



# **Growth and Yield Performance of Chili (*Capsicum annuum* L.) on Rooftop of Different Height of Buildings**

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## **Authors' contributions**

*This work was carried out in collaboration among all authors. Authors MUH and AH designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors NN, ZFBH and HR managed the analyses of the study and the literature searches. All authors read and approved the final manuscript.*

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## **ABSTRACT**

In urban agriculture, rooftop gardening is a remarkable part which is practiced to overcome the food crisis and climate change; if it is not economically viable on the basis of productivity, then rooftop garden will not enhance and sustain. So, a pot experiment was conducted during November 2021 to April 2022 on the rooftop of different height of buildings and Agroforestry research field at Sher-e-Bangla Agricultural University, Dhaka-1207 to study the productivity of chili (BARI Morich 3). The experiment was laid out in a Completely Randomized Design with four replications. The treatments of this experiment were T<sub>1</sub>= Control (Ground, 0.0 m), T<sub>2</sub>= Rooftop of three storied building (11.28 m), T<sub>3</sub>= Rooftop of six storied building (21.34 m) and T<sub>4</sub> = Rooftop of ten storied building (34.75 m).

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Results indicated that soil moisture content, plant height, stem diameter, number of (leaf, branch and fruit), fresh and dry weight of plant, single fruit (weight, length and diameter), fresh and dry weight of yield per plant were significantly decreased with the increased of building height ( $T_1 > T_2 > T_3 > T_4$ ) and air temperature, soil temperature and light intensity were significantly increased with the increased of building height ( $T_4 > T_3 > T_2 > T_1$ ). As gradually increased the height of building rooftop, sequentially decreased the growth, yield and yield contributing characteristics of chili plant. Although ground performed the best productivity, up to rooftop of three storied building can be selected as an appropriate height for chili (BARI Morich-3) cultivation to increase the rooftop gardening.

**Keywords:** Rooftop; building height; temperature; moisture; light intensity; growth; yield.

## 1. INTRODUCTION

Bangladesh is recognized as one of the vulnerable country which is facing many problems related to crop production, food scarcity, poverty etc due to adverse impact of climate change. In Bangladesh, there are total 543 urban areas (11 city corporations, 329 municipal corporations and 203 Upazila towns). Among these urban areas, Dhaka is the largest city by population and area, with a population of 19.10 million [1]. According to 2011 population census, Bangladesh has an urban population of 28%, with a growth rate of 2.8% [2]. At this growth rate, it is estimated that the urban population of Bangladesh will reach 79 million or 42% of total population by 2035. It has been reported that urban agriculture has most important contribution to meet the food demand as well as help to improve surrounding environment. Due to the fastest growth and development of urbanization, this process is also placing a great demand of food supply systems in the urban areas. Rooftop gardening is an important part of urban agriculture to grow different vegetables and fruits on the building roof. For this reason, urban agriculture or rooftop gardening is promoted as a potential solution to minimize this entire problem [3].

Rooftop gardening can be an effective method for ensuring food supply and satisfying nutritional needs of the inhabitants. As a part of urban vegetation, rooftop garden systems improve air quality and decrease urban temperature, extend roof life, reduce energy use, increase property value, pleasing work environment, increased ecological benefits (biodiversity) and economic benefits (source of crop production) etc. [4-5], including storm water management, energy conservation, mitigation of the urban heat island effect, increased longevity of roofing membranes, also provide a more aesthetically pleasing environment in which to work and live [6].

Rooftop gardening has additionally a promising plausible for small-scale enterprise that can speed up extra household income. Nevertheless, it may additionally generate some employment services via its backward and ahead linkages. The manufacturing of clean fruits and greens from the rooftop backyard can be multiplied dietary fame for family contributors of the city residents and it will make a high-quality contribution to the environment. Sajjaduzzaman [7] said that the most important reason of roof gardening is passing amusement time (100%), growing aesthetic values (100%), contributing in environmental amelioration (45%) and economic reap being a very minor subject (4% only) in Dhaka Metropolitan metropolis of Bangladesh.

Rooftop farming help to reduce the temperature of roofs and the surrounding air that contribute to overall cooling a local climate [8] and which also help to lessen urban heat island effect [4]. Rooftop farming can also help to absorb carbon emissions and noise [9]. Rain water is captured and absorbed by the plants and overflowing effect on infrastructure is also reduced [8].

Chili (*Capsicum annuum* L.) belongs to the nightshade family, Solanaceae which is originated from South America; the name comes from Nahuat via the Spanish word chili. Chili is an important spice crop in Bangladesh. Chilies are the fruits or berries of plants which belonging to the genus *Capsicum* under the family, Solanaceae. Chili is one of the most important domesticated spices in Bangladesh. It is grown throughout the year and used as green and dry stages for their pungency and color [10]. It is also a cash crop of the country [11]. In Bangladesh, chili crops occupies 103.24 thousand hectare of land with a production of 137 thousand metric tons [12].

Chili is an excellent source of vitamin A and C. Being richest source of vitamin C, it is sometimes referred as capsule of vitamin C [13]. The

pungency in chili is due to an alkaloid capsaicin ( $C_9H_{14}O_2$ ) which is a digestive stimulant. It contains high nutritive value with 1.29 mg/100 g protein, 11 mg/100 g calcium, 870 I.U vitamins-A, 175 mg ascorbic acid, 0.06 mg thiamine, 0.03 mg riboflavin, 0.55 niacin per 100 g edible fruit and 321mg per 100 g of vitamin C [10]. They have beta carotene which is as much as that found in spinach of 180 mg per 100 g [14].

In the majority of cases, growth & yield performance of different vegetable crops in rooftop gardening depends on environmental factors (temperature, moisture content, light intensity, humidity etc). Fahim et al. [15], revealed that environmental factors (temperature at day & night and soil moisture content) effect the growth and yield of vegetable (tomato). High temperatures and low moisture condition inhibit the growth and production of chili [16], resulting in poor fertilization and fruit set reviewed in [17]. Development of plant is highly linked to temperature [18]. But in urban areas, the environmental factors (temperature, moisture, light intensity, humidity etc.) may be different on rooftop of different height of building.

Chili is a highly well-liked vegetable in Bangladesh among the probable vegetables. Unfortunately, not enough research has been done to determine how different building heights affect the growth and production of chili. In light of the aforementioned information, a well-known chili variety was chosen for this study's aim of analyzing the growth and yield performance of chili on rooftops of various building heights. Considering the above-mentioned facts, a famous chili variety was selected in this study to determine the growth & yield performance of chili on rooftop of different building height with the following objectives:

1. To evaluate the growth and yield contributing characteristics and yield of chili on rooftop of different height of buildings.
2. To determine the air temperature, soil temperature, soil moisture and light intensity on rooftop of different height of buildings.
3. To select the optimum height of building for chili production in rooftop gardening.

## 2. MATERIALS AND METHODS

### 2.1 Location of the Experiment

The experiment was conducted on the roofs of different buildings and Agroforestry research field

between 23°74/N latitude and 90°35/E longitudes with an altitude of 8.2 m, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh.

### 2.2 Plant Material

BARI Morich-3.

### 2.3 Treatments of the Replications

Rooftop of different height of buildings and ground level were used in the experiment.

- T<sub>1</sub> = Control (Ground level, 0.0 m)
- T<sub>2</sub> = Rooftop of three storied building (11.28 m)
- T<sub>3</sub> = Rooftop of six storied building (21.34 m)
- T<sub>4</sub> = Rooftop of ten storied building (34.75 m)

### 2.4 Experimental Design and Layout

The experiment was laid out in a Completely Randomized Design (CRD). It was carried out in pots of 14 cm<sup>2</sup> top surface area. Four replications (4 plots in ground and 12 rooftops of different building) were maintained for each treatment. Each replication contained four pots and each pot contained one seedling.

### 2.5 Raising of Seedlings

On November 15th, 2021, seeds were sown in the pot, and 50g of furadan was used as an insecticide. 5-8 days after sowing, the seedlings were emerged. For illness prevention, diathane M-45 was sprayed in the pot @ 2 g/l. The appropriate amount of irrigation, mulching, and weeding was done.

### 2.6 Pot Preparation, Manure and Fertilizer Application

Ten days before to seedling transplantation, plastic pots were filled with weed-free soil and fertilised with cow dung, urea, TSP, and MP for nitrogen, phosphorous, and potassium. The final pot soil was made using 318 kg of cow dung, 320 g of TSP, and 1/4 of 256 g of urea. The remaining 192 g of urea and 192 g of MP were consumed at a rate of 3 g/pot over three portions.

### 2.7 Uprooting and Transplanting of Seedlings

Seedlings of 35 days old on 21<sup>th</sup> December 2021 were uprooted separately from the pot and transplanted properly.

## 2.8 Intercultural Operations

Intercultural operations were done whenever needed for better growth and development. Intercultural operations followed in the experiment were:

**Irrigation:** Irrigation was provided once a day on the basis of need to the pots of ground level. Same amount of water was provided to all the pots.

**Weeding:** Weeding was done whenever it was necessary, mostly in vegetative stage for better growth and development.

**Staking:** Staking of each pot was done whenever it was necessary especially in vegetative and fruit setting stages for protecting the plants from leaning.

## 2.9 Harvesting

Since chili plants were semi-indeterminate type which continuously grown new stems, leaves and fruits. So fruits of the plants were harvested when the fruits turned into red color. Harvesting was started from 22<sup>th</sup> March, 2022 and was continued up to 14<sup>th</sup> April 2022.

## 2.10 Data Collection and Recording

Experimental Data were recorded from 15 days after transplanting and continued until last harvest. The following Data were recorded during the experimental period.

### 2.10.1 Air temperature of day and night (°C)

The air temperature of day at 12.00 pm and night at 10.00 pm was taken by help of Thermometer at 60 DAT, 65 DAT and 70 DAT. The temperature was taken in Celsius (°C).

### 2.10.2 Temperature of the pot soil (°C)

The temperature of the pot soil at 4.00 pm was taken by help of Thermometer at 60 DAT, 65 DAT and 70 DAT. The temperature was taken in Celsius (°C).

### 2.10.3 Moisture Content of the Soil (%)

The moisture content of the soil was taken at 4.00 pm by Moisture meter at 60 DAT, 65 DAT and 70 DAT. It was taken in Percentage.

### 2.10.4 Light intensity

Light intensity was measured by lux meter. The light intensity was recorded in lux.

### 2.10.5 Plant height (cm)

Plant height was measured from the sample plants in centimeter using measuring tape from the ground level to the tip of the highest leaf and means value was calculated. To observe the growth rate plant height was recorded at 15, 30, 45, 60 days after transplanting and final harvesting.

### 2.10.6 Plant stem diameter (cm)

Plant stem diameter was measured from the sample plants in centimeter using slide caliper. Stem diameter was recorded at 15, 30, 45, 60 days after transplanting and final harvesting.

### 2.10.7 Number of Leaves per Plant

Leaf number was counted from each plant at 15, 30, 45, 60 days after transplanting and final harvesting.

### 2.10.8 Number of Branches per Plant

The total number of branches per plant was counted from each plant at 30 DAT, 45 DAT, 60 DAT and final harvesting.

### 2.10.9 SPAD value

SPAD value of the plant was measured by using SPAD-meter (spectrophotometer) at 65 and 70 DAT.

### 2.10.10 Days to 1<sup>st</sup> flowering

Number of days from transplanting to 1<sup>st</sup> flowering was observed from every replication.

### 2.10.11 Number of flowers per plant

Number of flowers from every chili plant was recorded at 45 DAT, 60 DAT and 75 DAT by counting.

### 2.10.12 Days to 1<sup>st</sup> Fruit Setting

Number of days from transplanting to 1<sup>st</sup> fruiting was observed from every replication.

### 2.10.13 Number of fruits per plant

The number of fruits per plant was counted and recorded.

### 2.10.14 Days to 1<sup>st</sup> fruit ripening

From transplanting date, days to 1<sup>st</sup> fruit ripening was observed from every replication.

### 2.10.15 Fresh weight and dry weight of plant (g)

Fresh weight of plant was calculated by measuring the weight of a plant including root and was recorded in gram (g).

Dry weight of plant was calculated by oven dry for 24 hours of the plant then measured with a weight machine and was recorded in gram (g).

### 2.10.16 Single fruit weight (g)

Fruits were only harvested when fully ripe. Ten fruits from each plant were randomly selected each time fruits were picked. The weight of each selected fruit was measured in grammas (g) using a weight machine and the average value was computed and displayed as the weight of a single fruit.

### 2.10.17 Single fruit length (cm)

Fruits were picked once they had ripened. Ten fruits from each plant were randomly chosen at the time of each harvest. Using a slide caliper, the length of each chosen fruit was measured in centimeters (cm) from the fruit's neck to its bottom, and the average was determined, showing the length of a single fruit.

### 2.10.18 Single fruit diameter (cm)

Fruits were picked once they had ripened. At the time of each harvest, 10 distinct fruits from each plant were chosen at random. With a slide

caliper, the diameter of each chosen fruit was measured in the middle and recorded in centimeters (cm). The average value was calculated and represented as the diameter of a single fruit.

### 2.10.19 Fresh weight and dry weight of fruit yield per plant (g)

Fresh weight of fruit yield per plant was calculated by using formula: (Fresh fruit yield = Number of total fruit × Single fruit weight) from first to final harvest of a plant and was recorded in gram (g).

Dry weight of fruit yield per plant was calculated after oven dry for 24 hours of the yield per plant, then measured with a weight machine and was recorded in gram (g).

## 2.11 Statistical Analysis

All the obtained data were subjected to compiled and analyzed by Microsoft Excel Worksheet and Statistix 10 software and the mean differences were adjudged by least significant difference (LSD) test at 5% level of significance.

## 3. RESULTS AND DISCUSSION

The results of the experiment have been presented and discussed in this section with a view to determining the soil temperature, light intensity, soil moisture, daytime and nighttime air temperatures, and the growth, yield-contributing traits, and yield performance of chili on various building rooftop heights. Different tables and graphics display the data. The outcomes have been talked about, and pertinent interpretations are shown under the following headings:

### 3.1 Air temperature at Day and Night (°C)

**Table 1. Air temperature of day and night on rooftop of different height of buildings at different days after transplanting (DAT)**

Treatments	Air Temperature of Day (°C)			Air Temperature of Night (°C)		
	60 DAT	65 DAT	70 DAT	60 DAT	65 DAT	70 DAT
T <sub>1</sub>	30.23 d	29.7 d	30.01 d	23.21 d	23.73 d	25.36 d
T <sub>2</sub>	31.01 c	30.41 c	32.6 c	25.7 c	26.76 c	29.58 c
T <sub>3</sub>	31.61 b	31.12 b	33.73 b	26.75 b	27.84 b	30.49 b
T <sub>4</sub>	32.50 a	32.99 a	34.34 a	29.04 a	28.55 a	30.28 a
CV (%)	1.24	1.06	1.00	2.00	1.83	1.22
LSD (0.05)	0.57	0.51	0.36	0.81	0.75	0.25

Note: Here, DAT= Days after transplanting, T<sub>1</sub>= Control (Ground level, 0.0 m), T<sub>2</sub>= Rooftop of three storied building (11.28 m), T<sub>3</sub>= Rooftop of six storied building (21.34 m) and T<sub>4</sub>= Rooftop of ten storied building (34.75 m), CV= Coefficient of variation, LSD= Least significant difference. In a column, means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

The air temperature of day and night at 60 DAT, 65 DAT and 70 DAT, highest air temperature was recorded in T<sub>4</sub> which was significantly higher than T<sub>1</sub>, T<sub>2</sub> and T<sub>3</sub>. The lowest air temperature of day and night was recorded in T<sub>1</sub> at 60 DAT, 65 DAT and 70 DAT which was compared with T<sub>2</sub>, T<sub>3</sub> and T<sub>4</sub>. In every case, T<sub>2</sub> and T<sub>3</sub> showed significantly lower air temperature of day and night than T<sub>4</sub> and T<sub>3</sub> was significantly higher than T<sub>2</sub>. The sequence of day and night air temperature were T<sub>4</sub>>T<sub>3</sub>>T<sub>2</sub>>T<sub>1</sub> (Table 1). Fahim et al. [15], also found the same result and they observed that the air temperature of day and night were increased with the increased of building rooftop height.

### 3.2 Temperature of the Pot Soil

The temperature of the pot soil at 60 DAT, 65 DAT and 70 DAT, highest temperature of the pot soil was recorded in T<sub>4</sub> which was significantly higher than T<sub>1</sub>, T<sub>2</sub> and T<sub>3</sub>; the lowest temperature of the pot soil was recorded in T<sub>1</sub> which was compared with T<sub>2</sub>, T<sub>3</sub> and T<sub>4</sub>, except T<sub>3</sub> showed statistically similar result with T<sub>4</sub> at 60 DAT. In every case, T<sub>2</sub> and T<sub>3</sub> showed significantly lower temperature of the pot soil than T<sub>4</sub> and T<sub>3</sub> was

significantly higher than T<sub>2</sub>. The sequence of temperature of the pot soil was T<sub>4</sub>>T<sub>3</sub> >T<sub>2</sub>>T<sub>1</sub> (Table 2). Fahim et al. [15] also found the same result and they observed that the temperature of pot soil was increased with the increased of building rooftop height.

### 3.3 Moisture Content of the Pot Soil

The moisture content of the pot soil at 60 DAT and 65 DAT, highest moisture content of the pot soil was recorded in T<sub>1</sub> which was significantly higher than T<sub>2</sub>, T<sub>3</sub> and T<sub>4</sub>; the lowest moisture content of the pot soil was recorded in T<sub>4</sub> was compared with T<sub>3</sub>, T<sub>2</sub> and T<sub>1</sub>. In every case, T<sub>2</sub> and T<sub>3</sub> showed significantly higher moisture content of the pot soil than T<sub>4</sub> and T<sub>2</sub> was significantly higher than T<sub>3</sub>. At 70 DAT, T<sub>1</sub>, T<sub>2</sub> and T<sub>3</sub> showed statistically similar result. The sequence of moisture content of the pot soil was T<sub>4</sub><T<sub>3</sub> <T<sub>2</sub><T<sub>1</sub> (Table 3). As increase in building height of rooftop with a decrease moisture content of pot soil is associated with the study of Fahim et al. [15] which was moisture content of the pot soil was decreased with the increased of building rooftop height.

**Table 2. Temperature of the pot soil of chili on rooftop of different height of buildings at different days after transplanting (DAT)**

Treatments	Temperature of Pot Soil (°C)		
	60 DAT	65 DAT	70 DAT
T <sub>1</sub>	28.5 c	31.71 d	31.41 d
T <sub>2</sub>	31.5 b	32.78 c	32.66 c
T <sub>3</sub>	32.5 ab	33.98 b	34.01 b
T <sub>4</sub>	33.4 a	34.98 a	35.33 a
CV (%)	2.19	1.70	1.14
LSD(0.05)	1.06	0.87	0.58

Note: Here, DAT= Days after transplanting, T<sub>1</sub>= Control (Ground level, 0.0 m), T<sub>2</sub> = Rooftop of three storied building (11.28 m), T<sub>3</sub> = Rooftop of six storied building (21.34 m) and T<sub>4</sub> = Rooftop of ten storied building (34.75 m), CV= Coefficient of variation, LSD= Least significant difference. In a column, means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

**Table 3. Moisture content of the pot soil of chili on rooftop of different height of buildings at different days after transplanting (DAT)**

Treatments	Moisture Content of Pot Soil (%)		
	60 DAT	65 DAT	70 DAT
T <sub>1</sub>	24.53 a	24.20 a	23.56 a
T <sub>2</sub>	22.65 b	22.64 b	21.73 ab
T <sub>3</sub>	20.59 c	20.85 c	20.11 b
T <sub>4</sub>	18.71 d	17.98 d	19.03 c
CV (%)	2.27	2.80	2.95
LSD(0.05)	0.76	0.92	0.77

Note: Here, DAT= Days after transplanting, T<sub>1</sub>= Control (Ground level, 0.0 m), T<sub>2</sub> = Rooftop of three storied building (11.28 m), T<sub>3</sub> = Rooftop of six storied building (21.34 m) and T<sub>4</sub> = Rooftop of ten storied building (34.75 m), CV= Coefficient of variation, LSD= Least significant difference. In a column, means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

### 3.4 Light Intensity

Fig. 1 showed that, there was statistical difference among T<sub>1</sub>, T<sub>2</sub>, T<sub>3</sub>, and T<sub>4</sub>. Highest light intensity was found in T<sub>4</sub> which was 1515.3 lux. Lowest light intensity was found in T<sub>1</sub> which was 1109.8 lux. In T<sub>3</sub> light intensity was significantly higher than T<sub>2</sub> (Fig. 1). Light intensity showed an increasing sequence with the increasing of building height of rooftop. The sequence of light intensity was T<sub>4</sub>>T<sub>3</sub>>T<sub>2</sub>>T<sub>1</sub>.

### 3.5 Plant Height

At 15 DAT, 30 DAT, 45 DAT, 60 DAT and Final harvest, the tallest plants were found in T<sub>1</sub> which was significantly higher than T<sub>2</sub>, T<sub>3</sub> and T<sub>4</sub>; the shortest plants were observed in T<sub>4</sub> which was compared with T<sub>1</sub>, T<sub>2</sub> and T<sub>3</sub>. In every case, T<sub>2</sub> and T<sub>3</sub> showed significantly higher plant height than T<sub>4</sub> and T<sub>2</sub> was significantly higher than T<sub>3</sub> (Table 4). It was noted that plant height at 15 DAT, 30 DAT, 45 DAT, 60 DAT and Final harvest showed a decreasing plant height with the

increase of building height of rooftop. The sequence of plant height was T<sub>1</sub>>T<sub>2</sub>>T<sub>3</sub>>T<sub>4</sub>. As increase in building height of rooftop with an increase air temperature of day & night, temperature of pot soil but moisture content of pot soil decreased which inversely affected on plant height; high air temperature and low soil moisture occurred due to increased height of building rooftop, plant height decreased [15]. High temperature affects plant life process by affecting the stability of various proteins, membranes creates metabolic imbalance ultimately reduced plant height [19-21]. Soil moisture affected the vegetative growth of tomato and severe moisture stress (40% of PC) decreased the plant height by 24% compared to the control [22-23].

### 3.6 Plant Stem Diameter

At 15 DAT, 30 DAT, 45 DAT, 60 DAT and Final harvest, the highest plant stem diameter was found in T<sub>1</sub> which was significantly higher than T<sub>2</sub>, T<sub>3</sub>, and T<sub>4</sub>; the lowest plant stem diameter

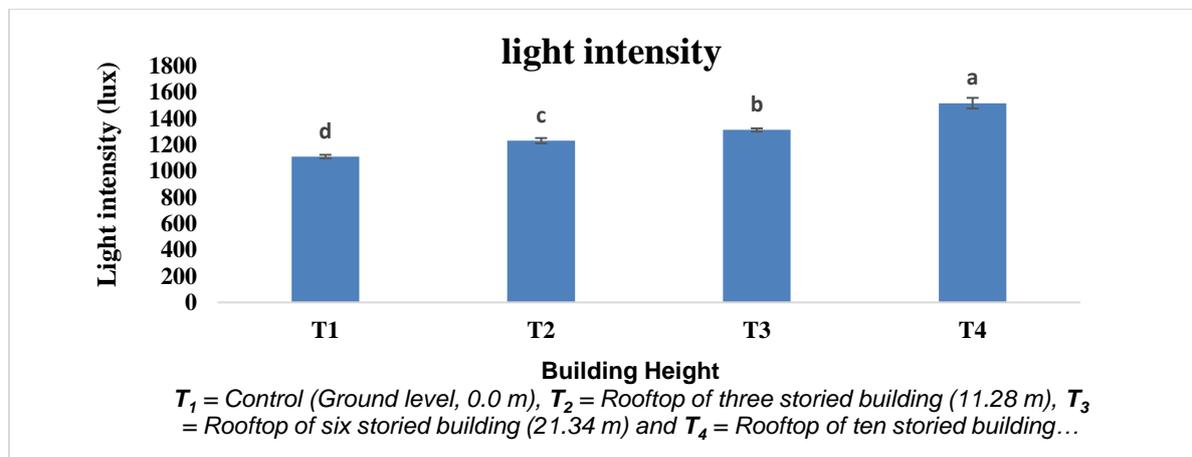


Fig. 1. Light intensity on rooftop of different height of buildings

Table 4. Plant height (cm) of chili on rooftop of different height of buildings at different days after transplanting (DAT)

Treatments	Plant Height (cm)				
	15 DAT	30 DAT	45 DAT	60 DAT	Final harvest
T <sub>1</sub>	29.72 a	42.84 a	56.14 a	66.13 a	74.37 a
T <sub>2</sub>	26.73 b	38.23 b	51.26 b	61.10 b	63.03 b
T <sub>3</sub>	24.54 c	35.57 c	45.12 c	54.96 c	56.35 c
T <sub>4</sub>	21.45 d	29.37 d	40.45 d	48.93 d	50.09 d
CV (%)	4.46	5.10	4.92	8.22	6.11
LSD (0.05)	1.76	2.83	3.65	4.02	5.73

Note: Here, DAT= Days after transplanting, T<sub>1</sub>= Control (Ground level, 0.0 m), T<sub>2</sub> = Rooftop of three storied building (11.28 m), T<sub>3</sub> = Rooftop of six storied building (21.34 m) and T<sub>4</sub> = Rooftop of ten storied building (34.75 m), CV= Coefficient of variation, LSD= Least significant difference. In a column, means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

**Table 5. Plant stem diameter (cm) of chili on rooftop of different height of buildings at different days after transplanting (DAT)**

Treatments	Plant Stem Diameter (cm)				
	15 DAT	30 DAT	45 DAT	60 DAT	Final harvest
T <sub>1</sub>	0.35 a	0.47 a	0.66 a	0.87 a	0.93 a
T <sub>2</sub>	0.32 b	0.44 b	0.63 b	0.82 b	0.89 b
T <sub>3</sub>	0.29 c	0.41 c	0.59 c	0.79 c	0.84 c
T <sub>4</sub>	0.26 d	0.38 d	0.55 d	0.73 d	0.79 d
CV (%)	4.91	2.31	2.33	1.93	0.91
LSD (0.05)	0.02	0.02	0.02	0.02	0.01

Note: Here, DAT= Days after transplanting, T<sub>1</sub>= Control (Ground level, 0.0 m), T<sub>2</sub> = Rooftop of three storied building (11.28 m), T<sub>3</sub> = Rooftop of six storied building (21.34 m) and T<sub>4</sub> = Rooftop of ten storied building (34.75 m), CV= Coefficient of variation, LSD= Least significant difference. In a column, means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

were observed in T<sub>4</sub> which was compared with T<sub>1</sub>, T<sub>2</sub> and T<sub>3</sub>. In every case, T<sub>2</sub> and T<sub>3</sub> showed significantly higher plant stem diameter than T<sub>4</sub> and T<sub>2</sub> was significantly higher than T<sub>3</sub>. An inverse relationship was noted between plant stem diameters and building height, where plant stem diameter at 15 DAT, 30 DAT, 45 DAT, 60 DAT and Final harvest showed a decreasing sequence of plant stem diameter with the increase of building height of rooftop. The sequence of plant stem diameter was T<sub>1</sub> > T<sub>2</sub> > T<sub>3</sub> > T<sub>4</sub> (Table 5). High air temperature and low soil moisture occurred due to increased height of building rooftop, plant stem diameter decreased [15]. High temperature affects plant process like inhibits plant stem growth, development as a result decrease the plant stem diameter [24-27]. Severe moisture stress (40% of PC) decreased the plant stem diameter by 24% compared to the control [23]. Light quality affected significantly stem of pepper [28].

### 3.7 Leaf Number per Plant

Leaf number was recorded at 15 DAT, 30 DAT, 45 DAT, 60 DAT and Final harvest, the highest

leaf number was found in T<sub>1</sub> which was significantly more than T<sub>2</sub>, T<sub>3</sub>, and T<sub>4</sub>. But at 15 DAT, the leaf number at T<sub>2</sub>, T<sub>3</sub> and T<sub>4</sub> were statistically similar but lower than T<sub>1</sub> and at 30 DAT, there were no statistically difference in number of leaf per plant observed between T<sub>3</sub> and T<sub>4</sub> with increasing building height. In every case, the lowest number of leaf was found in T<sub>4</sub>. At 45 DAT, 60 DAT and Final harvest, leaf number per plant showed a reverse relationship with the increasing of building rooftop height. The sequence of leaf number per plant was T<sub>1</sub> > T<sub>2</sub> > T<sub>3</sub> > T<sub>4</sub> (Table 6). As increase in building height of rooftop with an increase air temperature of day & night, temperature of pot soil but moisture content of pot soil decreased which adversely affected on leaf number of plant and decreased the leaf number of plant [15]. Soil moisture affected the vegetative growth of tomato and severe moisture stress (40% of PC) decreased the plant height by 24% compared to the control [22-23]. It was found that expansion growth of plant leaf is extremely sensitive to water stress [29-30] and that reduced the number of leaf per plant [31].

**Table 6. Leaf number of chili on rooftop of different height of buildings at different days after transplanting (DAT)**

Treatments	Leaf Number per Plant				
	15 DAT	30 DAT	45 DAT	60 DAT	Final harvest
T <sub>1</sub>	14.38 a	67.69 a	168.19 a	192.94 a	212.5 a
T <sub>2</sub>	11.06 b	63.00 b	158.06 b	182.19 b	195.27 b
T <sub>3</sub>	10.25 bc	54.88 c	147.94 c	170.06 c	185.6 c
T <sub>4</sub>	9.44 c	49.00 c	137.82 d	160.63 d	175.12 d
CV (%)	7.08	7.11	2.74	2.91	3.04
LSD (0.05)	1.23	2.95	6.46	7.90	9.01

Note: Here, DAT= Days after transplanting, T<sub>1</sub>= Control (Ground level, 0.0 m), T<sub>2</sub> = Rooftop of three storied building (11.28 m), T<sub>3</sub> = Rooftop of six storied building (21.34 m) and T<sub>4</sub> = Rooftop of ten storied building (34.75 m), CV= Coefficient of variation, LSD= Least significant difference. In a column, means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

### 3.8 Branch Number per Plant

At 30 DAT, the highest number of branch per plant was found at T<sub>1</sub> which was statistically similar with T<sub>2</sub> and the lowest number of branch per plant was recorded in T<sub>4</sub>. Similar number of branch per plant recorded in T<sub>2</sub> and T<sub>3</sub> but statistically higher than T<sub>4</sub>. At 45 DAT, at 60 DAT and at Final harvest the highest number of branch per plant was recorded at the ground level (T<sub>1</sub>) which was and the lowest number of branch per plant was recorded in T<sub>4</sub>. Plant number of branch per plant recorded in T<sub>2</sub> and T<sub>3</sub> which were higher than T<sub>4</sub> but lower than T<sub>1</sub>. However, there was an opposite relationship observed between number of branch per plant and building height, where number of branch per plant showed a decreased sequence of number of branch per plant with an increasing building height of rooftop. The sequence of branch number per plant was T<sub>1</sub>>T<sub>2</sub>>T<sub>3</sub>>T<sub>4</sub> (Table 7). High air temperature and low soil moisture occurred due to increased height of building rooftop, number of branch per plant decreased [15]. High air temperature and low moisture

content of pot soil occurred due to increased building rooftop height that affected the branch number of plant [32-35], revealed the adverse effect of high temperature on the vegetative development in tomato plants. It was found that expansion growth of plant leaf is extremely sensitive to water stress [29-30] and that reduced the number of branch per plant [31].

### 3.9 Chlorophyll Content of Chili Leaf

At 65 DAT and at 70 DAT, the lowest SPAD value was calculated at T<sub>4</sub> and the highest SPAD value was found in T<sub>2</sub> and T<sub>1</sub>. There was no statistically difference among T<sub>1</sub>, T<sub>2</sub>, T<sub>3</sub> and T<sub>4</sub> (Table 8). The similar result was observed in the study of Fahim et al. [15]. At different building height of rooftop garden, chlorophyll content of leaf tissue is influenced by nutrient unavailability and environmental stresses (such as drought, salinity, cold and heat etc.), but in order to same nutrient, soil pH, and not extreme or drought condition of plant chlorophyll content was not affected significantly [36].

**Table 7. Branch number of chili on rooftop of different height of buildings at different days after transplanting (DAT)**

Treatments	Branch Number per Plant			
	30 DAT	45 DAT	60 DAT	Final harvest
T <sub>1</sub>	17.69 a	33.25 a	39.44 a	40.50 a
T <sub>2</sub>	16.44 ab	31.13 b	38.19 b	38.75 b
T <sub>3</sub>	15.06 b	27.88 c	34.00 c	35.31 c
T <sub>4</sub>	13.31 c	26.13 d	31.38 d	32.44 d
CV (%)	5.90	3.04	1.88	2.32
LSD(0.05)	1.41	1.38	1.03	1.31

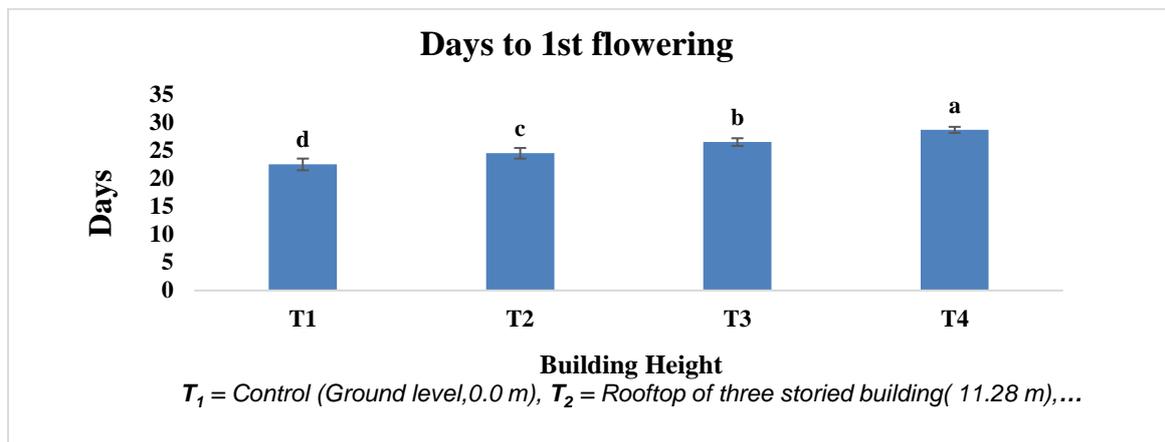
Note: Here, DAT= Days after transplanting, T<sub>1</sub>= Control (Ground level, 0.0 m), T<sub>2</sub>= Rooftop of three storied building (11.28 m), T<sub>3</sub>= Rooftop of six storied building (21.34 m) and T<sub>4</sub>= Rooftop of ten storied building (34.75 m), CV= Coefficient of variation, LSD= Least significant difference. In a column, means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

**Table 8. SPAD value chili on rooftop of different height of buildings at different days after transplanting (DAT)**

Treatments	SPAD Value	
	65 DAT	70 DAT
T <sub>1</sub>	59.05	60.19
T <sub>2</sub>	60.31	58.74
T <sub>3</sub>	56.68	59.02
T <sub>4</sub>	55.10	57.86
CV (%)	8.42	8.53
LSD(0.05)	NS	NS

Note: Here, DAT= Days after transplanting, T<sub>1</sub>= Control (Ground level, 0.0 m), T<sub>2</sub>= Rooftop of three storied building (11.28 m), T<sub>3</sub>= Rooftop of six storied building (21.34 m) and T<sub>4</sub>= Rooftop of ten storied building (34.75 m), CV= Coefficient of variation, LSD= Least significant difference, NS= Non-significant. In a column, means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of probability

### 3.10 Days to 1<sup>st</sup> Flowering



**Fig. 2. Days to 1<sup>st</sup> flowering of chili on rooftop of different height of buildings**

Fig. 2 showed that in terms of days to 1<sup>st</sup> flowering the highest days (29 DAT) took the 1<sup>st</sup> flowering observed in T<sub>4</sub> which was statistically higher than T<sub>1</sub>, T<sub>2</sub> and T<sub>3</sub>; the lowest days (23 DAT) took in T<sub>1</sub> which was compared with other treatments. In T<sub>3</sub> was statistically higher than T<sub>2</sub>. However, days to 1<sup>st</sup> flowering showed affirmative relationship with increasing building height of rooftop. The sequence of days to 1<sup>st</sup> flowering was T<sub>4</sub>>T<sub>3</sub>>T<sub>2</sub>>T<sub>1</sub>. High temperature affected on the reproductive development (flowering stage, fruiting stage etc.) in winter vegetables (tomato) plants and under a high temperature condition leading to late flowering [32-35]. High temperatures and low moisture condition inhibit the growth of chili, resulting late flowering [16]. High temperature delayed flowering of Pepper plant [37].

### 3.11 Number of Flowers per Plant

At 45 DAT, 60 DAT and 75 DAT, the highest number of flowers per plant was recorded in T<sub>1</sub> which was significantly higher than T<sub>2</sub>, T<sub>3</sub> and T<sub>4</sub> and the lowest number of flowers per plant was recorded in T<sub>4</sub> which was compared with T<sub>1</sub>, T<sub>2</sub> and T<sub>3</sub>. In every case, T<sub>2</sub> and T<sub>3</sub> showed significantly higher number of flower per plant than T<sub>4</sub> and T<sub>2</sub> was significantly higher than T<sub>3</sub>. The sequence of number of flower per plant was T<sub>1</sub>>T<sub>2</sub>>T<sub>3</sub>>T<sub>4</sub> (Table 9). As increase in building height of rooftop with an increase air temperature of day & night, temperature of pot soil but moisture content of pot soil decreased which adversely affected on number of flower per plant; high air temperature and low soil moisture occurred due to increased height of building rooftop, number of flower per plant decreased

[15]. Flower of plant abortion due to high-temperature correlated with increases in Ethylene, ACC, and ABA and decreases in IAA, Cytokinin, and polyamine ultimately reduced flower number of plant [38-39]. Heat stress responsible severe damage to spikelet, disrupts cytokinin synthesis, causes peroxide accumulation, decreases sugar levels, and damages cell construction as a result reduced flower number of pant [40-43]. Ibukun TA and Kelly TM [44], revealed that the winter Vegetables (tomato) drop flowers when exposed to several days of daytime temperature above 29°C and nighttime temperature above 21°C.

### 3.12 Days to 1<sup>st</sup> Fruiting

Fig. 3 showed that in terms of days to 1<sup>st</sup> fruiting the highest days (49 DAT) took the 1<sup>st</sup> fruiting observed in T<sub>4</sub> which was statistically higher than T<sub>1</sub>, T<sub>2</sub> and T<sub>3</sub>; the lowest days (43 DAT) took in T<sub>1</sub> which was compared with other treatment. In T<sub>3</sub> was statistically higher than T<sub>2</sub>, where T<sub>1</sub> and T<sub>2</sub> showed statistically same result. High temperatures and low moisture condition inhibit the growth and production of chili [16], resulting in poor fertilization and fruit set as a result late fruiting reviewed in (Snider et al. 2011). High temperature inhibits the development of pollen grains and reduces the pollen viability lead to late fruit setting of sweet pepper [45]. High temperature delayed fruiting of Pepper plant [37].

### 3.13 Number of Fruits per Plant

The highest number of fruits (102.31) per plant was found at T<sub>1</sub> which was statistically higher than T<sub>2</sub>, T<sub>3</sub> and T<sub>4</sub> and the lowest number of fruits

(59.11) per plant was recorded in T<sub>4</sub> which was compared with other treatments. In T<sub>2</sub> was statistically higher than T<sub>3</sub> (Fig. 4). However, there was an inverse relationship observed between number of fruits per plant and building height, where number of fruits per plant decreased as building height increased. The sequence of number of fruits per plant was T<sub>1</sub> > T<sub>2</sub> > T<sub>3</sub> > T<sub>4</sub> (Fig. 4). As increase in building height of rooftop with an increase air temperature of day & night, temperature of pot soil but moisture content of pot soil decreased which adversely affected on number of fruits per plant; high air temperature and low soil moisture occurred due to increased height of building rooftop, number of fruits per plant decreased [15]. With high temperature stress, a study reported reductions in the number of fruit in tomatoes [46-47] and rice [48]. Drought affects plant's assimilatory organs,

which usually decrease in number of fruits per plant [49-52].

### 3.14 Days to 1<sup>st</sup> Fruit Ripening

Fig. 5 showed that 1<sup>st</sup> fruit ripening was observed in T<sub>4</sub> which took the least time of 79 days after transplanting and the longest time of 86 days after transplanting took to make the 1<sup>st</sup> fruit ripening observed in T<sub>1</sub>. In T<sub>2</sub> and T<sub>3</sub>, days took to 1<sup>st</sup> fruit ripening was observed 84 DAT and 82 DAT respectively. Days to 1<sup>st</sup> fruit ripening in T<sub>1</sub>, T<sub>2</sub>, T<sub>3</sub> and T<sub>4</sub> were statistically different from each other. The sequence of days to 1<sup>st</sup> fruit ripening was T<sub>1</sub> > T<sub>2</sub> > T<sub>3</sub> > T<sub>4</sub>. Fahim et al. [15] also found that the air temperature of day and night were increased and soil moisture decreased with the increased of building rooftop height, high temperature helped to reaching harvest maturity

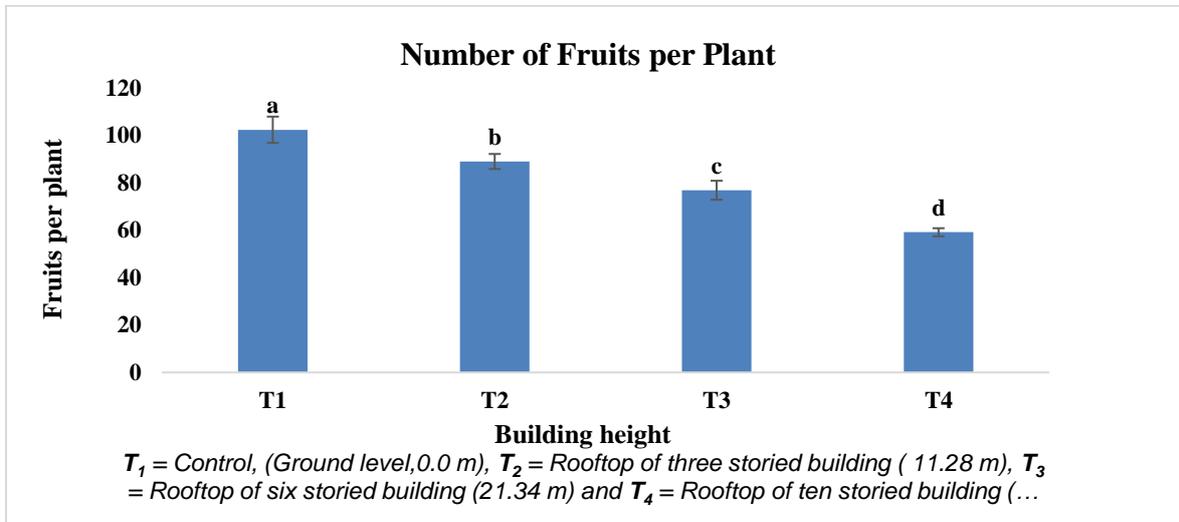


Fig. 4. Number of fruits per chili plant on rooftop of different height of buildings

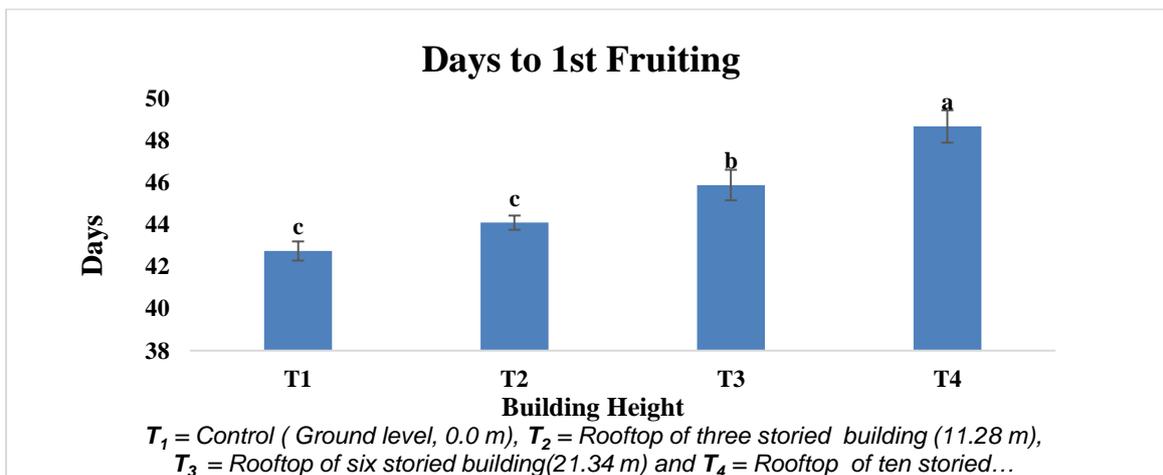
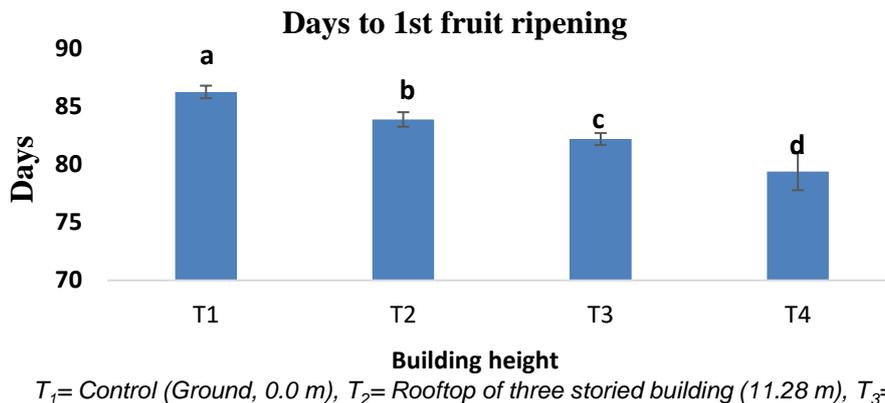


Fig. 3. Days to 1<sup>st</sup> fruiting of chili on rooftop of different height of buildings

**Table 9. Total number chili flower on rooftop of different height of buildings at different days after transplanting (DAT)**

Treatments	Number of Flowers per Plant		
	45 DAT	60 DAT	75 DAT
T <sub>1</sub>	57.13 a	42.62 a	27.88 a
T <sub>2</sub>	52.38 b	33.87 b	22.75 b
T <sub>3</sub>	46.56 c	27.68 c	18.46 c
T <sub>4</sub>	41.81 d	24.18 d	15.54 d
CV (%)	3.35	3.93	5.61
LSD(0.05)	2.55	1.94	1.83

Note: Here, DAT= Days after transplanting, T<sub>1</sub>= Control (Ground level, 0.0 m), T<sub>2</sub> = Rooftop of three storied building (11.28 m), T<sub>3</sub> = Rooftop of six storied building (21.34 m) and T<sub>4</sub> = Rooftop of ten storied building (34.75 m), CV= Coefficient of variation, LSD= Least significant difference. In a column, means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of probability



**Fig. 5. Days to 1<sup>st</sup> fruit ripening of chili on rooftop of different height of buildings**

of chili pepper at 45 and 55 days after sowing in HST (Huay Si Thon, Japan) and SST (Takii Co. Ltd, Japan) with the highest full-red fruits [53]. Hot pepper taken 7.6 and 5.4 days at temperatures of 25°C and 30°C and 11.0 and 16.5 days at temperature of 15 - 20°C days from green mature fruit to ripen fruit [54].

### 3.15 Fresh Weight and Dry Weight of Plant

The highest fresh weight (166.19 g) and dry weight (84.94 g) of plant was found in T<sub>1</sub> which was statistically higher than T<sub>2</sub>, T<sub>3</sub> and T<sub>4</sub>; the lowest fresh weight (96.15 g) and dry weight (30.81 g) of plant was recorded in T<sub>4</sub> which compared with T<sub>1</sub>, T<sub>2</sub> and T<sub>3</sub> (Fig. 6). Fresh weight and dry weight of plant recorded in T<sub>2</sub> and T<sub>3</sub> which were higher than T<sub>4</sub> and T<sub>2</sub> was statistically higher than T<sub>3</sub>. However, there was an inverse relationship observed between fresh weight & dry weight of plant and building height of rooftop, where fresh weight & dry weight of plant decreased as building height of rooftop

increased. The sequence of fresh weight & dry weight of plant were T<sub>1</sub> > T<sub>2</sub> > T<sub>3</sub> > T<sub>4</sub> (Fig. 6). Hatfield *et al.* 2011 and Zhao *et al.* 2017 [55-56], reported a decrease in production, fresh weight and dry weight of some plants due to high-temperature stress. Drought affects plant's assimilatory organs, which usually decrease in size of plant resulting in lower photosynthates production, ultimately reduced fresh weight and dry weight of plant [49-52].

### 3.16 Single Fruit Weight

The highest single fruit weight was found in T<sub>1</sub> (3.48 g) which was statistically higher than T<sub>2</sub>, T<sub>3</sub> and T<sub>4</sub>; the lowest single fruit weight was recorded in T<sub>4</sub> (1.95 g) which compared with others treatments. Fruit weight was recorded in T<sub>2</sub> and T<sub>3</sub> which were statistically higher than T<sub>4</sub> and T<sub>2</sub> was significantly higher than T<sub>3</sub>. However, single fruit weight showed a decreasing trend with increasing building height of rooftop. The trend of single fruit weight was T<sub>1</sub> > T<sub>2</sub> > T<sub>3</sub> > T<sub>4</sub> (Fig. 7). As increase in building height of rooftop with

an increase air temperature of day & night, temperature of pot soil but moisture content of pot soil decreased which adversely affected on single fruits weight of plant; high air temperature and low soil moisture occurred due to increased height of building rooftop, single fruits weight of plant decreased [15]. A decrease in the fruit weight due to temperature stress was also reported by [57-59]. Liu et al. [22] published that winter vegetables (Tomato) yield as affected by soil moisture during fruit development stage.

### 3.17 Single Fruit Length

Fig. 8 showed that the highest single fruit length was found in  $T_1$  (7.93 cm) which was statistically higher than  $T_2$ ,  $T_3$  and  $T_4$ ; the lowest single fruit weight was recorded in  $T_4$  (6.04 cm) which compared with others treatments. Fruit length

was recorded in  $T_2$  and  $T_3$  which were statistically higher than  $T_4$  and  $T_2$  was significantly higher than  $T_3$ . However, single fruit length showed a decreasing trend with increasing building height of rooftop. The trend of single fruit length was  $T_1 > T_2 > T_3 > T_4$  (Fig. 8). High air temperature and low soil moisture occurred due to increased height of building rooftop, single fruits length of plant decreased [15]. A decrease in the fruit length due to temperature stress was also reported by [57-59].

### 3.18 Single Fruit Diameter

The highest single fruit diameter (0.91 cm) was found at  $T_1$  which was statistically higher than  $T_2$ ,  $T_3$  and  $T_4$ ; the lowest fruit diameter (0.59 cm) was recorded in  $T_4$  which was compared with other treatments. Fruit diameter was recorded

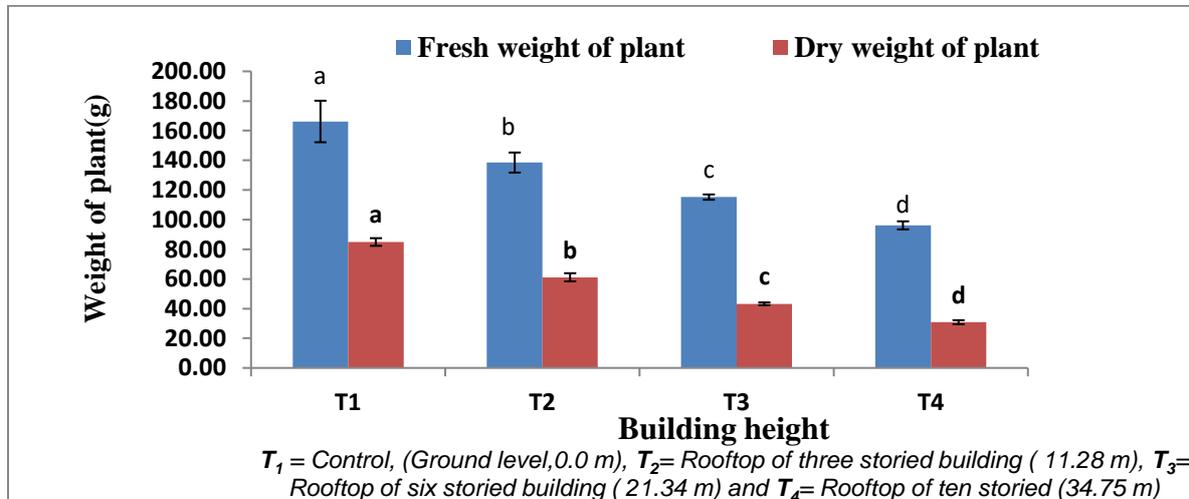


Fig. 6. Fresh weight and dry weight of chili plant on rooftop of different height of buildings

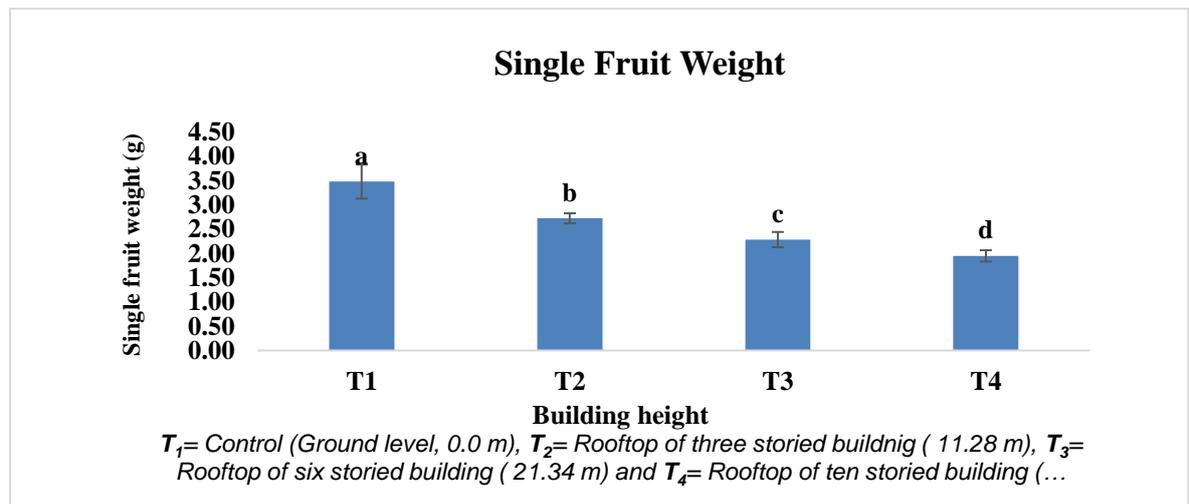


Fig. 7. Single fruit weight of chili on rooftop of different height of buildings

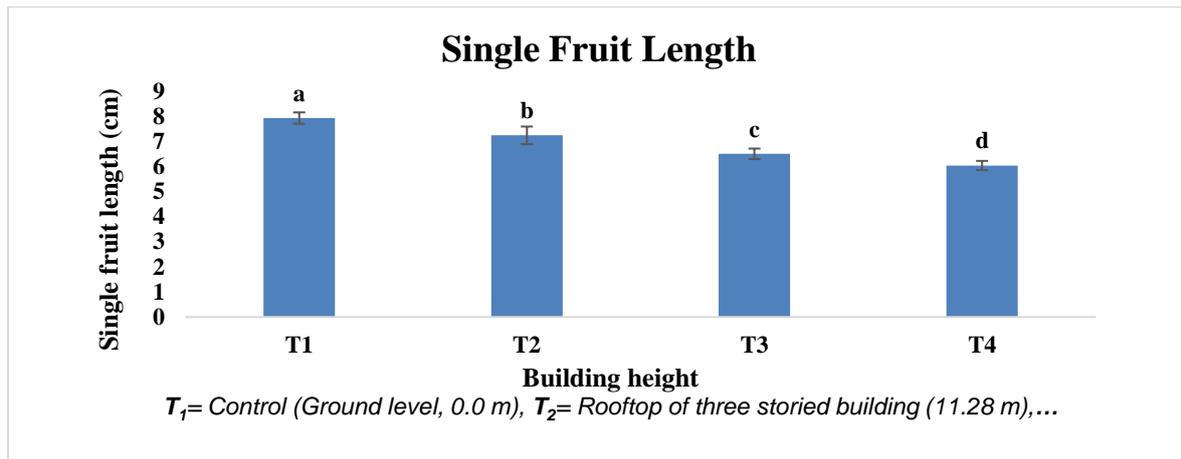


Fig. 8. Single fruit length of chili on rooftop of different height of buildings

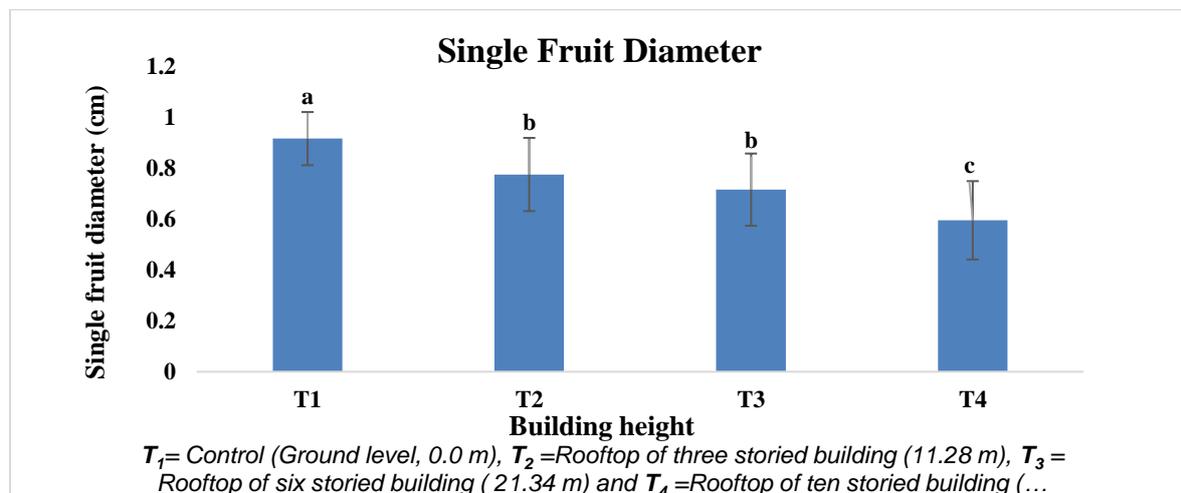


Fig. 9. Single fruit diameter of chili on rooftop of different height of buildings

in T<sub>2</sub> and T<sub>3</sub> which was statistically similar but higher than T<sub>4</sub> (Fig. 9). A decrease in the fruit diameter due to temperature stress was also reported by [57-59]. High air temperature and low soil moisture occurred due to increased height of building rooftop, single fruits diameter of plant decreased [15].

### 3.19 Fresh Weight and Dry Weight of Yield per Plant

Fig. 10 showed that the highest fresh weight (215.33 g) and dry weight (84.68 g) of fruit per plant was recorded in T<sub>1</sub> which was statistically higher than T<sub>2</sub>, T<sub>3</sub> and T<sub>4</sub>; the lowest fresh weight (136.88 g) and dry weight (40.98 g) of fruit per plant was recorded in T<sub>4</sub> which compared with the treatments (T<sub>1</sub>, T<sub>2</sub> and T<sub>3</sub>). Fresh weight and dry weight of fruit per plant was recorded in T<sub>2</sub> and T<sub>3</sub> which were statistically higher than T<sub>4</sub> and T<sub>2</sub> was significantly higher than T<sub>3</sub>. However,

fresh weight and dry weight of fruit per plant showed a decreasing trend with increasing building height of rooftop. The trend of fresh weight and dry weight of fruit per plant was T<sub>1</sub> > T<sub>2</sub> > T<sub>3</sub> > T<sub>4</sub> (Fig. 10). High temperatures during the reproductive stage will affect pollen viability, fertilization, and grain or fruit formation decreased the weight of fruits in plants and reduced the yield due to high-temperature stress of 6% in wheat, 3.2% in rice, 3.1% in soybean, and 7.4% in corn [55-56]. Lobell et al. [26] explained that each increase of 1°C caused a decrease in the production of up to 8.3% in corn. Drought affects plants which usually decrease yield due to less amount of assimilate available to the developing pods [49-52]. High air temperature and low soil moisture occurred due to increased height of building rooftop, fresh weight and dry weight of fruit per plant decreased [15].

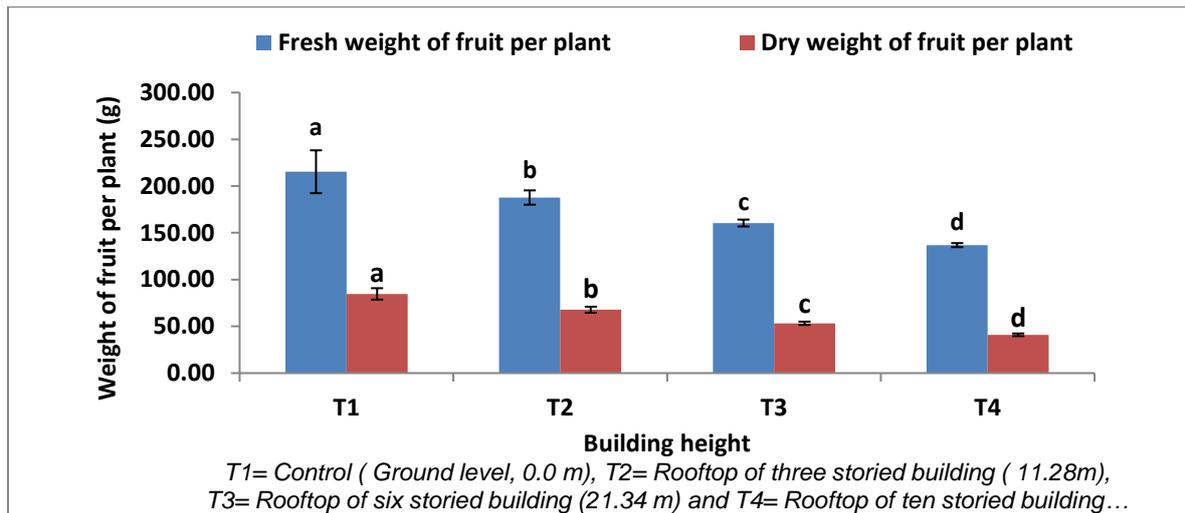


Fig. 10. Fresh weight of fruit per chili plant on rooftop of different height of buildings

#### 4. CONCLUSION

Different building height of rooftop revealed that the treatment T<sub>1</sub> had significantly highest moisture content of pot soil, growth, yield contributing characters and yield of chili plants which were significantly higher than all other treatments (T<sub>2</sub>, T<sub>3</sub> and T<sub>4</sub>) and T<sub>4</sub> showed significantly lowest result which compared with all other treatments (T<sub>1</sub>, T<sub>2</sub> and T<sub>3</sub>) but T<sub>2</sub> was significantly higher than T<sub>3</sub> and T<sub>4</sub>. The lowest light intensity, air temperature at day and night and temperature of pot soil was significantly found in T<sub>1</sub> which compared with all other treatments (T<sub>2</sub>, T<sub>3</sub> and T<sub>4</sub>) but the highest was found in T<sub>4</sub> which was significantly higher than all other treatments but T<sub>2</sub> and T<sub>3</sub> showed significantly lower result than T<sub>4</sub> and T<sub>2</sub> was statistically lower than T<sub>3</sub>. The sequence of moisture content of pot soil, growth, yield contributing characters and yield of chili plants were T<sub>1</sub>>T<sub>2</sub>>T<sub>3</sub>>T<sub>4</sub> but in case of light intensity, air temperature at day and at night and temperature of pot soil were T<sub>4</sub>>T<sub>3</sub>>T<sub>2</sub>>T<sub>1</sub>). The growth, yield, and yield-contributing characteristics of the chili plant reduced consecutively as the height of a building's rooftop gradually grew. The best production was achieved on the ground, however to boost rooftop gardening, chili (BARI Morich-3) can be grown up to the rooftop of a three-storied building.

#### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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