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# A comparison of onion seedling growth under various environmental conditions, with an emphasis on mechanical transplanting

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## Abstract

A healthy and robust seedling is one of the benchmarks for mechanical transplantation. The investigation aimed to see how different environmental conditions affect the growth of onion seedlings. Onion seedlings (varieties Puna Fursungi and Gavraan) were grown in an open field nursery compared to a protected structure *viz*., low tunnel and a 50 % shade net. During the nursery's growth period, environmental conditions such as temperature, humidity, and solar intensity were recorded. At 50 days after sowing, physical and mechanical properties were observed. Higher temperature was measured in a low tunnel structure, followed by shade net and open field. The shade net structure had the highest percentage of seedling survival (76.23 %), followed by the low tunnel (68.77 %) and the open field (58.37 %). Plant height was also greater in the shade net structure, followed by the low tunnel and open field conditions, respectively. This could be attributed to how plants compete for sunlight, water, aeration, and nutrition under different growing conditions. Except for plant height, all physical and mechanical properties were higher in open field conditions. Because of its adequate strength, the healthy seedling obtained from open field conditions was more suitable for mechanical transplanting.

**Key words**: Onion seedling, physical, mechanical properties, shade net, low tunnel.

## Introduction

Global warming has significant impact on agricultural production and environment, including an increase in atmospheric $CO_2$ concentrations, which may alter the interior quality of vegetable products or result in a reduction in photosynthetic activity (Shah and Shrivastava, 2017). Among others, the challenges brought upon by global warming include an increase in air temperature (AT) and solar radiation intensity which are the main cause to drive climate change, which possibly affects the yield and productivity of the agricultural crop (Chauhan *et al.*, 2014). As a result, improved farming technology is required to mitigate the adverse environmental impact on agricultural production. Modern farming technology *e.g.*, poly tunnel, shade net, greenhouse technology are increasingly being used to control the quality and quantity of ambient light to improve the yield, quality and provides favourable conditions for nursery growing. Pandiyaraj (2017) studied on modern protected structures for vegetable nursery raising and concluded that light is one of the prominent environmental factors. Light is an indispensable environmental factor in the life cycle of plants and is the main factor driving plant photosynthesis. Protected structures have become a successful solution in recent years for optimizing plant growth environment.

Healthy and strong seedlings are important aspects of mechanical transplanting. Its working mechanisms are prominently dependent on the various physical and mechanical properties of plant/ seedlings. Some researchers have shown the importance of engineering properties of plant to the effective working part of transplanting mechanism. Developed transplanter based on different mechanism such as gravity drop (Nandede *et al.*, 2017), plug and finger type (Pandirwar *et al.*, 2019) and multi stack of metering wheel with slotted plate (Nandede *et al.*, 2013) worked effectively with higher efficiency due to the enough compressive strength of seedlings and desired physical properties, which could be easily synchronized with working mechanism and transplanted effectively. Developed robotic arm by Rahul *et al.* (2020) also worked based on the adequate strength of seedlings. Adequate environmental conditions are needed during the nursery stage to obtain healthy and strong seedlings.

Numerous studies have reported the impact of environmental conditions under various protected structures, with their research emphasizing on the impact on plant growth performance and yield during the time of harvesting. Muskmelon cultivation under polytunnel and open field was compared by Ranjan *et al.* (2019). The research showed that the number of leaves per plant, number of branches, vine length, number of fruits per plant, fruit diameter, and fruit yield/plant were significantly higher in poly tunnel cultivation. Singh (2020) conducted experiment on bottle guard crop under poly tunnel cultivation. The result reported higher fruit yield in ploytunnel due to raised temperature at flowering and fruiting stage. It gave early and improved crop under controlled environmental condition. Plants induced early flowering in the off-season under low tunnel (Kumar *et al.*, 2018).

Shade net structures are available with shade percentages of 15, 35, 40, 50, 75 and 90 %. Nangare *et al.* (2015) compared shade net structures with different heights and suggested that 35 % shade net gives the best result for tomato crop. In the same manner, the yield was found significantly higher and increased from 15.85 to 932.20 % under protected cultivation as compared to open field conditions (Negi *et al.*, 2013).

In various parts of the country biotic stress affects vegetable cultivation during rainy and post rainy seasons. Vegetables are damaged due to the severe influence of viruses as well as by adverse atmospheric changes. The onion (*Allium cepa* L.) is one of the important commercially valuable crops, which is very much sensitive, especially at the nursery stage. The onion nursery production was evaluated and compared by Tripathi and Lawande (2011), under different shade net structures. The final stand of the nursery after 45 days was found higher in hessian cloth shading (58.26 %) which was at par with 50 % agrished net (57.67 %). The higher seedling height and lower seedling girth were due to the lower sunlight to young plants by preventing the light through shading material. Similarly, seedling properties of onion were observed by Pandirwar *et al.* (2015), for mechanical transplanting. Physical properties of 50 days old seedlings were observed in the open field environment. The weight of seedling, bulb diameter, stem diameter, and height were observed as 0.57 g, 3.13 mm, 2.44 mm, and 176.5 mm, respectively for Pusa red variety. The compressive force of the seedling bulb and stem were recorded as 10.65 and 4.38 N, respectively.

Very few studies have been conducted regarding onion nursery raising to assess the nursery growth under protected cultivation. The objective of this research was to compare and evaluate the growth of onion seedlings raised under protected structures and open field environments with the aim to acquire healthy and strong seedling which would be suitable for either mechanical or automated transplanting.

## Materials and methods

The research was conducted on growth of onion seedlings under low tunnel, shed net and open field during November to December 2020 in Central Institute of Agricultural Engineering Bhopal, India (23.3159° N lat., 77.4039° E long.), to find out the effect of environmental conditions. Onion seeds were planted on the bed using a standard agronomic process and raised the effective onion nursery. A one-meter square bed was prepared for each block under all treatments. FYM (farmyard manure) was mixed with the soil before sowing to supply the basic nutrients to the seedlings. Liquid fertilizers were provided after sowing at a certain interval during nursery growth. Two varieties of onion namely Puna fursungi and Gavraan was planted under treatments- low poly tunnel, shade net and open field. Low polytunnel was made of 50 μ thick poly film with 8 mm gauge wire and placed in a hemispherical shape (Singh, 2020) with a height of 4’ in a north-south direction (Kumar *et al.*, 2017). It can reduce 20-30 % photosynthetically active radiation than open field environment (Cowan *et al.*, 2014). Additionally, the shade net (50 %) served to provide protection for another treatment, as reported by Tripathi *et al.* (2011). As a control treatment, open field was considered.

**Environmental factors**: The data pertaining to the continually changing atmosphere were recorded after sowing the onion seed into the bed. Environmental parameters like temperature, humidity, light radiance (Longwave radiation) and illuminance (visible range) were observed. Data were continuously recorded from zero to fifty days at 9 am and 1 pm, whereas the maximum solar intensity was acquired for each day. Atmospheric temperature and humidity were observed by using a hygrometer (model: testo 623). The long wave ultra violet light radiation (mW/cm$^2$) was measured by using a UV light meter (model: SDL470) with the help of UVA probe, which can capture the long wave in the spectrum of 390 to 280 nm. Additionally, Lux meter was used to measure light radiation or luminous intensity at visible spectrum, which was helpful to monitor and control the light regularly according to the crop requirement. Hence, the diverse factors were carefully monitored during onion nursery growth for up to 50 days. The final stand percentage and physical characteristics of onion seedlings were observed, which illustrated the distinctions between the treatments.

**Physical and mechanical parameters of seedlings**: Seedling or plant growth is directly impacted by the effect of climate change on agriculture. A percentage of the final stand was determined by counting the number of survived onion seedlings at a selected unit area after 50 days of sowing. Forty samples were collected from each treatment to find the all-basic physical parameter.

The dimensional properties of onion seedlings as girth, bulb diameter and height were measured by digital vernier caliper (make BAKER) having 0.1 mm resolution. Weight is another parameter which can be influenced by changing the environmental properties. The fresh seedling weight, bulb weight, and dry weight were measured and replicated thirty times under the treatment using a weighing balance (model: Citizen CY 304) having the least count of 0.0001 g.

Mechanical transplanting is much more dependent on seedling maturity. A seedling’s maturity might vary even at the same age based on environmental factors. As a result, seedlings grown in different environments may have a different hardness. The compressive force predict the magnitude of seedling’s compressive strength (Khadatkar *et al.*, 2020). It could vary corresponding to the environment conditions. To measure compressive strength for seedlings and bulbs, ten readings per treatment for each variety were taken using a texture analyser (TA.XT.Plus).

**Statistical analysis**: Statistical analysis was done by using two factorial completely randomized designs, performed with SAS 9.3 software. Additionally, a pairwise comparison test was used to look significance at $P$=0.05 using Tukey’s test.

## Results and discussion

The temperature increased at the initial week of onion seedling’s growth in the nursery. After some days, humidity and solar intensity varied as a result of climate change. In the initial ten days, the temperature was higher from 9 am to 1 pm, as indicated in Fig. 1.a, but the humidity seemed to be lower (Fig. 1.b) on clear, sunny days. Due to weather changes, the temperature however was slightly lower after second week. Solar intensity at long wave (UVA) and at visible range was changed (Figs. 1.c and d).

Temperature was found highest, due to increased $CO_2$ concentration in low tunnels. Previous researchers have also revealed elevated air temperatures in low tunnel and it ranged between 3-20°C than open field environment (Ogden *et al.*, 2009). Maximum average temperatures were recorded as 27.5°C

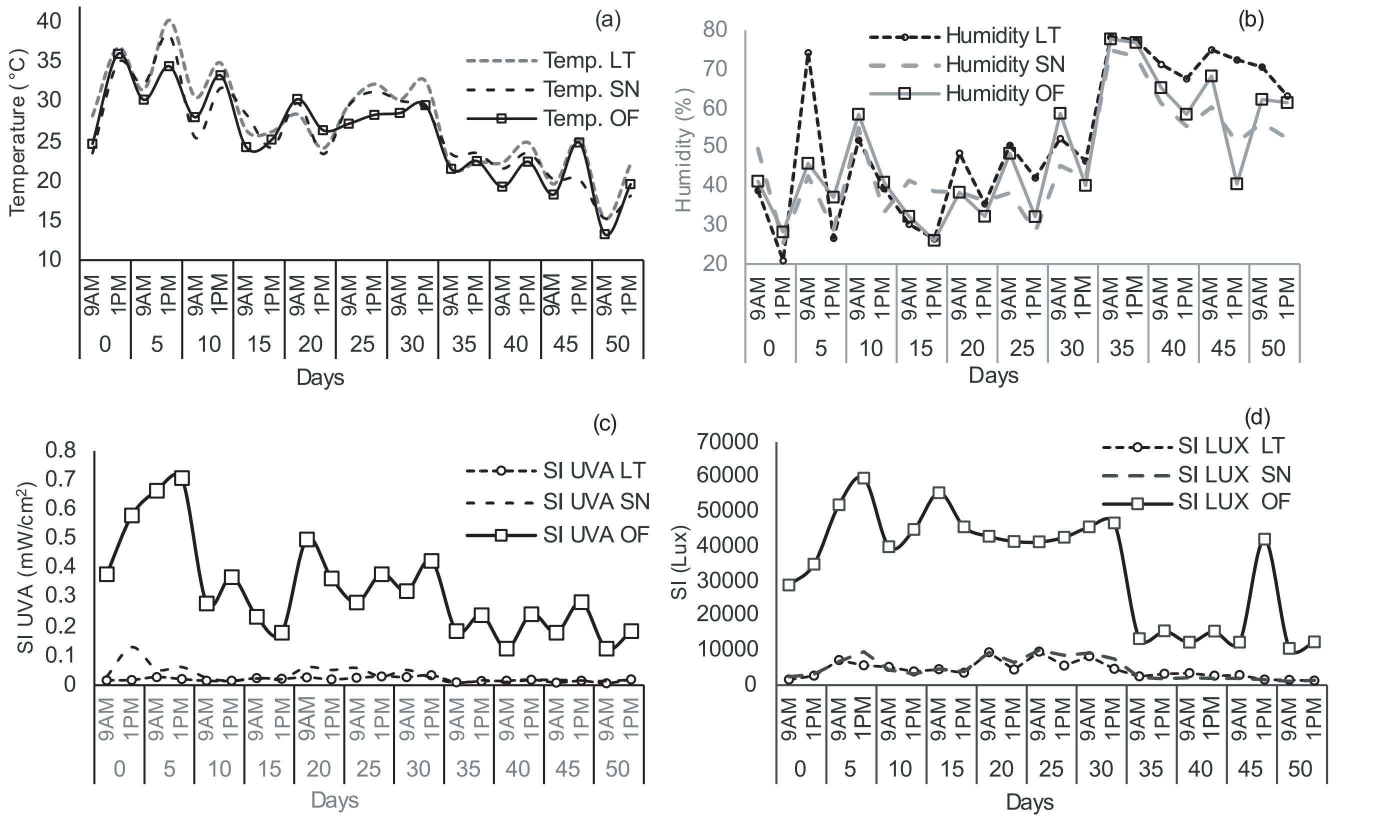


Fig. 1. Growth of different environmental parameters during onion nursery growing, a. Temperature b. Humidity, c. Solar intensity (UVA) and d. Solar intensity at visible range

in low tunnel, followed by shade net (26.26°C) and open field (25.20°C). The fluctuation in the temperature was minimum due to cold weather.

Maximum humidity was recorded 52.71 % in low tunnel followed by open field and shade net with 48.65 and 46.72 % (Fig. 1.b), respectively. As a result, a coefficient of variation of 0.35 was determined in low tunnel structure, followed by 0.32 in open field and 0.28 in shade net. Hence, due to less humidity fluctuation, shade net provided a controlled environment during nursery growing.

The solar intensity was reduced at UV range and visible range as winter arrives after mid-November (Rabi Season) in central region of India. The apparent difference was observed among all treatment, particularly in open fields which showed higher outcome compared to other treatments. Maximum UVA (long wave) values were determined to be 0.034, 0.13 and 0.70 mW/cm$^2$ for low tunnel, shade net and open field environments, respectively. Accordingly, the minimum UVA values were 0.07, 0.08, 0.125 mW/cm$^2$, respectively as shown in Fig. 1.c. The long wave radiation was significantly higher in open field environment, which would directly impact to the survival percentage of seedlings.

The mean solar intensity at a visible range was found to be highest in open field (34298.91 Lux) followed by shade net (4720.87 Lux) and low tunnel (4335.66), respectively (Fig. 1.d). Only 14 % of solar rays were incident in the shade net as compared to open field, whereas only 12 % of solar radiation was incident in a low tunnel. Consequently, growing seedling was highly influenced in the open field environment due to higher intensity. It influences the growth of seedling under different protected conditions; therefore, seedling characterstics were measured to find variation among all protected structures.

The percentage of survival of seedling was observed after fifty days of sowing. Maximum survival plant stand was 76.23 % in Gavraan variety under Shade net structure followed by 68.77 and 64.06 % for low tunnel structure and open field, respectively. Puna fursungi also showed the same trend with the percentage of survival seedlings of 67.69, 64.75 and 58.37 % for shade net, low tunnel, and open field, respectively. It shows that plant survival percentage was maximum under shade net structure due to better environmental control whereas plant survival was minimum under open field environment. The results clearly revealed the impact of environmental factors on seedling growth under different protective structures.

There was no significance difference found in the moisture content of seedlings under different treatments as well as in the varieties. The average moisture content (on a wet basis) for Puna fursungi and Gavraan variety were 88.77 and 88.54 %, respectively. Minimum moisture content was observed as 85.46 % in open field while maximum moisture content was observed 90.92 % in shade net structure. It was found similar result as 89.59 % at par with low tunnel structure. Obtained result regarding moisture content was inline as research findings by Turbatmath 2011. Moisture content of onion seedling was observed as 86-89.5 % on seventh week of seedlings in their study.

**Physical parameters**: Physical parameters of 50 days onion seedling regarding girth, bulb diameter, and height are shown in Table 1. Maximum seedling girth was found under open field environment, whereas maximum girth for Puna fursungi and Gavraan was found as 2.71 ± 0.68 and 2.78 ± 0.59 mm, respectively. The less girth was found under shade net structure. Furthermore, the seedlings obtained under shade net and low tunnel were softer than open field environment. A similar pattern was seen in case of bulb diameter, where bigger bulb was acquired under open fields while it was found smaller under shade nets. However, the height represented the reciprocal relation among the treatment. Puna fursungi and Gavraan variety had maximum heights of 205 mm and 247.13 mm, respectively under shade net structures. A minimum value was found under open field conditions (188.87 and 180.80 mm for Puna fursungi and Gavraan). Pandirwar *et al.* (2015) also observed the physical properties, which were helpful to design the holding mechanism or gripping arm to hold and convey the seedling to transplant effectively without any damage.

Table 1. Physical properties of onion seedlings (girth, bulb diameter and height)

| Structure | Girth (mm) | Bulb diameter (mm) | Height (mm) |
|---|---|---|---|
| | Puna Fursungi | | |
| Low Tunnel | 1.57 ± 0.29 | 2.33 ± 0.33 | 185.53 ± 45.64 |
| Shade Net | 1 ± 0.28 | 1.81 ± 0.33 | 205 ± 45.84 |
| Open Field | 2.71 ± 0.68 | 3.47 ± 0.74 | 182.87 ± 42.05 |
| | Light Red Gavraan | | |
| Low Tunnel | 1.42 ± 0.24 | 2.16 ± 0.31 | 187.90 ± 37.25 |
| Shade Net | 1.14 ± 0.32 | 1.88 ± 0.31 | 247.13 ± 59.94 |
| Open Field | 2.78 ± 0.59 | 3.32 ± 0.60 | 180.80 ± 22.74 |

The gravimetric analysis of weight of onion seedlings has been presented in Table 2. Apparently, it shows the difference between the treatments in terms of the fresh weight of the seedling, the seedling bulb weight, as well as the dry weight. Maximum weights were observed under open field conditions followed by low tunnels and shade net structures, respectively. The percentage of bulb weight and seedling weight was found higher for open field environment as 33-37 %, followed by low tunnel (20.33-27.37 %) and shade net (20.99-25.00 %). Moreover, the percentage of bulb weight was found higher in open fields and higher quantity of dry matter as well. The greater dry weights were 81.87 mg and 73.04 mg under open field, while the lowest dry weights were 16.52 mg (Puna Fursungi) and 25.74 mg (Gavran) under shade net structure. Higher weight of onion seedling would be helpful in transplanting in case of bare root seedling. It supported the seedling for vertical dropping with less deviation from the path during transplanting mechanically.

Table 2. Gravimetric properties of onion seedling as fresh weight of seedling, bulb weight and dry weight of seedling

| Structure | Fresh seedling weight (mg) | Fresh bulb weight (mg) | Dry weight (mg) |
|---|---|---|---|
| | Puna Fursungi | | |
| Low Tunnel | 376 ± 153.47 | 78.70 ± 25.96 | 48.32 ± 13.19 |
| Shade Net | 180.53 ± 89.06 | 45.24 ± 20.92 | 16.52 ± 6.78 |
| Open Field | 658.02 ± 210.24 | 219.36 ± 84.81 | 81.78 ± 22.54 |
| | Light Red Gavraan | | |
| Low Tunnel | 324.20 ± 144.16 | 88.75 ± 53.24 | 34.07 ± 9.52 |
| Shade Net | 272.58 ± 94.06 | 57.23 ± 20.72 | 25.74 ± 8.32 |
| Open Field | 447.34 ± 0.44 | 168.46 ± 62.82 | 73.04 ± 32.89 |

As a result, value of physical parameters was observed to be higher in open field, while height and survival rate was higher in a shaded net. Therefore, nutritional competition between the plants increased under shade net which affected seedling growth.

Table 3 shows that the structure are significantly different. The other parameters, replication, variety, and the interaction of structure and variety, were found non-significant. The less coefficient of variation denoted the homogeneity. Even though the coefficient of variation (CV) was found slight greater regarding outer properties of biological materials. Based on findings, it was shown the clear distinction with respect to the physical properties among all protected structures.

Table 3. Analysis of variance for physical and mechanical properties of onion seedling at 5 % level of significance

| Source of variation | Girth (mm) | Bulb diameter (mm) | Height (mm) | Fresh seedling weight (mg) | Fresh bulb weight (mg) | Dry weight (mg) | Force in seedling stem (N) | Force in seedling bulb (N) |
|---|---|---|---|---|---|---|---|---|
| Model | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | 0.583 | <.0001 |
| Replication | 0.705 | 0.037 | 0.187 | 0.681 | 0.048 | 0.341 | 0.432 | 0.285 |
| Structure (S) | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | 0.838 | <.0001 |
| Variety (V) | 0.808 | 0.208 | 0.031 | 0.018 | 0.194 | 0.378 | 0.728 | 0.039 |
| S x V | 0.179 | 0.292 | 0.011 | <.0001 | 0.0006 | 0.164 | 0.272 | 0.577 |
| Mean | 1.77 | 2.49 | 198.20 | 376.65 | 109.62 | 46.57 | 4.11 | 7.26 |
| CV (%) | 25.43 | 18.13 | 21.94 | 42.34 | 45.14 | 40.68 | 39.08 | 27.92 |
| $R^2$ | 0.76 | 0.74 | 0.37 | 0.56 | 0.69 | 0.71 | 0.22 | 0.63 |
| RMSE | 0.45 | 0.45 | 43.49 | 159.41 | 49.49 | 18.95 | 1.60 | 2.02 |

A pairwise comparison Tukey test was performed (as shown in Table 4) to find out an individual effect of protected structure and variety. In all physical parameters except height, the nursery growing under protective structure differed significantly from the other. Shade nets led to significantly different and higher seedling heights than other protective structures. The individual effect of variety was shown significantly different for girth, height, and fresh seedlings, whereas the parameter of Gavraan variety was found higher. The remaining parameters were found similar at par with each other.

Tukey pairwise comparison shown in Table 5 was the interaction of structure and variety. A significant difference was found among the different treatments under different varieties for girth and bulb

Table 4. Physical and mechanical properties of onion seedlings, means separated using Tukey pairwise comparison

| Level | Structure | | | Variety | |
|---|---|---|---|---|---|
| (Least square mean value of all factors) | Low tunnel | Shade net | Open field | Puna Fursungi | Gavraan |
| Girth (mm) | 1.49$^{b}$ | 1.07$^{c}$ | 2.74$^{a}$ | 1.76$^{a}$ | 1.78$^{b}$ |
| Bulb diameter (mm) | 2.24$^{b}$ | 1.84$^{c}$ | 3.39$^{a}$ | 2.54$^{a}$ | 2.45$^{a}$ |
| Height (mm) | 186.71$^{b}$ | 226.06$^{a}$ | 181.83$^{b}$ | 191.13$^{b}$ | 205.27$^{a}$ |
| Fresh seedling weight (mg) | 350.13$^{b}$ | 226.57$^{c}$ | 552.68$^{a}$ | 404.87$^{a}$ | 348.04$^{b}$ |
| Fresh bulb weight (mg) | 83.72$^{b}$ | 51.23$^{c}$ | 193.91$^{a}$ | 114.43$^{a}$ | 104.81$^{a}$ |
| Dry weight (mg) | 41.94$^{b}$ | 21.13$^{c}$ | 77.41$^{a}$ | 48.87$^{a}$ | 44.28$^{a}$ |
| Force in seedling stem (N) | 4.26$^{a}$ | 4.12$^{a}$ | 3.94$^{a}$ | 4.18$^{a}$ | 4.03$^{a}$ |
| Force in seedling bulb (N) | 6.96$^{b}$ | 4.89$^{c}$ | 9.89$^{a}$ | 7.84$^{a}$ | 6.65$^{b}$ |

Table 5. Tukey pairwise comparison of interaction of structure and variety by findings of least square mean (LSM) for basic physical and mechanical properties of onion seedlings

| Level | Puna Fursungi | | | Gavraan | | |
|---|---|---|---|---|---|---|
| (LSM value of all factors) | Low tunnel | Shade net | Open field | Low tunnel | Shade net | Open field |
| Girth (mm) | 1.57$^{b}$ | 1.01$^{d}$ | 2.71$^{a}$ | 1.42$^{cb}$ | 1.14$^{cd}$ | 2.77$^{a}$ |
| Bulb diameter (mm) | 2.33$^{b}$ | 1.81$^{d}$ | 3.47$^{a}$ | 2.16$^{cb}$ | 1.87$^{cd}$ | 3.32$^{a}$ |
| Height (mm) | 185.53$^{b}$ | 205$^{b}$ | 182.86$^{b}$ | 187.9$^{b}$ | 247.13$^{a}$ | 180.8$^{b}$ |
| Fresh seedling wt. (mg) | 376.06$^{cb}$ | 180.52$^{d}$ | 658.01$^{a}$ | 324.19$^{c}$ | 272.58$^{cd}$ | 447.34$^{b}$ |
| Fresh bulb weight (mg) | 78.7$^{dc}$ | 45.24$^{d}$ | 219.36$^{a}$ | 88.74$^{c}$ | 57.23$^{dc}$ | 168.46$^{b}$ |
| Dry weight (mg) | 48.32$^{bc}$ | 16.52$^{d}$ | 81.77$^{a}$ | 34.06$^{dc}$ | 25.74$^{dc}$ | 73.04$^{ba}$ |
| Force stem (N) | 4.58$^{a}$ | 4.28$^{a}$ | 3.69$^{a}$ | 3.94$^{a}$ | 3.61$^{a}$ | 4.55$^{a}$ |
| Force bulb (N) | 7.22$^{bc}$ | 5.48$^{cd}$ | 10.83$^{a}$ | 6.76$^{bcd}$ | 4.30$^{d}$ | 8.95$^{ba}$ |

diameter. Though, the non-significant difference was found in the different protected structures with a different type of variety. Fresh seedling weight and bulb weight of Puna fursungi in an open field were significantly different from Gavraan variety raised in the same structure and even significantly different from other treatments (structures). The observed value for fresh seedling weight, bulb weight and dry weight of onion seedling under shade net and low tunnel was found non-significant.

**Compressive strength of seedlings**: Compressive strength for bulb and stem of 50-day-old seedlings was recorded maximum under open field, followed by low tunnel and shade net structure, respectively (as shown in Table 6). The maximum compressive strength of bulb and stem for both varieties namely Puna fursungi and Gavraan was recorded under open field environment as 10.83 ± 3.17 N and 8.96 ± 2.55 N for onion bulb and 4.25 ± 0.69 N and 4.56 ± 2.41 N for stem, respectively. Findings results have been similar as quoted by Pandirwar *et al.* (2015) and Turbatmath, (2011) under an open field environment. It is a prominent affecting factor in holding, conveying, metering, dropping and transplanting. Seedlings with less strength does not survive under hostile conditions due to damage caused by transplanting mechanism.

Accordingly, onion seedlings' compressive strength was found to be higher in the open field. Seedlings from open fields also showed higher maturity or sturdiness. Robustness of seedlings, make it easier to handle, transport, and transplant into the field. Study revealed that the crushing load increases with the bulb size (Pandirwar *et al.*, 2015). Significant differences in bulb size and compressive strength under the different protective structures indicates different maturity levels. Similar outcomes have been reported by Pandirwar *et al.* (2015) for bulb and stem compressive strength in open field as 10.65 N and 4.38 N respectively for 50-day old seedlings (Var. Pusa Red). Hence, seedling obtained from open field are more acceptable with reference to mechanical transplanting. Seedling obtained from other two structures would take more time to reach the desired growth in terms of size and strength for mechanical transplanting.

Table 6. Compressive strength of onion seedling's bulb and stems (50 days after sowing) under different protective structures of nursery growing

| Structure | Bulb | | | Stem | | |
|---|---|---|---|---|---|---|
| | Force (N) | Distance (mm) | Time (sec) | Force (N) | Distance (mm) | Time (sec) |
| Puna Fursungi | | | | | | |
| Low Tunnel | 6.78 ± 1.47 | 0.72 ± 0.14 | 1.44 ± 0.28 | 3.95 ± 0.76 | 0.37 ± 0.07 | 0.76 ± 0.14 |
| Shade Net | 5.49 ± 1.12 | 0.44 ± 0.03 | 0.88 ± 0.06 | 3.69 ± 1.57 | 0.90 ± 0.27 | 1.80 ± 0.55 |
| Open Field | 10.83 ± 3.17 | 1.10 ± 0.28 | 2.21 ± 0.56 | 4.25 ± 0.69 | 0.61 ± 0.15 | 1.22 ± 0.30 |
| Light Red Gavraan | | | | | | |
| Low Tunnel | 6.77 ± 0.81 | 0.62 ± 0.08 | 1.26 ± 0.16 | 3.94 ± 1.27 | 0.55 ± 0.07 | 1.12 ± 0.13 |
| Shade Net | 4.30 ± 0.95 | 0.47 ± 0.06 | 0.94 ± 0.12 | 3.61 ± 0.88 | 0.41 ± 0.09 | 0.81 ± 0.20 |
| Open Field | 8.96 ± 2.55 | 1.02 ± 0.29 | 2.05 ± 0.59 | 4.56 ± 2.41 | 0.75 ± 0.23 | 1.52 ± 0.46 |

The model revealed a significant difference at a 5 % level of significance for the compressive strength of bulb as given in Table 3. Analysis of variance shows that structure was found significantly different for compressive force of bulb, whereas other parameters *viz*., replication, variety and interaction of structure and variety was found non-significant. Mean compressive strength of 4.11 N was found for seedling stems and 7.26 N was obtained for seedling bulbs.

There was a significant difference observed only in the compressive strength of the bulb after pairwise comparison (as shown in Table 4) of individual effects of structure and variety. A significant difference was revealed among the different protective structures as well as between both varieties. Under the interaction of structure and variety as depicted in Table 5, similar trends are observed that were significantly different only for the compressive strength of the bulb. The compressive strength of bulb of Puna fursungi variety under open field is significantly different than compressive force found in remaining two structures. Major, significant difference was found between open fields and shade net structures, thereby apparent differences in seedling properties were reflected in the results.

The analysis shows that environmental conditions play a significant role in the growth of onion nursery. Nursery plants in an open field environment had higher physical and mechanical properties except height. The height of nursery planted in the shade net (50 %) was found higher but their maturity, stem firmness and compressive strength of the bulb were comparatively less. Crop stand percentage in mechanical transplanting can be improved with healthy seedlings. Compressive strength of seedling stem was observed as 10.83 N (Puna fursungi) in case of open field, whereas it was found 6.78 N and 5.49 N in case of low tunnel and shade net structure respectively. Mechanical transplanting involves the metering of seedlings by the means of gripping, conveying, dropping, *etc.* Therefore, seedlings grown in open field are recommended for mechanical transplanting.

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