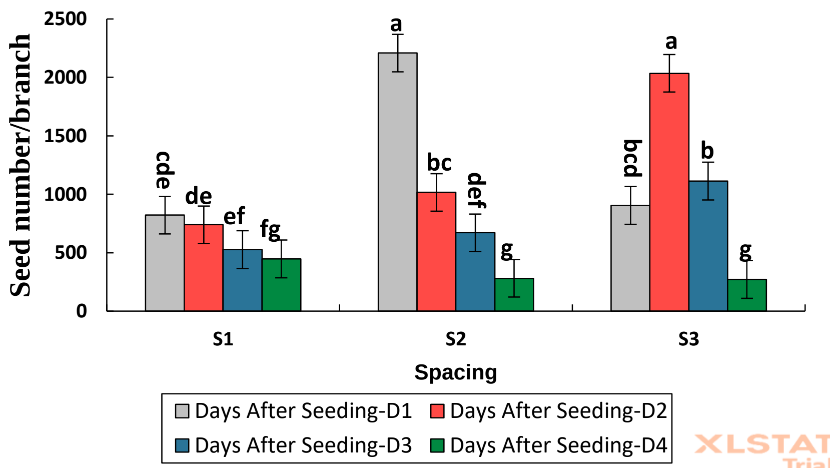

Figure 15: Seed yield (no.) performance per branch in SAU Perilla-1 as studied by growing through different seeding dates and spacings

[Where D_1 = 21st November, D_2 = 28th November, D_3 = 05th December, D_4 = 12th December and S_1= 40cm × 40cm, S_2 = 40cm × 30cm, S_3 = 40cm × 20cm with $LSD_{5\%}$ = 227.28]

vi) Effect of treatments on stover weight per plant

The stover weight per plant found in different dates of seeding is depicted by a line graph (Figure 16). Here the highest stover weight per plant was accumulated when the crop was sown as of D_1 treatment. However, the stover production decreased gradually from D_1 towards D_2, D_3 and D_4. Although there were non-significant differences on the said parameter at D_2 and D_3 but D_4 differed significantly over D_2 and D_3 in producing the stover per plant, which was found at least amount per plant among the treatments under study (Figure 16).

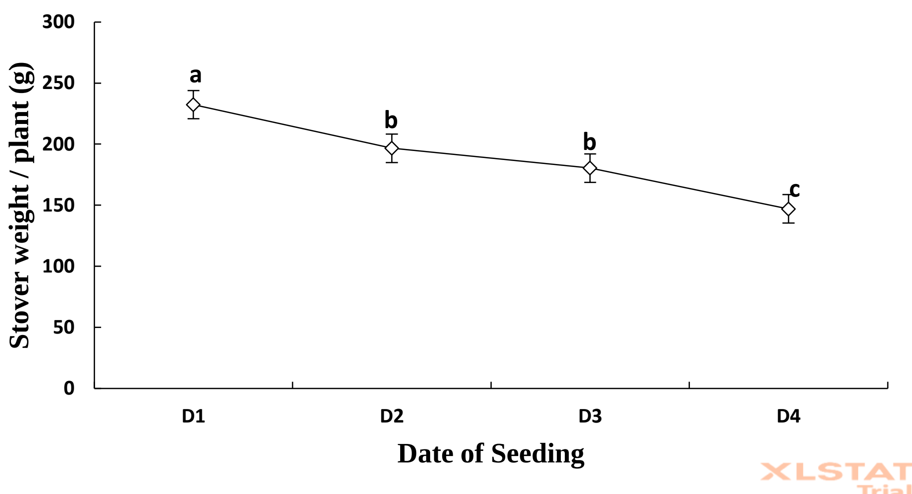

Figure 16: Evaluation on stover yield per plant of SAU Perilla-1 when grown with different sowing dates
[Where D_1 = 21st November, D_2 = 28th November, D_3 = 05th December, D_4 = 12th December and $LSD_{5\%}$ = 16.45]

The Figure 17 demonstrates the stover yield variations per plant when grown with different spacing. Among the spacing levels, the highest result was found in S_2 treatment. The difference between the S_3 and S_1 treatment means was found statistically non-significant in producing the stover per plant (Figure 17).

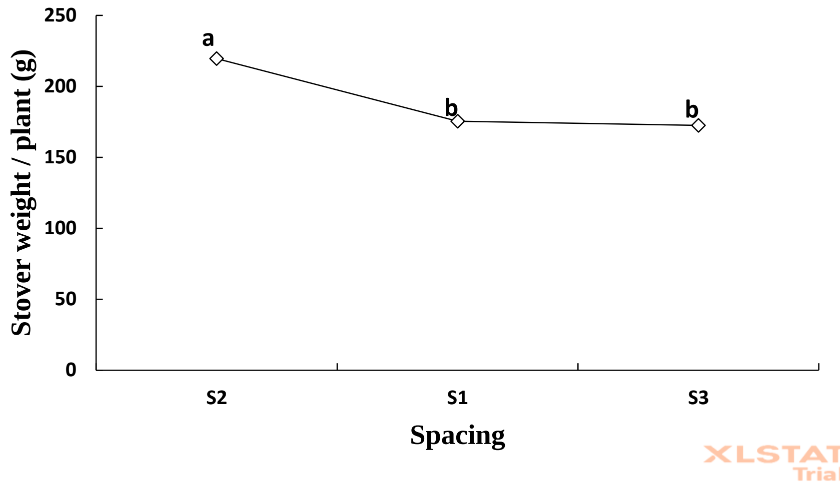

Figure 17: Stover yield per plant of SAU Perilla-1 grown under different spacings [Where S_1= 40cm × 40cm, S_2 = 40cm × 30cm, S_3 = 40cm × 20cm with $LSD_{5\%}$ = 14.25]

The Figure 18 above is presented with a histogram on stover weight per plant, which differed with combination treatments (Date of seeding× Spacing). The highest stover weight was recorded in D_1S_2 and that of the lowest weight was found in D_4S_1 combination of treatments. In every level of the spacing, stover weights per plant were found in decreasing pattern with sowing dates. As the sowing date is delayed, the stover yield went down at D_4 level with combination of spacing levels (D_4S_1, D_4S_2 and D_4S_3) although the values were found non-significantly different among each other. Moreover, combinations of S_2 spacing levels with all the dates of sowing levels were found comparatively better, from the rest of the combinations of treatments under study, in producing the stover per plant (Figure 18). Kim et al., (1995) studied about the distance from stem-base to nutrient solution, and the planting density for the growth of *Perilla frutescens* by deep flow culture in the winter season. In an experiment for the distance from stem-base to nutrient solution, leaf numbers and leaf mineral contents were not affected by the distance, but yields, root weights, stem-base circumferences, and shoot heights gave the best results in the high distance. In the planting density experiment, leaf emergence rates and shoot heights were not affected by the density. The yields per plant were much lower in 20 x 10 cm treatment, but the yields per unit area were much higher. So the cultivation brings a lot of advantage in the high density up to 20 x 10 cm.

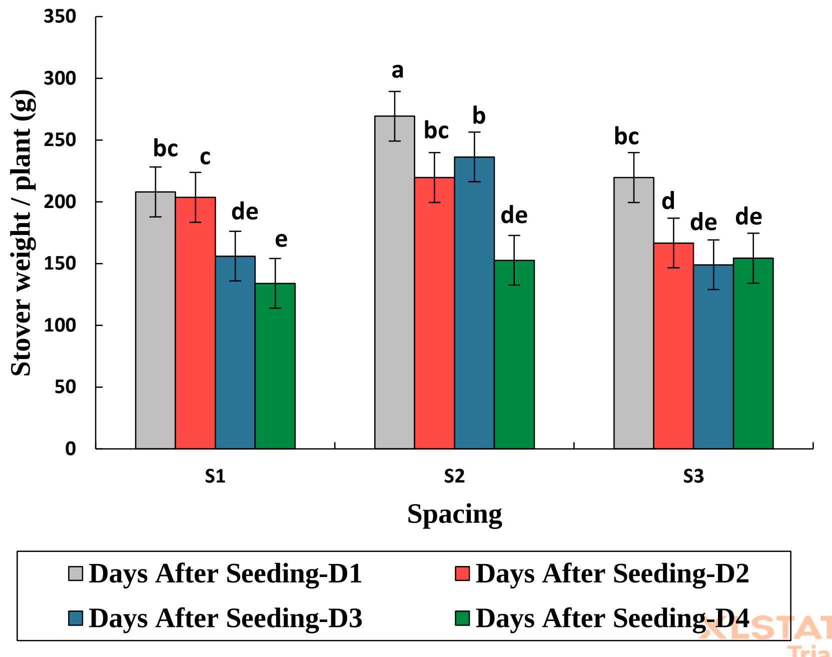

Figure 18: Combined effect of spacings and days after sowing on mean yield of stover per plant of SAU Perilla-1

[Where D_1 = 21st November, D_2 = 28th November, D_3 = 05th December, D_4 = 12th December and S_1= 40cm × 40cm, S_2 = 40cm × 30cm, S_3 = 40cm × 20cm with $LSD_{5\%}$ = 28.50]

vii) Effect of treatments on seed weight per plant

The line chart (Figure 19) represents seed weight per plant, which differed on the basis effects of days after seeding. Due to the treatment effect, D_2 showed the uppermost level of seed weight per plant. The D_4 treatment scored the lowest result and it was statistically similar with D_3 treatment. Similarly, the D_3 treatment showed same effect as of the D_1 in our study (Figure 19).

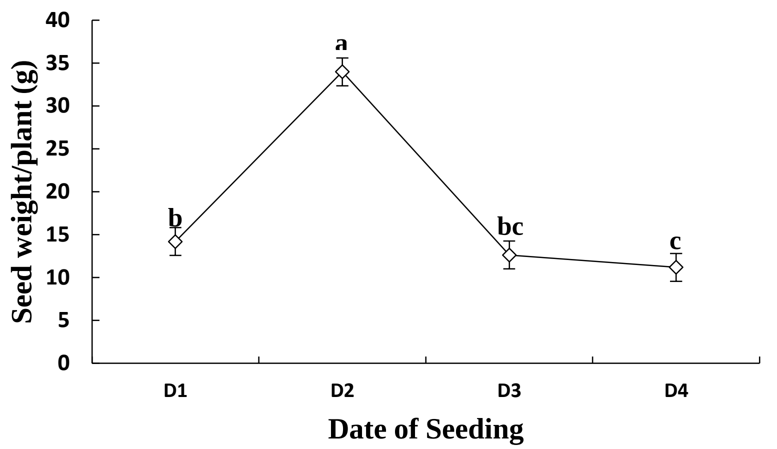

Figure 19: Effect of days after seeding on seed yield per plant in SAU Perilla-1

[Where D_1 = 21st November, D_2 = 28th November, D_3 = 05th December, D_4 = 12th December and $LSD_{5\%}$ = 16.45]

The linear chart (Figure 20) displays the seed weight per plant at different spacing. The obtained results changed due to treatment effects. However, the highest seed mass per plant was recorded due to the effect of S_3 and that of the value touched at the bottom for S_2, which were statistically different with each other (Figure 20).

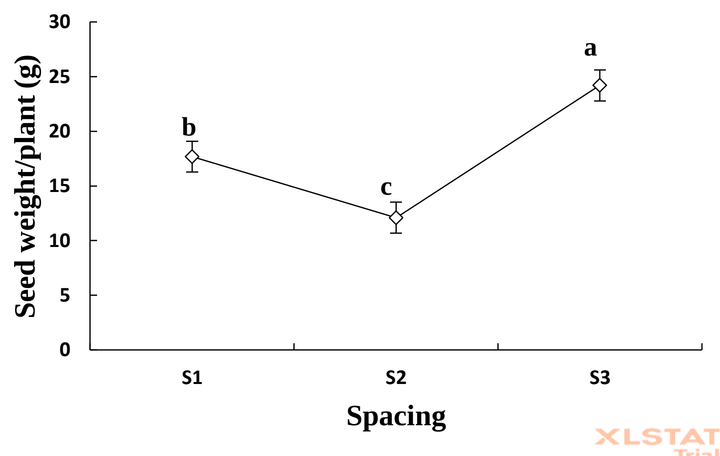

Figure 20: Seed yield per plant of SAU Perilla-1 as grown with different spacing [Where S_1= 40cm × 40cm, S_2 = 40cm × 30cm, S_3 = 40cm × 20cm and $LSD_{5\%}$ = 14.25]

The histogram (Figure 21) above is depicted with seed weight per plant, which was found with different values as of the combination of treatments (Date of seeding× Spacing). The maximum seed weight was recorded in D_2S_3 and that of the lowest value was found in D_4S_3. The next highest peak value representing the seed weight per plant was found in D_2S_1 combination followed by the D_1S_1 treatment, which were statistically different from each other. Moreover, all the combination of treatments at D_3 and D_4 levels turned into lower amount of seed yield per plant comparing to D_2S_3 combination and the differences were found nonsignificant with the lowest seed yield shown by the D_4S_3 treatment (Figure 21). Sharma et al., (2022) also showed the morphological and physiological response of Perilla to the change in climatic and edaphic factors with altitude and environmental factors that promote the growth of Perilla. Morphological and physiological traits of perilla differed in their response at different altitudes. Perilla showed better performance at higher altitudes as an emerging industrial crop.

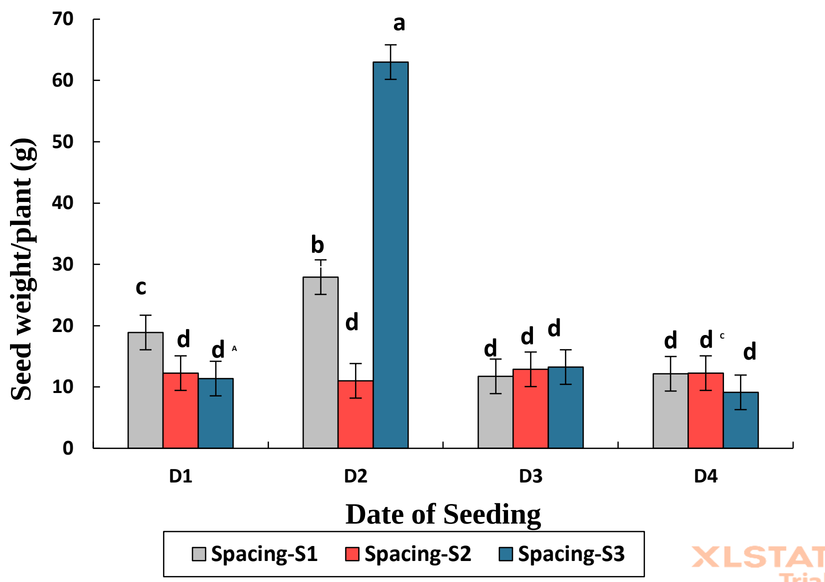

Figure 21: Effect of treatment combinations on seed yield per plant of SAU Perilla-1 [Where D1 = 21st November, D2 = 28th November, D3 = 05th December, D4 = 12th December and S1= 40cm × 40cm, S2 = 40cm × 30cm, S3 = 40cm × 20cm with $LSD_{5\%}$ = 28.50]

viii) Requirement of growing degree days (GDD) towards gemination, flowering and physiological maturity of SAU Perilla-1

The GDD requirement from sowing to germination due to variation in dates of sowing is shown in Table 1. The GDD values increased with increasing days to germination of seeds. Sowing date strongly influenced the GDD requirement for germination of SAU Perilla-1. The cumulative GDD (270.9°F) was recorded highest on 05th Feb., 2022 required to be germinated (D_4) by 12 days after seeding (23rd Dec., 2021). The lowest amount of GDD (246.6°F) was needed for germination of seeds sown on 21st Nov., 2021 (D_1) requiring 08 days to complete the process. The increase in thermal requirements with delay in sowing may possibly be due to low temperature in late sown crop. The reduction in GDD accumulation was due to reduction in number of days taken to germination.

Table 1: Sowing date effects on GDD (°F) requirement for days to germination, days to flowering, and days to physiological maturity of SAU Perilla-1 grown during the Robi season at SAU farm

a) GDD (°F) calculation on germination

Date of Sowing	Date of Germination	Days required to emergence	GDD (°F) Utilized
D1 (21st Nov., 2021)	29th Nov., 2021	08	246.6
D2 (28th Nov., 2021)	07th Dec., 2021	09	250.2
D3 (05th Dec., 2021)	14th Dec., 2021	10	256.5
D4 (12th Dec., 2021)	23rd Dec., 2021	12	270.9

b) GDD (°F) calculation on flowering

Date of Sowing	Date of Flowering	Days required to flowering	GDD (°F) Utilized
D1 (21st Nov., 2021)	05th Feb., 2022	75	1670.4
D2 (28th Nov., 2021)	12th Feb., 2022	75	1594.8
D3 (05th Dec., 2021)	23rd Feb., 2022	78	1661.4
D4 (12th Dec., 2021)	06th March, 2022	82	1802.7

c) GDD (°F) calculation on physiological maturity

Date of Sowing	Date of Physiological Maturity	Days required to physiological maturity	GDD (°F) Utilized
D1 (21st Nov., 2021)	05th April, 2022	134	3289.5
D2 (28th Nov., 2021)	10th April, 2022	132	3262.5
D3 (05th Dec., 2021)	27th April, 2022	141	3640.5
D4 (12th Dec., 2021)	27th April, 2022	148	3470.4

The GDD requirement from sowing to flowering and physiological maturity differed due to variation in dates of sowing (Table 1). When the crop was sown on D_1, 75 days were needed accumulating 1670.4 **°F** for flowering of the crop. The GDD requirement was highest (1802**°F)** in D_4 sowing treatment, where 82 days were required to initiate flowering. The GDD requirement declined when the crop was sown on D_2 and D_3 sowing. The results indicated that the variation in temperature prevailed under different dates of sowing. Moreover, the maximum GDD (3470.4**°F)** was recorded in D_4 treatment where 148 days required to reach the physiological maturity of SAU Perilla-1. The second lowest GDD (3262.5**°F)** with lowest number of days (132) were required to complete the physiological maturity stage of the crop when sown on 28th Nov., 2021 (D_2). The difference in GDD values obtained, for physiological maturity in different sowing times might be attributed to the differences in the maximum and minimum temperature observed with succeeding days.

We started sowing SAU Perilla-1 from 21st November to 12th December with 07 days interval of the *Rabi* season, 2021. The sown seeds during this time were exposed to different temperature regimes affecting germination duration (08-12 days) under gradually increased amount of GDD required (Table 1a). Similarly, the flower induction and physiological maturity attained by 75 to 82 and 134-148 days respectively. The GDD amount also found progressively increasing (Table 1b and 1c). The production of seed per plant was shown highest in plots when sown on 28th November (D_2 treatment) using 40cm × 20cm (S_3) spacing (Figure 21). However, as the sowing time is delayed HUE in producing stover per plant was declined (Figure 22) although the highest value grain yield was recorded in D_2 at the expense of the lowest amount (3262.5) of GDD by 132 days to maturity (Table 1c). The GDD indicates the thermal environment of a particular crop (Nath *et al*., 1999). Onset of different phenophases is initiated when a specific temperature regime is available (Chakraborty *et al*., 1994). The sensitivity of this crop to the change in temperature and day duration is especially remarkable as the crop switches to reproductive stage when a certain extent of thermal and photoperiod are observed.

Similar to other photosensitive crop, SAU Perilla-1 has its own optimal requirements of climatic variables viz. temperature, sunshine hours, rainfall etc. for attaining potential yield. The responses and requirements of these variables determine the growth and development of this crop in a given environment. Changes in photo duration affect the productivity through the changes in phenological development especially flowering of this crop. As such, date of sowing is the most important factors that regulates the flowering events and also influence the conversion of biomass into economic yield. Due to photosensitivity, the late-sown SAU Perilla-1 in *Robi* season exposed initially to low temperatures when the establishment phase of the crop is going on. Later on, it progresses to long day duration (short night) with warm temperatures triggering longer vegetative growth and thus halting the reproductive phase till the introduction of long night next. In our previous experiment it appeared that this event not only facilitate higher accumulation of dry matter but yielding utmost amount of grain per plant due to the longer vegetative growth with experiencing maximum cropping duration of SAU Perilla-1. *Perilla frutescens L. Britt.* is an obligatory short-day plant (Jacobs 1982). Growing of Perilla, later than the optimum time, appears short statured plants with slow vegetative growth following induction of flowers due to the advent of long nights (Zeevaart, 1969). Wada and Totsuka (1982) also reported that perilla becomes photosensitive at the fourth leaf pair stage and flowering starts by 18-20 days after starting of long nights. The later the transplanting time the shorter the plant height and the smaller the leaf area and plant weights (Lee and Yang, 2006). Therefore, the optimization of sowing time is an important parameter to attain maximum yield and efficient conversion of biological yield into economic yield of SAU Perilla-1 in Bangladesh. Generally, normal sowing has longer growth duration which consequently supports high biomass accumulation as compared to late sowing and henceforth manifested in higher grain and biological yield (Wadaa *et al*., 2010). Hence, it becomes imperative to have knowledge of exact duration of phenological stages in a particular crop-growing season and their impact on yield of crop.

ix) Heat use efficiency (HUE)

Heat use efficiency determines the ability of a plant to convert per unit available energy into the economic product. The data presented in the Figure 22 revealed that HUE was higher in producing stover plant when sown on 21st November (D_1) with second highest grain production (4.10 mg/plant//°F/Day). Contrary to that the highest amount of grain (8.13 mg/plant//°F/Day) was yielded in D_2 sowing date although the stover production was reduced from that of D_1 treatment found. As the sowing is delayed either the grain and stover synthesis were lowered down as found in D_3 and D_4 treatments.

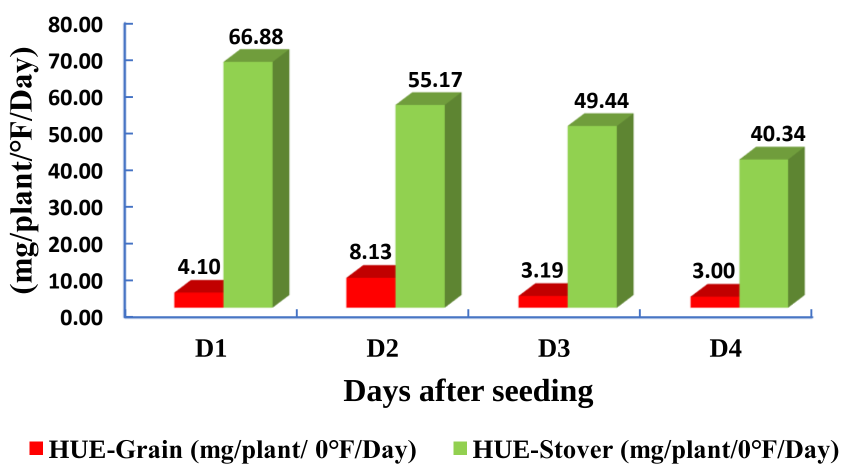

Figure 22: Heat use efficiency in producing grain and Stover of SAU Perilla-1 grown with different dates of sowing during the Robi season at SAU farm [Where D_1 = 21st November, D_2 = 28th November, D_3 = 05th December, D_4 = 12th December]

We started sowing SAU Perilla-1 from 21st November to 12th December with 07 days interval of the *Rabi* season, 2021. The sown seeds during this time were exposed to different temperature regimes affecting germination duration (08-12 days) under gradually increased amount of GDD required (Table 1a). Similarly, the flower induction and physiological maturity attained by 75 to 82 and 134-148 days respectively. The GDD amount also found progressively increasing (Table 1b and 1c). The production of seed per plant was shown highest in plots when sown on 28th November (D_2 treatment) using 40cm × 20cm (S_3) spacing (Figure 21). However, as the sowing time is delayed HUE in producing Stover per plant was declined (Figure 22) although the highest value grain yield was recorded in D_2 at the expense of the lowest amount (3262.5) of GDD by 132 days to maturity (Table 1c). The GDD indicates the thermal environment of a particular crop (Nath *et al*., 1999). Onset of different phenophases is initiated when a specific temperature regime is available (Chakraborty *et al*., 1994). The sensitivity of this crop to the change in temperature and day duration is especially remarkable as the crop switches to reproductive stage when a certain extent of thermal and photoperiod are observed.

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CHAPTER V

SUMMARY AND CONCLUSION

The present piece of work was carried out at the Research Farm of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh during November 2021 to April 2022, to investigate the effect of sowing time and spacing on Perilla growth and yield response. The experimental field belongs to the Agro-ecological zone (AEZ) of "The Madhupur Tract", AEZ-28. The soil of the experimental field belongs to the General soil type, Deep Red Brown Terrace Soils under Tejgaon soil series. We started sowing SAU Perilla-1 from 21st November to 12th December with 07 days interval of the *Rabi* season, 2021. The experiment consisted of two factors, and followed Randomized Complete Block Design (RCBD) design. The trial was done with two factors of which were I) Sowing dates and ii) Planting configuration. The levels of the factors were 04 and 03, respectively. The levels of sowing dates were designated D_1, D_2, D_3, and D_4 representing 21st November, 28th November, 05th December, and 12th December respectively. Similarly, the planting configurations were denoted by S_1, S_2, and S_3, for 40cm × 40cm, 40cm × 30cm, 40cm × 20cm presenting row to row and plant to plant distances, respectively. The sown seeds during this time were exposed to different temperature regimes affecting germination duration (08-12 days) under gradually increased amount of GDD required (Table 1a). Similarly, the flower induction and physiological maturity attained by 75 to 82 and 134-148 days respectively. The GDD amount also found progressively increasing (Table 1b and 1c). The production of seed per plant was shown highest in plots when sown on 28th November (D_2 treatment) using 40cm × 20cm (S_3) spacing (Figure 21). However, as the sowing time is delayed HUE in producing Stover per plant was declined (Figure 22) although the highest value grain yield was recorded in D_2 at the expense of the lowest amount (3262.5) of GDD by 132 days to maturity (Table 1c). The GDD indicates the thermal environment of a particular crop (Nath *et al*., 1999). Onset of different phenophases is initiated when a specific temperature regime is available (Chakraborty *et al*., 1994). The sensitivity of this crop to the change in temperature and day duration is especially remarkable as the crop switches to reproductive stage when a certain extent of thermal and photoperiod are observed. The results revealed that sowing dates had significant effect on the yield variations as evaluated by the studied parameters of the crop. However, D_2 showed the uppermost level of seed weight per plant. The highest seed weight per plant was recorded due to the effect of S_3 and that of the value touched at the bottom for S_2. The maximum seed weight was recorded in D_2S_3 and that of the lowest was found in D_4S_3. The GDD values increased with increasing days to germination of seeds. Sowing date strongly influenced the GDD requirement for germination of SAU Perilla-1. When the crop was sown on D_1, 75 days were needed accumulating 1670.4 **°F** for flowering of the crop. The GDD requirement was highest (1802**°F)** in D_4 sowing treatment, when 82 days were required to initiate flowering. The GDD requirement declined as sown on D_2 and D_3 dates. The results indicated that the variation in temperature prevailed under different dates of sowing. HUE was higher in producing stover plant when sown on 21st November (D_1) with second highest grain production (4.10 mg/plant//°F/Day). Contrary to that the highest HUE for grain (8.13 mg/plant//°F/Day) was yielded in D_2 sowing date although the stover production was reduced from that of D_1 treatment found. When sowing is delayed, either of grain and stover synthesis were lowered down as found in D_3 and D_4 treatments.

Recommendations

The crop sown on 28th November (D_2 treatment) using 40cm × 20cm (S_3) spacing took minimum calendar days (132) with the GDD (3262.5**°F)** required to complete the physiological maturity stage of the crop. Thus, SAU Perilla-1 could be started sowing on the 28th November for cultivation in *Robi* season of Bangladesh because of high potential (of D_2 over the other dates) to efficiently convert the heat units (HUE = 8.13 mg/plant//°F/Day) into the economic yield of the crop.

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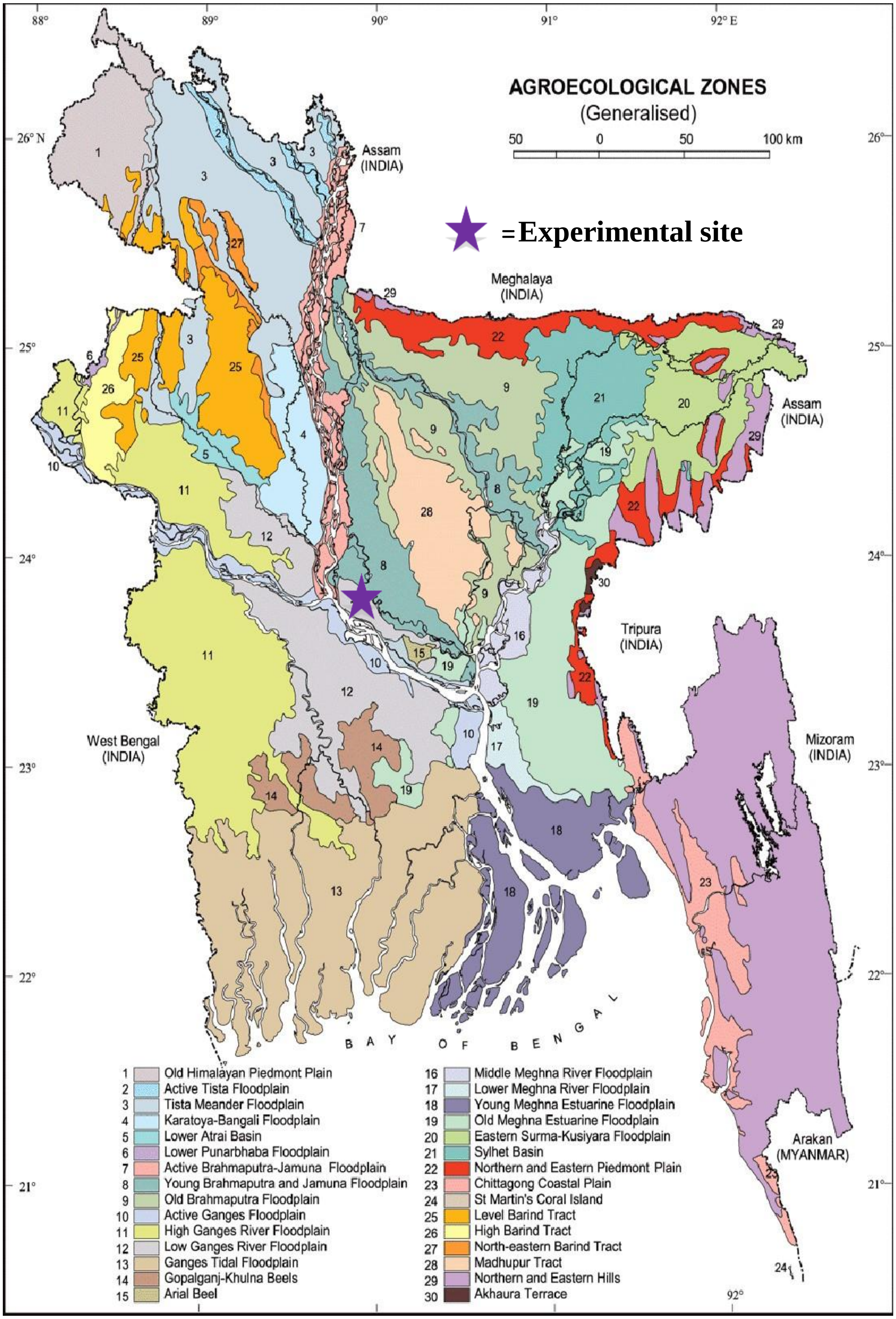
Appendix I. Map showing the experimental location under study



Appendix II. Monthly meteorological information during the period from November 2021 to April 2022

Year	Month	Air temperature (^{0}C)		Relative humidity (%)	rainfall (mm)
		Maximum	Minimum		
2021	November	29.6	19.2	73	34.4
	December	26.4	14.1	73	12.8
2022	January	25.5	12.7	71	7.7
	February	28.1	15.5	64	28.9
	March	32.5	20.4	62	65.8
	April	33.7	23.6	71	156.3

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

Appendix III. Soil Characteristics of the experimental field

A. Morphological characteristics of the experimental field

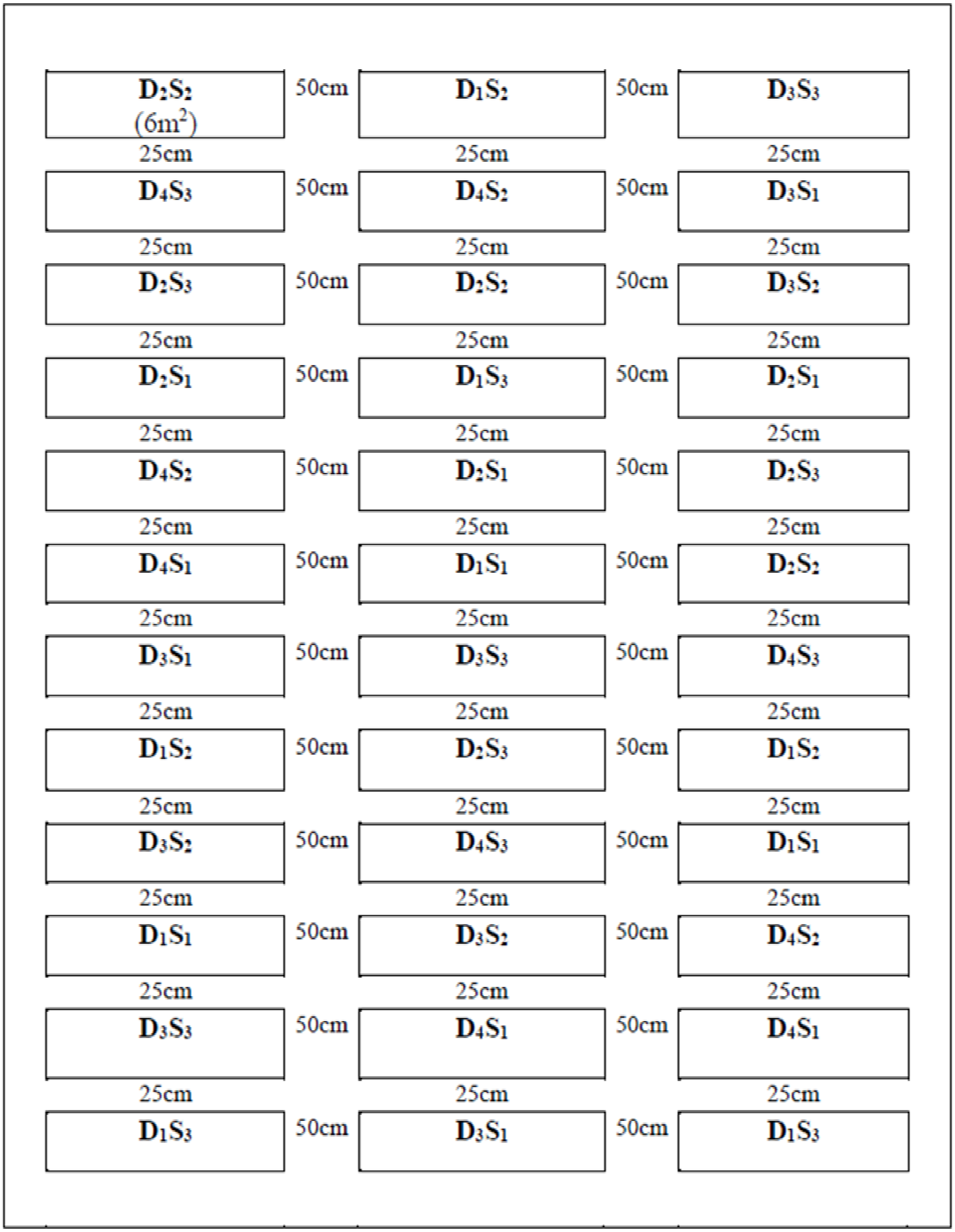
Morphological features	Characteristics
Location	Sher-e-Bangla Agricultural University Agronomy research field, Dhaka
AEZ	AEZ-28, Modhupur Tract
General Soil Type	Shallow Red Brown Terrace Soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled

B. The initial physical and chemical characteristics of soil of the experimental site (0 - 15 cm depth)

Physical characteristics	
Constituents	**Percent**
Sand	26 %
Silt	45%
Clay	29%
Textural class	Silty clay

Chemical characteristics	
Soil characteristics	**Value**
pH	5.6
Organic carbon (%)	0.45
Organic matter (%)	0.78
Total nitrogen (%)	0.03
Available P (ppm)	20.54
Exchangeable K (mg/100 g soil)	0.10

Appendix IV. Layout of the experimental field



1.Factorial ANOVA Table for Fruit number

Source	DF	SS	MS	F
Replication	2	1.2817	0.64083	
Sowing interval	3	27.6097	9.20324	22.25^{NS}
Spacing	2	7.9717	3.98583	9.64^{NS}
Combination	6	7.3861	1.23102	2.98^{NS}
Error	22	9.0983	0.41356	
Total	35	53.3475		

2. Factorial ANOVA Table for Fruit number / Branch

Source	DF	SS	MS	F
Replication	2	0.02391	0.01	
Sowing interval	3	12002.5	4000.82	9233.10*
Spacing	2	824.613	412.31	951.52*
Combination	6	1263.55	210.59	486.00^{NS}
Error	22	9.53289	0.43	
Total	35	14100.2		

3. Factorial ANOVA Table for SEED WEIGHT (g)

Source	DF	SS	MS	F
Replication	2	3.964E-05	1.982E-05	
Sowing interval	3	1.501E-03	5.005E-04	35.13^{NS}
Spacing	2	3.620E-04	1.810E-04	12.71*
Combination	6	1.562E-03	2.603E-04	18.28^{NS}
Error	22	3.134E-04	1.424E-05	
Total	35	3.778E-03		

4. Factorial ANOVA Table for SEED NUMBER

Source	DF	SS	MS	F
Replication	2	3049.60	1525	
Sowing interval	3	7555470	2518490	502.09*
Spacing	2	316630	158315	31.56*
Combination	6	2061564	343594	68.50^{NS}
Error	22	110353	5016	
Total	35	1.005E+07		

5. Factorial ANOVA Table for SEED NUMBER/Branch

Source	DF	SS	MS	F
Replication	2	0.9	0.46	
Sowing interval	3	8083.2	2694.41	10298.08*
Spacing	2	1922.5	961.26	3673.97*
Combination	6	2177.4	362.90	1387.00^{NS}
Error	22	5.8	0.26	
Total	35	12189.8		

6. Factorial ANOVA Table for PLANT WEIGHT(g)

Source	DF	SS	MS	F
Replication	2	2340.1	1170.03	
Sowing interval	3	24778.3	8259.44	4.32^{NS}
Spacing	2	9172.7	4586.36	0.1142^{NS}
Combination	6	4537.9	756.32	0.8739^{NS}
Error	22	42066.6	1912.12	
Total	35	82895.6		

Plate 1: Vegetative Stage of SAU Perilla-1

Plate 2: Weeding of the experimental field of SAU Perilla-1

Plate 3: Inflorescence of *Perilla frutescens*

Plate 4: Gap filling and thinning process of SAU Perilla-1

Plate 5: SAU Perilla-1 after harvesting