Original Research Article

Integrated Growing Environment, Medium and Priming Significantly Affect Sweet Pepper Seedling Establishment Characteristics

**ABSTRACT**

Sweet pepper (*Capsicum annum* L.) is ranked among the most highly consumed vegetable crops in the world. It is rich in beneficial vitamins, minerals, and pharmaceuticals for humans. Meeting the growing global demand remains a challenge since production has been dwindling in some countries, partly due to challenges encountered during seedling production stage, and yet its success is governed by a myriad of factors and contributes to over 50% of overall crop production. This study, therefore, determined the combined effect of growing environment, medium type, and priming proficiency on sweet pepper seedling establishment characteristics. It was conducted in a three-way factorial arrangement of 3 environments x 4 media x 3 primings in a completely randomized design with three replications and two trials. Data values were collected on environmental conditions, media characteristics, sweet pepper seedling height (SH), collar diameter (CD), number of leaves (NL), fresh weight (FW), dry weight (DW), and Dickson Quality Index (DQI). Data was subjected to analysis of variance using SAS version 9.4. Significant means were separated using the LSD test at *α*=0.05. Seedling establishment in trail 1 was lower than in trail 2. Furthermore, growing environment, medium type, and priming proficiency had significant (*P*=0.0001) effects on seedling establishment characteristics. The seedlings that were significantly (*P*=0.0001) tallest (SH), sturdiest (DQI), and thickest (CD) were for lathhouse, open-field, and greenhouse environments, respectively. Hygromix had highest characteristics that were significantly (*P*=0.0001) different from those of other media. Halo- and hydro-priming had highest characteristics that were significantly (*P*=0.0001) different from those of no priming. Thus, the suitable environment, medium and priming depended on the seedling characteristic. The HP1L gave the earliest, best performance of 10.4 cm SH, 3.17 mm CD, 6-well-developed leaves at 35 DAS, and DQI of 0.375 at 56 DAS, indicating that the three factors interacted significantly in influencing sweet pepper seedling establishment. Consequently, this study recommends geminating halo-primed sweet pepper seeds in hygromix followed by raising their seedlings in a lathhouse to obtain high quality seedlings that should potentially result in high yields and income.

***Keywords****: Collar diameter, Dickson Quality Index, Fruit-vegetable, Propagation medium, Seedling propagation*

**1. INTRODUCTION**

Sweet pepper (*Capsicum annum* L*.*) is among the most important vegetable crops in terms of consumption in the world (Edgar *et al*., 2016) in the world. Its global production was about 36 million tonnes in 2020, but Kenya contributed only 2,271 tonnes (FAOSTAT, 2021). Nonetheless, it is increasingly becoming popular in Kenyan diets, owing to its richness in vitamins (Muhammad and Auwal, 2008), as well as calcium, phosphorus and potassium (Olatunji and Afolayan, 2018). It is consumable as a spice or salad in diverse dishes and curries. It is also used in pharmaceutical industries to treat hypertension, obesity and cardiovascular anomalies (Sun *et al*., 2016). Production of healthy seedlings is a prerequisite for raising vigorous, high-quality crops, which increase returns since a good seedling accounts for half of the final production (Minami, 2001; Pandiyaraj, 2017).

Seedling establishment is key for successful growth and yield of a crop plant and is highly influenced by growing environmental conditions (Adondakis and Venable, 2004). Various technologies developed to provide microclimates include tunnels, greenhouses, shade-nets and lathhouses (Lybbert and Sumner, 2012). However, they are mostly selected based on the growing conditions suitable for advanced phases of growth with less or no attention given to the first two phases, yet they influence up to 50% of the subsequent growth stages of sweet pepper (Minami, 2001; Rajasekar *et al*., 2013; Ayyogari *et al*., 2014; Bisbis *et al*., 2018). In this regard, there is no such information on Kenyan-based sweet pepper varieties.

Growing medium is one of the main factors influencing the success of horticultural nursery activity (Paul and Metzger, 2005; Raviv and Lieth, 2008). It directly contributes to the quality of the utilized planting materials (Reis and Coelho, 2007), which in turn promote optimum growth of plants (Pascual *et al*., 2018). Additionally, availability of proper nutrients, water, and oxygen for seedling development and physical supporting of whole plant growth even after transplanting into the soil are highly influenced by media quality (Raviv, 2005). The use of substrates is a modern technology involving either inert organic or inorganic materials, which are mostly enriched with nutrients for proper plant growth (Olympios, 1999; Sterrett, 2001; Raviv, 2013; Gruda *et al*., 2019; Nerlich and Danneh, 2021). Peat moss usage, though previously common, is decreasing due to high costs (Jung and Yang, 2014; Taparia *et al*., 2021), extreme degradation of peat lands releasing 25%of all CO2 emissions (Barrett *et al*., 2016), and long renewal process of peatlands (Gruda, 2019). Consequently, other alternative organic materials are being sought over peat (Gruda, 2011). In Kenya, vegetable seedlings are mostly grown using imported cocopeat and peat moss (Anjichi and Odhiambo, 2021). However, it usage is increasingly becoming restricted, leading to low vegetable productivity due to poor nursery seedling establishment (Herrera *et al*., 2009; Anjichi and Odhiambo, 2021). Organic agricultural wastes and similar absorbent materials such as maize cobs and groundnut shells can be used to produce soilless media rather than being burned or discarded in landfills (Oworu *et al*., 2010; Torkashvand *et al*., 2015; Nalluri and Karri, 2018). However, there is limited information on their application as a natural fertilizer additive to other nursery growing mixtures such as cob-formulated media.

Seed germination is the beginning of a plant life; thus, survival of crop plants is highly determined by its success (Manjaiah *et al*., 2019; Carrera-Castaño *et al*., 2020). However, presence of capsaicinoids in pepper seeds suppresses their germination through allelopathic effects (Kato-Noguchi and Tanaka, 2003; Barchenger and Bosland, 2016). Additionally, sweet pepper seedlings take a lengthy up to 56 days to be ready for transplanting (Julė and Laužikė, 2023). To reverse these challenges, various treatments have been designed to improve germination and growth of sweet pepper (Kucera *et al*., 2005; Ahmad *et al*., 2023). They include seed treatment (Hosseini and Koocheki, 2007; Adhikari *et al*., 2021; Singh *et al*., 2020) using halo-, hydro-, hormonal-, bio-, and solid-matrix- priming, as well as chemical, hormonal, and biological techniques (Adnan *et al*., 2020; Rhaman *et al*., 2020; Sime and Aune, 2020; Mitra *et al*., 2021). However, although cheap, affordable and easily accessible, there is inadequate information on their effects on Kenyan-based sweet pepper varieties. Subsequently, this research evaluated the potency of integrated growing environment, medium, and priming on sweet pepper seedling establishment.

**2. MATERIALS AND METHODS**

**2.1. Research Site and Design**

The experiment was conducted on-farm in two trials from 20th June – 8th August 2023 and 19th August - 6th October 2023. The farm lies at approximately 1399 m above sea level, latitude 0◦20ꞌ0ꞌꞌ S and longitude 37◦39ꞌ0ꞌꞌ E. Temperature ranges from 20.97◦C to 27.25**◦**C, while rainfall averages 1178 mm per annum (Jaetzold et al., 2006). The area has nitisol type of soils (Kinyanjui, 1979). The experiment with three factors and 36 treatments, comprising 4 media x 3 primings x 3 environments, was arranged in a Completely Randomized Design replicated three times. Each treatment had five seedlings, but measurements were taken on the middle three, which served as the sample size, while the exterior two seedlings served as guard plants.

**2.2. Growing Environment Set-up**

(a) Open field set-up (O): Nursery beds measuring 2 m x 1 m x 0.5 m were prepared and their soil drenched with miticide against white ants. A total of 198 propagation pots measuring 7 cm × 7 cm ×6.5 cm and spaced at 10 cm were placed on an area of 5 m × 4 m × 0.5 m that was free of vegetation.

(b) Greenhouse set-up (G): The greenhouse measured 30 m by 8 m and was covered with a white rigid plastic paper. Three wooden benches measuring 2 m x 1m x 0.5 m with the top covered with a net were constructed. A total of 198 propagation pots of size 7 cm × 7 cm × 6.5 cm and spaced at 10 cm apart were placed on the benches.

(c) Lathhouse set-up (L): A lathhouse measuring 10 m by 10 m, with 6 open-meshed windows, measuring 1 m by 1.5 m and roofed with gal sheets on the outer side, and a shade netting (75% light transmission) on the inside, was used. Three wooden benches measuring 2 m x 1 m x 0.5 m with the top made of a net were constructed inside the lathhouse. A total of 198 propagation pots were placed on the benches at a spacing of 10 cm.

**2.3. Media Formulation**

Fresh maize cobs were obtained from neighbourhood farmers, sun-dried on white PVC sheet, drenched with Terrazole, chopped on both far ends, and the middle part milled using a commercial grinder. Similarly, dry groundnut shells were collected from neighbourhood farmers, dried for one day on white PVC sheet, winnowed, sieved and ground using a commercial grinder. Tithonia leaves were collected from young non-flowering plants, dried at room temperatures, and then ground. Thorough cleaning of the grinder was done after grinding each component. The three ground components (ground cobs, groundnut shells and Tithonia leaves) were mixed at a ratio of 2:1:1 (CFM1) and 1:1:1 (CFM2), respectively. The formulated media were drenched with Terrazole to prevent fungal infection. Hygromix (H), which served as a positive control due to frequent use in the horticultural vegetable nursery sector, is a peat-based growing medium with nutrient supplement. It was obtained from Hygrotech Company in Nairobi. Forest soil (S), which was used as a negative control, was collected from Mt. Kenya Forest.

**2.4. Seed Priming**

(a) Halo-priming (P1): Admiral F1 sweet pepper seeds were obtained from Syngenta Seed Company. They were soaked in a 4 g/L sodium chloride solution for 24 hours (El-Sanatawy *et al*., 2021). They were dried on paper for 12 hours, kept in size 2 khaki envelopes at room temperature, and sown the next day.

(b) Hydro-priming (P2): Admiral F1 sweet pepper seeds were soaked in 1 litre distilled water for 24 hours, dried on corrugated paper for 12 hours, stored in size 2 khaki envelopes at room temperatures, and sown the next day.

(c) Non-primed seeds (P): Admiral F1 sweet pepper seeds were not subjected to any priming. They were also kept in size 2 khaki envelopes at room temperature, while awaiting sowing the next day.

**2.5. Seedling Growing Procedures**

The growing media were filled in propagation pots, watered with 50 ml per pot before seed sowing. Two seeds were sown in each pot to a depth of 4 times the seed size by using a calibrated and sterilized drilling stick. The seeds were covered with the respective growing medium. After germination, seedlings were thinned to leave one per pot. Watering using 25 ml per pot was done once daily in the morning for the first 21 days, twice daily for the next 7 days, daily for another 21 days, and once every other day for the next 7 days. Hand weeding was done every 3 days especially in the soil-based treatments. Drenching the open-filed was done to control ants that were affecting the cob-formulated treatments. Shading of the open-field set up using 75% shade nets was done seven days after sowing to protect the germinating seeds from the scorching sun, which would dehydrate the seedlings, heavy rainy drops, which would expose the germinating seeds, and also fill up rain water in the propagation pots.

**2.6. Data Collection**

***2.6.1. Environmental conditions*** were monitored and recorded for 56 DAS. Daily temperature was read using a digital temperature meter. Root zone temperature was read using a probe. Relative humidity was read daily using a digital humidity meter. Light intensity was measured daily using a light intensity meter.

***2.6.2. Media characterization and analysis*** was done to determine essential media characteristics; the variables given below were assessed.

(a) Bulk density: About 25 g of each medium was placed in separate propagation pots. The volume of each medium was then obtained by measuring the L×W×H occupied by each medium. The mass was then divided by the volume of each medium to obtain the bulk density (Blake and Hartge, 1986).

(b) Particle density: Approximately 25 g of each medium was placed in separate propagation pots. Each medium was pulverized by pressing it to remove all air pores. The weight of the media after removing the pore spaces was obtained and then divided by the new volume of the media to obtain the particle density (Blake and Hartge, 1986).

(c) Porosity: Porosity was calculated and recorded using the formulae: [1-(Bulk density/Particle density)] ×100.

(d) Water holding capacity: Funnels lined with no. 1 filter papers were placed on 100 ml measuring cylinders, 25 g of medium sample was placed in each funnel and 25 ml of water was poured on top. The volume of filtered water in the measuring cylinder was recorded after water dripping stopped.

(e) The pH was measured using a pH meter, whereby a medium weighing 25 g was added to 50 ml of distilled water. It was then mixed for 30 seconds and left to stand for 5 minutes (Haluschak, 2006) before the electrode was inserted in the solution and the pH read and recorded. Three readings were taken and the average recorded.

(f) Determination of N was done using the Kjeldahl method, where 1 g of medium was placed into a conical flask, 0.3 g of CaSO4 and 3 g K2SO4 added. Thereafter, 15 ml sulfuric acid was added, the solution heated in a fume chamber, titrated against 50 ml HCl and results recorded.

(g) Determination of K and Ca was done by taking 1 g of each medium and shaking for 5 minutes with 10 ml of 1 N ammonium acetate at pH 7. Available K and Ca were measured in the filtered extract using an atomic absorption spectrometer set on emission mode at 766.5 nm. The results were generated electronically in ppm.

(h) Determination of P was done using Olsen’s method (FAO, 2021) by weighing 5 g of medium into a conical flask, adding 0.5 N sodium bi-carbonate solution, shaking and filtering the contents using Whatman No. 1 filter paper. About 5 ml of the filtrate was placed into a 25 ml volumetric flask and 5 ml ammonium molybdate solution was added, mixed well until CO2 evolution ceased. An aliquot of 10 ml of distilled water was added to wash any remaining molybdate. About 1 ml of working stannous chloride solution was added and the volume was made to the mark and titrated till change in blue colour.

***2.6.3. Seedling measurements:*** Plant height was measured at 28 to 56 DAS using a tape measure from the basal end of the stem to the tip of the stem (Wu *et al*., 2015). Collar diameter was measured using a vernier caliper at 28 to 56 DAS. The number of true leaves were counted and recorded at 28 to 56 DAS. Plants were uprooted from growing pots, roots washed, separated into roots and shoots, and then weighed on a weighing scale at 56 DAS to obtain fresh weight. Seedling parts (shoots, roots) were dried in an oven at 70°C for 48 hours (Kheloufi and Abdenour, 2017) and then weighed to obtain dry weight at 56 DAS. The Dickson Quality Index (DQI) predicts survival and growth of a plant in the main field. Plants with index greater or equal to 0.2 are considered of good quality (Nyoka *et al*., 2018). The DQI was calculated at 56 DAS as: DQI = Plant dry weight (g)/ ([Height (cm)/Collar diameter (mm)] + [Shoot dry weight (g)/Root dry weight (g)]) (Dickson *et al*., 1960).

**2.7. Data Analysis**

Seedling establishment data values were subjected to analysis of variance using SAS version 9.4. Significant means were separated using the Least Significant Difference at α = 0.05. The Statistical Model fitted was: Yijk = µ + Ai + Bj + Ck + (AB)ij + (AC)ik + (BC)jk + (ABC)ijk + Ɛijk

Where: µ = Standard mean; Ai = Effect of growing environment; Bj = Effect of medium; Ck = Effect of priming; (AB)ij = Interaction of growing environment + medium effect; (AC)ik = Interaction of growing environment + priming effect; (BC)jk = Interaction of medium + priming effect; and (ABC)ijk = Interaction of growing environment + medium + priming effect; and Ɛijk = Random error.

**3. RESULTS AND DISCUSSION**

**3.1. Environment and Media Effects on Seedling Establishment**

The weekly environmental conditions (light intensity, relative humidity and temperature), root zone temperature, and media physico-chemical conditions were recorded to help evaluate the effect of environment and medium on establishment of sweet pepper seedlings (Figures 1 to 7).

Light intensity was highest in the open field, followed by the greenhouse, and lathhouse (Figure 1). It was not constant in each growing environment, and was slightly higher in trail 2 than trail 1. Relative humidity fluctuated weekly at 40% - 80%, but it was fairly the same for the growing environments within each week (Figure 2). The weekly air temperature fluctuated between 20oC and 30oC, and was higher in trial 2 (Figure 3). The temperature was highest in the greenhouse, followed by open field, and lathhouse. The weekly root-zone temperature fluctuated and was near 20oC to 30oC. It was higher in trial 2 than trial 1. Overall, it was higher in greenhouse, followed by open field, and then lathhouse for each medium (Figures 4-7).

**Figure 1: A graph showing mean weekly light intensity for growing environments**

**Figure 2: A graph showing mean weekly relative humidity for growing environments**

**Figure 3: A graph showing mean weekly air temperature for growing environments**

**Figure 4: Mean weekly CFM1 root-zone temperature across growing environments**

The analyzed physico-chemical properties of the growing media used are shown in Table 1. The characteristics varied among the four media, with texture from coarse to very fine; bulk density from 0.55 to 0.11, particle density from 0.59 to 0.17; porosity from 45.5 to 6.8; pH from 6.2 to 5.6; WHC from 85 to 20%; N from 1.88 to 0.03%; P from 1.3 to 0.023%; K from 9.75 to 7.10 mg/kg; Ca from 7.55 to 1.81 mg/kg. The combined impacts of environmental conditions and media physico-chemical characteristics on sweet pepper seedlings are reflected in Plates 1-5.

**Figure 5: Mean weekly CFM2 root-zone temperature across growing environments**

**Figure 6: Mean weekly hygromix root-zone temperature across growing environments**

**Figure 7: Mean weekly soil root-zone temperature across growing environments**

**Table 1: Physico-chemical characteristics of growing media**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Characteristic** | **CFM1** | **CFM2** | **Hygromix** | **Soil** |
| Texture | Coarse | Medium | Fine | Very fine |
| Bulk Density (g/cm3) | 0.12 | 0.11 | 0.18 | 0.55 |
| Particle Density (g/cm3) | 0.17 | 0.16 | 0.33 | 0.59 |
| Porosity (%) | 29.4 | 31.3 | 45.5 | 6.8 |
| pH | 6.1 | 5.6 | 6.3 | 6.2 |
| WHC (%) | 45.0 | 20.0 | 85.0 | 75.0 |
| Total N (%) | 1.45 | 1.88 | 0.38 | 0.03 |
| Total P (%) | 0.12 | 0.09 | 1.30 | 0.023 |
| Total K (mg/kg) | 8.76 | 9.75 | 7.96 | 7.10 |
| Ca (mg/kg) | 3.09 | 5.15 | 7.55 | 1.81 |

|  |  |
| --- | --- |
| **Plate 1: Wilting and drooping in greehouse, phototropism in lathhouse**  *Left*: Wilting in soil treatments due to high temperatures in the greenhouse  *Centre*: Drooping in greenhouse due to evapotranspiration  *Right*: Phototropism in the lathhouse | **Plate 2: Effect of growing environment on media components**  *Left*: Algae development in hygromix media in the lathhouse  *Centre*: Shrinking + hardening of CFM2 due to degradation in greenhouse  *Right*: Scorching effect on hygromix medium in the greenhouse |
| **Plate 3: Sturdiness of seedlings**  *Left*: Sturdy and hardy seedlings in the open-field environment  *Centre*: Bright green leaves but less hardy seedlings in the lathhouse  *Right*: CFM1 seedling exhibiting proper establishment in the open-field | **Plate 4: Root development in soil and CFM media**  *Left*: Poor root formation in soil treatments in the lathhouse at 56 DAS  *Centre*: Poor root development in CFM at 56 DAS  *Right*: Coarse texture of CFM1 limiting root penetration |
| **Plate 5: Hygromix root formation under the various growing environments**. *Left*: Robust root formation in hygromix seedlings in the greenhouse. *Centre*: Fairly developed roots in hygromix seedlings in the lathhouse. *Right*: Root formation in hygromix treatments in the open-field | |

**3.2. Effects on Seedli****ng Establishment**

**3.2.1. Seedling stem height**

Plant height was higher in trail 2 than in trail 1 (Table 2). Each of the three factors had a significant effect (*P*<0.0001) on final plant height from 28 to 56 DAS (Table 2). All the three growing environments had different effects on seedling height, with the lathhouse recording highest seedling height in both trials from 28 to 56 DAS, whereas the open field had the lowest mean seedling height. All the mean seedling height of the four growing media were significantly (*P*<0.0001) different from each other, with Hygromix recording highest height and CFM2 recording the lowest height in both trials. Soil had higher mean in both trials compared to the cob-formulated media. In trail 1, hydro-priming had the highest seedling height, which was significantly (*P*<0.0001) different from both halo-priming and no priming at 56 DAS. In trail 2, halo and hydro-priming had the highest mean height that were not significantly different. In both trials non-primed level had the lowest height.

**Table 2: Sole effect of growing environment, medium, and priming on seedling height**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Day 28** | | **Day 35** | | **Day 42** | | **Day 49** | | **Day 56** | |
| **Factor** | **T1** | **T2** | **T1** | **T2** | **T1** | **T2** | **T1** | **T2** | **T1** | **T2** |
| Growing Environment | | | | | | | | | | |
| Lathhouse (L) | 2.21a | 2.85a | 3.07a | 4.39a | 3.79a | 5.65a | 4.30a | 6.19a | 4.74a | 6.94a |
| Open-field (O) | 1.59b | 1.39c | 2.35b | 1.76c | 2.61b | 2.57c | 2.99b | 2.73c | 3.03b | 2.96c |
| Greenhouse (G) | 1.09c | 1.94b | 1.64c | 3.29b | 2.15c | 4.59b | 2.44c | 4.96b | 2.45c | 5.35b |
| *P-*value | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| LSD 0.05 | 0.086 | 0.062 | 0.074 | 0.053 | 0.058 | 0.082 | 0.129 | 0.062 | 0.086 | 0.079 |
| Growing Medium | | | | | | | | | | |
| CFM1 (2:1:1) | 1.25c | 1.30c | 1.71c | 2.11c | 2.19c | 2.53c | 2.55c | 2.75c | 2.64c | 3.09c |
| CFM2 (1:1:1) | 0.25d | 1.21d | 0.34d | 1.62d | 0.43d | 1.89d | 0.52d | 2.13d | 0.54d | 2.46d |
| Hygromix (H) | 3.23a | 4.01a | 4.96a | 6.62a | 5.84a | 9.60a | 6.72a | 10.32a | 7.15a | 11.08a |
| Soil (S) | 1.80b | 1.64b | 2.39b | 2.35b | 2.78b | 3.05b | 3.00b | 3.34b | 2.92b | 3.78b |
| *P-*value | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| LSD 0.05 | 0.100 | 0.072 | 0.085 | 0.061 | 0.067 | 0.094 | 0.150 | 0.071 | 0.010 | 0.091 |
| Priming Proficiency | | | | | | | | | | |
| Halo (P1) | 1.60b | 2.16a | 2.33b | 3.51a | 2.97a | 4.62a | 3.33a | 4.97a | 3.48b | 5.44a |
| Hydro (P2) | 1.78a | 2.09bc | 2.55a | 3.18b | 2.92a | 4.45b | 3.40a | 4.90b | 3.57a | 5.46a |
| None (P) | 1.52c | 2.10ab | 2.18c | 3.11c | 2.64b | 4.16c | 3.04b | 4.49c | 3.19c | 4.90b |
| LSD 0.05 | 0.086 | 0.062 | 0.074 | 0.053 | 0.058 | 0.082 | 0.129 | 0.062 | 0.086 | 0.078 |
| *P-*value | 0.0001 | 0.6935 | 0.0001 | 0.0001 | 0.0001 | 0.0002 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| CV% | 11.3 | 5.9 | 6.6 | 3.9 | 4.3 | 3.7 | 8.1 | 2.6 | 5.1 | 3.0 |

\* Means followed by the same letter in a column are not significantly different at α = 0.05.

LSD = Least Significant Difference, CV = Coefficient of Variation, T1 = Trial 1, T2 = Trial 2

The combined three-factor effect was significant (*P*<0.0001) on seedling height in both trials (Table 3). Only the lathhouse environment had a significant influence on the combined factor effect on seedling height in both trials at 56 DAS, while the greenhouse environment had a slight influence in trail 2. The open-field environment, which served as the control, had no significant influence on the combined factor effect on seedling height in both trials. All media apart from hygromix, had no significant influence on the combined factor effect on seedling height in both trials at 56 DAS. In both trials, halo and hydro-priming had significant influence on the combined factor effect on seedling height, whereas no priming had no significant influence on the combined factor effect of the three factors on seedling height at 56 DAS.

Combined HP1L and HP2L treatments had the highest heights of 10.57 cm and 15.33 cm in trail 1 and trail 2, respectively. Lowest seedling height were for CFM2P2L (1.55 cm) and CFM2P1O (1.80 cm) in trail 1 and trail 2, respectively. Although the seedling height of cob-formulated media treatments did not match with that of hygromix media (positive control), they performed better compared to the control treatment (SPO) in both trials. The highest height among CFM treatments was 3.7 cm for CFM1PL in trail 1 and 4.1 cm for CFM1P1L in trail 2. The height of SPO control treatment was 2.8 cm and 2.0 cm in trail 1 and trail 2, respectively.

**Table 3: Combined effect of environment, medium, and priming on seedling height**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Treatment** | **Day 28** | | **Day 35** | | **Day 42** | | **Day 49** | | **Day 56** | |
| **T1** | **T2** | **T1** | **T2** | **T1** | **T2** | **T1** | **T2** | **T1** | **T2** |
| CFM1P1L | 1.7gh | 1.67gh | 2.3j | 2.70ij | 2.80j | 3.20jk | 2.97ijk | 3.47i | 3.00no | 4.07h |
| CFM1P2L | 1.8gh | 1.80gh | 2.1jk | 2.83i | 2.63jk | 3.33j | 2.80jkl | 3.47i | 2.87nop | 3.83hi |
| CFM1PL | 2.3f | 2.33f | 3.0h | 2.57jk | 3.47h | 2.93klm | 3.63h | 3.17j | 3.73kl | 3.63i |
| CFM2P1L | 1.0jkl | 0.00o | 1.2op | 2.10l | 2.20m | 2.53no | 2.35lmnop | 2.80kl | 2.60pqr | 3.30jk |
| CFM2P2L | 0.8lm | 0.80lm | 1.07p | 2.00l | 1.33o | 2.33opq | 1.67rs | 2.77kl | 1.55v | 3.57ij |
| CFM2PL | 0.4n | 0.40n | 0.8q | 2.43k | 0.93p | 2.83lm | 1.23s | 3.13j | 1.85tuv | 3.60i |
| HP1L | 4.1a | 4.13a | 6.4a | 10.47a | 7.87a | 12.67a | 9.57a | 13.57bc | 10.57a | 14.57b |
| HP2L | 4.0a | 4.03a | 6.0b | 7.67d | 7.00b | 123b | 8.37b | 13.73a | 9.57b | 15.33a |
| HPL | 2.9de | 2.90de | 4.7d | 9.33b | 5.87d | 12.67ab | 7.07c | 13.5c | 7.97c | 14.57b |
| SP1L | 1.8gh | 1.80gh | 2.3ij | 3.67g | 3.17i | 4.60gh | 3.36hi | 5.07g | 3.43lm | 5.80f |
| SP2L | 3.0d | 3.03d | 3.7f | 3.77g | 3.97g | 4.43h | 4.17fg | 5.03g | 4.23j | 5.67f |
| SPL | 2.6e | 2.63e | 3.3g | 3.13h | 3.70g | 4.03i | 3.80gh | 4.53h | 3.83k | 5.37g |
| CFM1P1G | 0.9lm | 0.90lm | 1.36no | 1.67mn | 1.90n | 1.90stu | 2.10opqr | 2.10op | 2.13st | 2.37pqr |
| CFM1P2G | 1.0kl | 1.00kl | 1.37no | 1.97l | 1.93n | 2.37op | 2.13nopq | 2.67lm | 2.30rs | 3.00lm |
| CFM1PG | 0.9lm | 0.90lm | 1.03pq | 1.70m | 1.87n | 2.03rst | 1.97pqr | 2.23o | 1.80uv | 2.50op |
| CFM2P1G | 0.0o | 1.03jkl | 0.00r | 1.95l | 0.00q | 2.10pqrs | 0.00t | 2.20op | 0.00w | 2.40opq |
| CFM2P2G | 0.0o | 0.00o | 0.00r | 1.40p | 0.00q | 1.60v | 0.00t | 1.77tu | 0.00w | 1.97tu |
| CFM2PG | 0.0o | 0.00o | 0.00r | 1.60mno | 0.00q | 2.03rst | 0.00t | 2.53m | 0.00w | 2.63no |
| HP1G | 2.6e | 2.63e | 4.2e | 7.23e | 4.83f | 10.93d | 5.53e | 11.70d | 5.73g | 12.46d |
| HP2G | 2.9d | 2.93d | 4.4e | 6.97f | 5.03f | 1050e | 5.20e | 11.30e | 5.33h | 11.93e |
| HPG | 1.1jkl | 1.07jkl | 2.2jk | 7.93c | 3.57gh | 11.47c | 4.60f | 12.10c | 4.97i | 12.87c |
| SP1G | 1.1jkl | 1.07jkl | 1.6m | 1.65mno | 1.80n | 2.80mn | 1.83qr | 2.95jk | 1.83tuv | 3.20kl |
| SP2G | 1.2jk | 1.23jk | 1.9kl | 2.47k | 3.03i | 3.10jkl | 3.13ij | 3.53i | 3.17mn | 4.10h |
| SPG | 1.3ij | 1.30ij | 1.6m | 2.00l | 1.87n | 2.80mn | 2.95ijk | 2.90k | 1.97tu | 3.10kl |
| CFM1P1O | 0.7m | 0.70m | 1.03pq | 2.00l | 2.30lm | 2.30opqr | 2.30mnop | 2.50mn | 2.30rs | 2.60no |
| CFM1P2O | 0.9lm | 0.90lm | 1.56mn | 1.50nop | 0.87p | 2.30opqr | 0.00t | 2.50mn | 3.50l | 2.80mn |
| CFM1PO | 1.0jkl | 1.03jkl | 1.8lm | 1.65mno | 1.90n | 2.05qrst | 2.00opqr | 2.30no | 2.00stu | 2.55nop |
| CFM2P1O | 0.0o | 0.00o | 0.00r | 1.40p | 0.00q | 1.60v | 3.00ijk | 1.60u | 0.00w | 1.80u |
| CFM2P2O | 0.0o | 0.00o | 0.00r | 1.70m | 0.00q | 1.80tuv | 0.00t | 1.90rst | 0.00w | 2.30qrs |
| CFM2PO | 0.0o | 0.00o | 0.00r | 0.00q | 0.00q | 0.00w | 0.00t | 0.00v | 0.00w | 0.00v |
| HP1O | 3.6c | 3.63c | 5.4c | 2.77i | 5.97d | 4.63gh | 6.53d | 5.00g | 6.53e | 5.33g |
| HP2O | 4.0ab | 4.00ab | 6.2a | 2.85i | 6..77c | 5.05f | 7.50c | 5.35f | 7.57d | 5.70f |
| HPO | 3.7bc | 3.73bc | 5.2c | 3.07h | 5.63e | 4.77fg | 6.10d | 4.93g | 6.13f | 5.20g |
| SP1O | 1.7gh | 1.67gh | 2.1jk | 1.47op | 2.37lm | 1.97stu | 2.43lmno | 2.00qrs | 2.50qr | 2.20rst |
| SP2O | 1.6hi | 1.57hi | 2.3ij | 1.40p | 2.47kl | 1.97stu | 2.57klmn | 2.10opq | 2.30rs | 2.40opq |
| SPO | 1.9g | 1.90g | 2.5i | 1.37p | 2.67jk | 1.73uv | 2.73jklm | 1.80stu | 2.77opq | 2.03stu |
| Mean | 1.63 | 2.12 | 2.35 | 3.26 | 2.84 | 4.40 | 3.26 | 4.77 | 3.41 | 5.25 |
| LSD 0.05 | 0.299 | 0.226 | 0.255 | 0.191 | 0.203 | 0.294 | 0.464 | 0.223 | 0.309 | 0.282 |
| *P*-value | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | <.0001 | <.0001 |
| CV% | 11.3 | 5.9 | 6.6 | 3.3 | 4.3 | 3.7 | 8.1 | 2.6 | 5.1 | 3.0 |

\* Means followed by the same letter in a column are not significantly different at α = 0.05.

LSD = Least Significant Difference, CV = Coefficient of Variation, T1 = Trial 1, T2 = Trial 2

Growth of seedling height is primarily determined by two major factors: the rate of internode elongation and the number of height growth units produced in every growing stage. These two factors are hugely influenced by availability and activity of growth hormones, moisture presence, climatic variation and medium quality. The average seedling height for trail 2 that was greater than for trail 1 can be attributed to the relatively lower root zone temperatures in trail 1 (Table 3; Figures 4-7), which could have interfered with P uptake as Llanderal *et al.* (2021) reported that low levels of P in pepper plants were due to prevailing low temperatures which inhibit orthophosphate uptake. The HP1L and HP2L highest height can be due hygromix quality, halo/hydro priming and the lathhouse environment all of which highly influenced the combined treatment effect on plant height.

Since it was observed that some of the lathhouse seedlings had bend stems, this study suggests that the relatively lower light conditions in the lathhouse made the young seedlings strive to reach for more light (Plate 1). Moreover, the stable weekly micro-climate recorded in the lathhouse could have prevented temperature fluctuations, thus promoting consistent seedling height growth as compared to the open-field and greenhouse conditions.

Desirable physico-chemical characteristics of hygromix media especially its water holding capacity, texture and nutrient composition make it a very efficient media for horticultural nursery application (Manyasha *et al.,* 2023). Its 85% water holding capacity established in the present study could have provided the seedlings with adequate water consistently (Table 1). Water is a crucial factor in the early stages of plant growth, when the rate of cell division and elongation of the shoot is high and consumes high energy obtained from aerobic respiration process that requires oxygen molecules supplied by water. The fine texture of hygromix could have made it easier for root development thus enabling rapid and timely uptake of nutrients for the seedling thus providing glucose substrate for energy production needed for rapid cell elongation in the stem (Table 1).

Hygromix also contained 1.3% phosphorus which enhances proper root development which in turn boosts water and nutrient uptake to the rapidly growing plant tissues including the shoot, which results in increased height (Table 1). Similar results were found by Mathowa *et al.* (2017) who reported that sweet pepper seedlings height was significantly higher in hygromix than in germination mix and cocopeat.

Halo-priming could also have contributed to the high seedling heights in HP1L and HP2L since NaCl triggers activation of stress-responsive proteins and antioxidant enzymes through creating a controlled osmotic stress leading to efficient water and nutrient uptake, resulting in faster growth in a bid to curb osmotic stress (Aloui *et al*., 2017). Moreover, since hydrated seeds have been found to have a quicker and more uniform germination that boosts robust growth (Adhikari *et al*., 2021) reflected in a greater seedling height (Tania *et al.,* 2020), the same reasons could be the cause of the high seedling height recorded in hydro-primed treatments.

**3.2.2. Seedling collar diameter**

All the three factors had significant (*P*<0.0001) effects on seedling collar diameter in both trials (Table 4). In trail 1, the highest collar diameter was for the open field at 28 DAS, but it was not significantly different from that in the lathhouse. Later on, the lathhouse had highest collar diameter that was significantly (*P*<0.0001) different from that of the open-field, while greenhouse had lowest collar diameter. In trail 2, the greenhouse had the highest collar diameter throughout, which was closely followed by the lathhouse, and lastly the open-field.

Seedling collar diameter was greater in trail 2 than in trail 1 under the influence of medium type (Table 4). All the medium type effects were significantly (*P*<0.0001) different from each other (Table 4), with hygromix posting the highest collar diameter. The lowest collar diameter among the media was recorded for CFM2 in both trials. The CFM1 and soil medium had the second highest collar diameter on most occasions.

Priming proficiency had a slightly significant (*P*=0.0180, 0.0001) effect on collar diameter in both trials at 56 DAS (Table 4). In trail 1, hydro-priming had higher collar diameter compared to halo-priming, although it was mostly not significantly different. In trail 2, hydro-priming had a higher collar diameter, although not significantly different from halo-priming at 28 and 42 DAS.

The interaction of the three factors was highly significant (*P*<0.0001) on collar diameter in both trials (Table 5).

**Table 4: Main factor effect of environment, medium, and priming on collar diameter**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Day 28** | | **Day 35** | | **Day 42** | | **Day 49** | | **Day 56** | |
| **Factor** | **T1** | **T2** | **T1** | **T2** | **T1** | **T2** | **T1** | **T2** | **T1** | **T2** |
| Growing Environment | | | | | | | | | | |
| Lathhouse (L) | 1.18a | 0.94c | 1.45a | 1.61b | 1.76a | 1.78b | 2.06a | 1.89b | 2.13a | 2.09b |
| Open-field (O) | 1.24a | 1.22b | 1.37b | 1.10c | 1.48b | 1.34c | 1.63b | 1.42c | 1.65b | 1.52c |
| Greenhouse (G) | 0.86b | 1.45a | 1.06c | 2.11a | 1.22c | 2.24a | 1.46c | 2.43a | 1.49c | 2.50a |
| *P-*value | 0.0001 | 0.6935 | 0.0001 | 0.0001 | 0.0001 | 0.0002 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| LSD 0.05 | 0.062 | 0.054 | 0.058 | 0.029 | 0.100 | 0.027 | 0.108 | 0.032 | 0.120 | 0.037 |
| Growing Medium | | | | | | | | | | |
| CFM1 (2:1:1) | 1.05c | 1.06b | 1.21c | 1.37b | 1.38c | 1.54b | 1.48c | 1.62b | 1.48c | 1.69b |
| CFM2 (1:1:1) | 0.26d | 0.66d | 0.24d | 1.04c | 0.36d | 1.15d | 0.39d | 1.21d | 0.40d | 1.27c |
| Hygromix (H) | 1.84a | 2.03a | 2.33a | 2.62a | 2.66a | 3.05a | 3.22a | 3.25a | 3.40a | 3.53a |
| Soil (S) | 1.21b | 0.94c | 1.37b | 1.35b | 1.69b | 1.43c | 1.80b | 1.57c | 1.77b | 1.66b |
| *P-*value | 0.0001 | 0.6935 | 0.0001 | 0.0001 | 0.0001 | 0.0002 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| LSD 0.05 | 0.072 | 0.062 | 0.067 | 0.034 | 0.115 | 0.031 | 0.125 | 0.037 | 0.138 | 0.043 |
| Priming Proficiency | | | | | | | | | | |
| Halo (P1) | 1.11a | 1.15a | 1.28b | 1.66a | 1.53a | 1.82a | 1.71ab | 2.02a | 1.79a | 2.17a |
| Hydro (P2) | 1.11a | 1.19a | 1.36a | 1.57b | 1.56a | 1.82a | 1.81a | 1.93b | 1.83a | 2.04b |
| Non-primed (P) | 1.05a | 1.18a | 1.23c | 1.58b | 1.47a | 1.72b | 1.64b | 1.80c | 1.66b | 1.91c |
| *P-*value | 0.1015 | 0.4156 | 0.0001 | 0.0001 | 0.1995 | 0.0001 | 0.0096 | 0.0001 | 0.0180 | 0.0001 |
| LSD 0.05 | 0.062 | 0.054 | 0.058 | 0.029 | 0100 | 0.027 | 0.108 | 0.032 | 0.120 | 0.037 |
| CV% | 12.1 | 9.7 | 9.5 | 3.8 | 14.0 | 3.1 | 13.3 | 3.5 | 14.4 | 3.8 |

\* Means followed by the same letter in a column are not significantly different at α = 0.05.

LSD = Least Significant Difference, CV = Coefficient of Variation, T1 = Trial 1, T2 = Trial 2

At 56 DAS, HP2O had the highest collar diameter of 4.27 mm in trail 1, while HP1L had the highest of 4.30 mm in trail 2 (Table 5). Lowest girth was recorded for CFM2PL (0.97 mm) in trail 1 and CFM1P2O (0.57 mm) in trail 2. Widest girth was 1.97 mm for CFM1PL and 2.23 mm for CFM1P2G for trail 1 and trail 2, respectively. SPO which served as the control treatment had 2.00 mm in trail 1 and 1.70 mm in trail 2.

Seedlings attained a girth of 3 mm first at 35 DAS by HPG (3.20 mm), HP1L (3.17 mm), HP2O (3.17 mm) and HP1G (3.13 mm) in trail 1. In trail 2, a similar girth was first attained at 42 DAS in all hygromix based treatments in the lathhouse and greenhouse. No treatment in the open-field in trail 2 attained a girth of 3 mm even at 56 DAS. None of the CFM1, CFM2 and soil-based treatments had attained a girth of 3 mm at 56 DAS. HP2O seedling attained 4 mm diameter firstly at 49 DAS in trail 1, whereas in trail 2, first 4 mm girth was attained at 56 DAS by HP1L and HP1G. Non-primed treatment attained a collar diameter of 4 mm at 56 DAS (Table 5).

Collar diameter is the thickness of the stem at the base of a plant, and it is a product of secondary growth that involves the thickening of plant roots and stems (Xu *et al.,* 2023). Secondary growth is driven by lateral meristems located on the lateral sides of stems and roots (Spicer and Groover, 2010). Lateral meristem comprises of the vascular and cork cambium. When the cells of the vascular cambium divide they form vessel elements and tracheids (secondary xylem) as well as the secondary phloem. As these cells appear they lead to increased stem girth (diameter). On the other hand, the cork cambium produces cork cells which in conjunction with the primary phloem tissue form the bark of a plant, thus increasing the collar diameter (Miodek *et al.,* 2021).

Since plant root is one of the two locations of the lateral meristems, seedlings with well-developed root systems stand higher chances of undergoing vascular and cork cambia development result in higher stem girths compared to seedlings with poor root development. Growing environments, media components, and priming techniques with ideal conditions that support proper shoot and root development will inevitably result in higher collar diameter of seedlings.

**Table 5: Combined effect of environment, medium, and priming on collar diameter**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Treatment** | **Day 28** | | **Day 35** | | **Day 42** | | **Day 49** | | **Day 56** | |
| **T1** | **T2** | **T1** | **T2** | **T1** | **T2** | **T1** | **T2** | **T1** | **T2** |
| CFM1P1L | 1.03ijk | 1.07fgh | 1.23hij | 1.20hij | 1.57ij | 1.37k | 1.83f | 1.47lm | 1.90f | 1.57op |
| CFM1P2L | 1.00ijk | 1.17fg | 1.40fgh | 1.30h | 1.53ij | 1.50j | 1.87f | 1.57kl | 1.87f | 1.67no |
| CFM1PL | 1.40ef | 1.00ghi | 1.50fg | 1.17ijk | 1.67ghij | 1.30kl | 1.93f | 1.33nop | 1.97f | 1.43qrs |
| CFM2P1L | 0.67mn | 0.77kl | 0.77mn | 1.10jkl | 1.07k | 1.27lm | 1.17hi | 1.33nop | 1.17gh | 1.43qrs |
| CFM2P2L | 0.77lmn | 0.83ijk | 0.77mn | 1.07kl | 1.17k | 1.27lm | 1.40gh | 1.33nop | 1.43gh | 1.40rs |
| CFM2PL | 0.60o | 0.83ijk | 0.60n | 1.07kl | 0.97k | 1.17no | 0.97ij | 1.23pq | 0.97huj | 1.33st |
| HP1L | 1.73c | 2.20bc | 2.43c | 3.17a | 2.70bc | 3.50a | 3.33c | 3.80a | 3.70bc | 4.30a |
| HP2L | 1.80c | 2.03c | 2.20d | 2.97b | 2.63cd | 3.30b | 3.37c | 3.57b | 3.53c | 3.90c |
| HPL | 1.33efg | 2.10bc | 1.93e | 2.90b | 2.40cde | 3.03c | 2.83d | 3.23d | 3.10d | 3.83c |
| SP1L | 1.27fgh | 0.97hij | 1.43fgh | 1.23hi | 1.70ghij | 1.30kl | 2.03ef | 1.37mno | 2.03ef | 1.47pqr |
| SP2L | 1.27fgh | 0.87ijk | 1.60f | 1.10jkl | 1.93fgh | 1.23lmn | 1.97ef | 1.27opq | 2.00ef | 1.27rst |
| SPL | 1.30efgh | 0.83ijk | 1.50fg | 1.07kl | 1.90fghi | 1.13o | 2.03ef | 1.20q | 2.00ef | 1.33st |
| CFM1P1G | 1.00ijk | 1.00ghi | 1.33ghi | 1.80d | 1.73fghij | 1.93gh | 1.83f | 2.07gh | 1.83fg | 2.20i |
| CFM1P2G | 1.00ijk | 0.97hij | 1.10jkl | 1.63f | 1.60hij | 2.03f | 1.73fg | 2.13g | 1.90f | 2.23h |
| CFM1PG | 1.00ijk | 0.97hij | 1.27hij | 1.80d | 1.67ghij | 1.90h | 1.83f | 1.97hi | 1.37gh | 1.73n |
| CFM2P1G | 0.33p | 0.87ijk | 0.00o | 1.80d | 0.00m | 1.95fgh | 0.00k | 2.05gh | 0.00k | 2.15ij |
| CFM2P2G | 0.00q | 1.00ghi | 0.00o | 1.77d | 0.00m | 1.90h | 0.00k | 2.00hi | 0.00k | 2.07jk |
| CFM2PG | 0.00q | 0.83ijk | 0.00o | 1.87cd | 0.00m | 2.00fg | 0.00k | 2.07gh | 0.00k | 2.13ij |
| HP1G | 1.67cd | 2.27b | 2.07de | 3.13a | 2.50cd | 3.47a | 2.73d | 3.80a | 2.87d | 4.10b |
| HP2G | 1.33efg | 2.17bc | 2.00de | 2.97b | 2.33de | 3.23b | 2.80d | 3.40c | 2.90d | 3.53e |
| HPG | 1.17ghi | 2.67a | 1.50fg | 3.20a | 2.07ef | 3.43a | 2.33e | 3.57b | 2.40e | 3.67d |
| SP1G | 0.93jkl | 0.63lm | 0.93klm | 1.65f | 1.17k | 1.20mno | 1.23hi | 1.90ij | 1.30gh | 1.95kl |
| SP2G | 1.00ijk | 1.43e | 1.50fg | 1.83cd | 1.80fghij | 1.93gh | 1.93f | 2.03gh | 2.00ef | 2.03jk |
| SPG | 0.83klm | 1.40e | 0.97klm | 1.67ef | 1.03k | 1.77i | 1.13hi | 1.83j | 1.30gh | 1.87lm |
| CFM1P1O | 0.77lmn | 1.20f | 0.83m | 1.30h | 1.07k | 1.50j | 0.60j | 1.55kl | 0.63j | 1.70n |
| CFM1P2O | 1.10hij | 1.10fgh | 1.10jkl | 1.07kl | 0.00m | 1.20mno | 0.60j | 1.30opq | 0.73ij | 0.57u |
| CFM1PO | 1.17ghi | 1.10fgh | 1.17ijk | 1.00l | 1.03k | 1.13o | 1.10hi | 1.20q | 1.10ghi | 1.27t |
| CFM2P1O | 0.00q | 0.33n | 0.00o | 0.40n | 0.00m | 0.50p | 0.00k | 0.53r | 0.00k | 1.40rs |
| CFM2P2O | 0.00q | 0.47mn | 0.00o | 0.53m | 0.53l | 0.53p | 0.00k | 0.60r | 0.00k | 0.63u |
| CFM2PO | 0.00q | 0.00n | 0.00o | 0.00o | 0.00m | 0.00q | 0.00k | 0.00s | 0.00k | 0.00v |
| HP1O | 2.40b | 1.47e | 2.87b | 1.87cd | 3.07a | 2.47d | 3.90ab | 2.70e | 4.07ab | 2.83f |
| HP2O | 2.67a | 1.73d | 3.17a | 1.43g | 3.33a | 2.50d | 4.10a | 2.60e | 4.27a | 2.75f |
| HPO | 2.50ab | 1.67d | 2.83b | 1.93c | 3.03ab | 2.30e | 3.60bc | 2.40f | 3.73bc | 2.57g |
| SP1O | 1.50de | 1.07fgh | 1.50fg | 1.23hi | 1.83fghij | 1.37k | 1.87f | 1.43mn | 1.93f | 1.53pq |
| SP2O | 1.43ef | 0.47mn | 1.50fg | 1.20hij | 1.97fg | 1.47j | 2.00ef | 1.57kl | 1.36gh | 1.77mn |
| SPO | 1.33efg | 0.80jkl | 1.43fgh | 1.30h | 1.90fghi | 1.50j | 1.97ef | 1.60k | 2.00ef | 1.70n |
| Mean | 1.09 | 1.17 | 1.29 | 1.60 | 1.52 | 1.79 | 1.72 | 1.91 | 1.76 | 2.04 |
| *P*-value | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| LSD 0.05 | 0.215 | 0.186 | 0.200 | 0.102 | 0.346 | 0.093 | 0.374 | 0.113 | 0.414 | 0.129 |
| CV% | 12.1 | 9.7 | 9.5 | 3.8 | 14.0 | 3.138 | 13.3 | 3.5 | 14.4 | 3.8 |

\* Means followed by the same letter in a column are not significantly different at α = 0.05.

LSD = Least Significant Difference, CV = Coefficient of Variation, T1 = Trial 1, T2 = Trial 2

High collar diameter in the lathhouse in both trials was attributed to its ideal microclimate which provided the seedlings with conditions that posed less stress and instead promoted proper stem formation. This accounted for the highest collar diameter by HP1L in trail 2. Open-field provided enough light for photosynthesis in trail 1, which increased the energy levels in the seedlings leading to increased girth (Figure 1). Similar explanation was given in a study investigating the combined effect of photoperiod, light intensity and air temperature on the growth and development of tomato and red pepper seedlings. The findings revealed improved seedling growth under higher light intensities and longer photoperiods (Hwang *et al.,* 2020). This accounts for the highest collar diameter in HP1O in trail 1.

In trail 2, the poor performance in open-field were attributed to adverse effects of high winds and rains that led to waterlogging and loss of sturdiness that affect lateral vascular arrangement and also inhibit aeration, thus resulting in poor shoot and root formation that are key in determination of collar diameter (Plate 4). These effects could also explain why open-field seedlings failed to attain 3 mm diameter in trail 2.

Hygromix exhibited better physicochemical characteristics especially high Ca content (Table 1), which could have led to better collar diameter growth because Ca plays a critical role in cell formation and lignification (White and Bradley, 2003) that have a direct correlation with growth of girth. The least collar diameter in CFM2 treatments can be due to inability to absorb nutrients due to its low pH of 5.6 (Table 1), which is way below the ideal of 6 - 6.5 for absorption of P and Ca ions that are crucial in root formation and meristematic activities.

Hygromix had a highly significant influence on collar diameter due to superior physico-chemical characteristics, which provided the seedlings with enough nutrients and aeration that promoted root and shoot development, resulting in an increase in lateral meristems responsible for stem girth growth (Table 1). Similar results were found in a study conducted in Botswana University of Agriculture and Natural Resources where hygromix exhibited significant effect on plant growth parameters (Mathowa *et al.,* 2017). Although the study did not measure collar diameter, it can still be concluded that hygromix had superior effect on collar diameter because of the established direct relationship between stem height and collar diameter (Novikova *et al.,* 2023). The highly significant effect of halo and hydro-priming in both trials was attributed to the impact on the initial seedling emergence, which has a direct correlation to its subsequent growth including collar diameter.

**3.2.3 Seedling number of leaves**

Growing environment, medium, and priming had significant (*P*<0.0001) effects on the seedling number of leaves across the growing period in both trials (Table 6). The number of leaves was higher in trail 2 than in trail 1 (Table 6). In trail 1, the open-field had greater number of leaves, which were significantly different from the rest of the environments until at 56 DAS when they had no significant difference with those in the lathhouse. Greenhouse had the fewest number of leaves in trail 1 (Table 6). In trail 2, the greenhouse and lathhouse had similar highest number of leaves at 35-56 DAS, while the open-field had the lowest (Table 6).

None of the medium types recorded similar number of leaves in both trials, except for CFM1 and CFM2, which had no leaves at 28 DAS (Table 6). Hygromix had highest number of leaves, followed by soil, CFM1 and CFM2, respectively.

In trail 1, hydro-priming had the highest number of leaves across the growing period (Table 6). Non-primed seeds had highest mean number of leaves only at 28 DAS in trail 1. In trail 2, priming had no significant (*P*=0.0548) effect on the number of leaves at 28 DAS. In trail 2, halo-priming had the highest number of leaves across the growing period, followed closely by non-priming. Hydro-priming had no the fewest number of leaves across the growing period in trail 2 (Table 6).

There was highly significant (*P*<0.0001) effect of treatment combinations on the number of leaves across the growing period in both trials (Table 7). After 56 days, the highest number of leaves in trail 1 was 7.33 for HP2O, HPL and HP2L, but these were not significantly (*P*<0.0001) different compared to HP1L, which had 7 leaves. In trail 2, the highest number of leaves was 8.67 for HP1G, which was significantly (*P*<0.0001) different from HP1L, HP2L and HPG, which had an average of 8 leaves. The least number of leaves in trail 1 was 0.67 for CFM1P1L, CFM1P2L, CFM2P1L, CFM1P1G and CFM1PO, CFM2PO. In trail 2, the least number of leaves was 0.67 for CFM1P1O, CFM1P2O, CFM1PO, CFM2PG and CFM2PO (Table 10). The control (SPO) had an average of 2 and 2.67 leaves in trials one and two, respectively, which were higher than those for CFM1 and CFM2. In trail 1, 6 leaves were first attained at 49 DAS in HP1L, HP2L, HPIO, HP2O and HP2O, whereas in trail 2, 6 leaves were first attained at 35 DAS in HP1L and HPL. None of the CFM1, CFM2 and soil treatments attained 6 leaves in this study. There was no major increase in the sweet pepper number of leaves after 49 days in both trials (Table 7).

**Table 6: Main factor effect of environment, medium, and priming on number of leaves**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Day 28** | | **Day 35** | | **Day 42** | | **Day 49** | | **Day 56`** | |
| **Factor** | **T1** | **T2** | **T1** | **T2** | **T1** | **T2** | **T1** | **T2** | **T1** | **T2** |
| Growing Environment | | | | | | | | | | |
| Lathhouse (L) | 0.89b | 1.06a | 1.17b | 1.89b | 1.33b | 2.14b | 2.22b | 2.83b | 2.75a | 3.47a |
| Open-field (O) | 1.28a | 0.22c | 1.44a | 0.94c | 1.56a | 1.39c | 2.72a | 2.00c | 2.78a | 2.17b |
| Greenhouse (G) | 0.44c | 0.61b | 0.61c | 2.11a | 1.00c | 2.67a | 1.86c | 3.36a | 1.94b | 3.47a |
| *P-*value | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| LSD 0.05 | 0.069 | 0.052 | 0.065 | 0.090 | 0.067 | 0.093 | 0.094 | 0.104 | 0.117 | 0.095 |
| Growing Medium | | | | | | | | | | |
| CFM1 (2:1:1) | 0.00c | 0.00c | 0.00c | 0.74c | 0.07c | 0.89c | 0.52c | 1.04c | 0.67c | 1.11c |
| CFM2 (1:1:1) | 0.00c | 0.00c | 0.00c | 0.15d | 0.00c | 0.44d | 0.15d | 0.59d | 0.15d | 0.89d |
| Hygromix (H) | 2.07a | 1.78a | 2.59a | 4.07a | 3.26a | 5.00a | 5.48a | 6.26a | 6.15a | 6.81a |
| Soil (S) | 1.41b | 0.74b | 1.70b | 1.63b | 1.85b | 1.93b | 2.93b | 3.04b | 3.00b | 3.33b |
| *P-*value | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| LSD 0.05 | 0.079 | 0.06 | 0.075 | 0.103 | 0.078 | 0.108 | 0.108 | 0.120 | 0.135 | 0.110 |
| Priming Proficiency | | | | | | | | | | |
| Halo (P1) | 0.78b | 0.67a | 1.17a | 1.72b | 1.28b | 2.14a | 2.31b | 2.83a | 2.50b | 3.17a |
| Hydro (P2) | 0.94a | 0.61b | 1.11a | 1.39c | 1.44a | 1.94b | 2.47a | 2.50b | 2.69a | 2.81b |
| None (P) | 0.89a | 0.61b | 0.94b | 1.83a | 1.17c | 2.11a | 2.03c | 2.86a | 2.28c | 3.14a |
| *P-*value | 0.0001 | 0.0548 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| LSD 0.05 | 0.069 | 0.052 | 0.065 | 0.090 | 0.067 | 0.093 | 0.094 | 0.104 | 0.117 | 0.095 |
| CV% | 16.8 | 17.6 | 12.8 | 11.6 | 11.0 | 9.6 | 8.8 | 8.1 | 10.0 | 6.7 |

\* Means followed by the same letter in a column are not significantly different at α = 0.05.

LSD = Least Significant Difference, CV = Coefficient of Variation, T1 = Trial 1, T2 = Trial 2

Understanding the process of leaf formation is critical in explaining the variations in the number of leaves in this study. Leaves originate from the shoot apical meristem (SAM), whose formation can be summarized into five processes namely: leaf primordium initiation, polarity establishment, leaf blade formation, leaf shape regulation, and lastly leaf senescence (Tian *et al.,* 2020; Wang *et al.,* 2021). Leaf primordium initiation is key in determining the number of leaves produced in a plant because it gives way to the subsequent leaf formation processes. The peripheral zone (PZ) in the SAM is the zone responsible for leaf formation (Kalve *et al.,* 2014). In this peripheral zone, the rate of cell division is high and faster, serving as the origin of leaf primordia (Xiong and Jiao, 2019). Two growth hormones namely auxins and cytokinins play significant roles in formation of leaves. Auxins mediate cellular responses for initiation of leaf primordium (Dong and Huang, 2018), while cytokinins help in maintaining the shoot apical meristem (Gordon *et al.,* 2009).

The lathhouse environment contained relatively lower light intensities (Figure 1), which lead to higher auxin concentration in the seedlings and hence development of many leaves. The rate of evapotranspiration in the lathhouse could also have been low, thus providing the seedlings with enough water which is vital in plant growth and development (Figure 2). These findings are similar to those of Maboko and DuPlooy (2015), who observed that consistent and controlled conditions similar to those in the lathhouse significantly improved the number of leaves because stable humidity and temperature reduced evapotranspiration and heat stress, thereby promoting optimal leaf growth. The high number of leaves in HP2O can be due to availability of enough light intensity in the open-field, which is crucial for photosynthesis that in turn has a direct impact on leaf growth (Figure 1). Miao *et al*. (2023) stated that faster growth and rapid growth of leaves in lettuce was highly contributed to exposure of the plants to higher light intensities. HP1L and HPL attaining 6 leaves at 35 DAS in trail 2 could be because of the increased light intensities and air temperatures in a well shaded micro-climate which hastened plant growth and development.

**Table 7: Combined effect of environment, medium, and priming on number of leaves**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Treatment** | **Day 28** | | **Day 35** | | **Day 42** | | **Day 49** | | **Day 56** | |
| **T1** | **T2** | **T1** | **T2** | **T1** | **T2** | **T1** | **T2** | **T1** | **T2** |
| CFM1P1L | 0.00f | 0.00e | 0.00g | 0.00i | 0.00h | 0.00j | 0.67l | 1.33i | 0.67k | 1.13k |
| CFM1P2L | 0.00f | 0.00e | 0.00g | 0.00i | 0.00h | 0.00j | 0.00m | 0.00k | 0.67k | 0.00m |
| CFM1PL | 0.00f | 0.00e | 0.00g | 0.00i | 0.00h | 0.67i | 0.67l | 0.67j | 0.00l | 1.13k |
| CFM2P1L | 0.00f | 0.00e | 0.00g | 0.00i | 0.00h | 0.00j | 0.00m | 0.00k | 0.00l | 1.13k |
| CFM2P2L | 0.00f | 0.00e | 0.00g | 0.00i | 0.00h | 0.67i | 0.67l | 0.67j | 0.67k | 1.13k |
| CFM2PL | 0.00f | 0.00e | 0.00g | 0.00i | 0.00h | 0.00j | 0.00m | 0.00k | 0.00l | 1.13k |
| HP1L | 2.00c | 2.00c | 2.67c | 6.00a | 3.33c | 6.33b | 6.00b | 7.67ab | 7.00ab | 8.00b |
| HP2L | 2.00c | 2.00c | 3.33b | 4.67c | 3.33c | 6.00c | 6.00b | 7.33b | 7.33a | 8.00b |
| HPL | 2.00c | 2.67b | 2.00d | 6.00a | 3.33c | 6.00c | 5.22c | 6.33c | 6.00c | 7.00c |
| SP1L | 0.67e | 2.00c | 2.00d | 2.00f | 2.00e | 2.00g | 2.33i | 4.00e | 0.00l | 4.00g |
| SP2L | 2.00c | 2.00c | 2.00d | 2.00f | 2.00e | 2.00g | 3.00g | 3.33f | 3.67fg | 4.00g |
| SPL | 2.00c | 2.00c | 2.00d | 2.00f | 2.00e | 2.00g | 2.00j | 2.67g | 3.33gh | 4.00g |
| CFM1P1G | 0.00f | 0.00e | 0.00g | 1.13g | 0.00h | 1.33h | 0.67l | 1.33i | 0.67k | 1.13k |
| CFM1P2G | 0.00f | 0.00e | 0.00g | 2.00f | 0.00h | 2.00g | 0.00m | 2.00h | 0.00l | 2.00j |
| CFM1PG | 0.00f | 0.00e | 0.00g | 2.00f | 0.00h | 2.00g | 0.00m | 2.00h | 0.00l | 2.00j |
| CFM2P1G | 0.00f | 0.00e | 0.00g | 0.67h | 0.00h | 1.33h | 0.00m | 1.33i | 0.00l | 1.13k |
| CFM2P2G | 0.00f | 0.00e | 0.00g | 0.67h | 0.00h | 1.33h | 0.00m | 1.33i | 0.00l | 1.13k |
| CFM2PG | 0.00f | 0.00e | 0.00g | 0.00i | 0.00h | 0.67i | 0.00m | 1.33i | 0.00l | 0.67l |
| HP1G | 1.13d | 3.33a | 2.00d | 4.67c | 2.67d | 6.67a | 4.67d | 7.67ab | 4.67d | 8.67a |
| HP2G | 1.13d | 2.00c | 1.33e | 3.33d | 2.67d | 4.67d | 4.67d | 5.33d | 4.67d | 6.33e |
| HPG | 0.67e | 2.00c | 0.67f | 5.33b | 2.00e | 6.00c | 3.33f | 8.00a | 4.33de | 8.00b |
| SP1G | 0.00f | 0.00e | 1.33e | 1.13g | 1.33f | 1.33h | 2.67h | 2.00h | 2.67hi | 2.00j |
| SP2G | 0.67e | 0.00e | 0.67f | 2.00f | 2.00e | 2.67f | 4.00e | 4.00e | 4.00ef | 4.00g |
| SPG | 1.13d | 0.00e | 1.33e | 2.00f | 1.33f | 2.00g | 2.33i | 4.00e | 2.33ij | 4.00g |
| CFM1P1O | 0.00f | 0.00e | 0.00g | 0.67h | 0.00h | 0.67i | 0.67l | 0.67j | 0.67k | 0.67l |
| CFM1P2O | 0.00f | 0.00e | 0.00g | 0.00i | 0.67g | 0.00j | 1.13k | 0.67j | 2.00j | 0.67l |
| CFM1PO | 0.00f | 0.00e | 0.00g | 0.67h | 0.00h | 0.67i | 0.67l | 0.67j | 0.67k | 0.67l |
| CFM2P1O | 0.00f | 0.00e | 0.00g | 0.00i | 0.00h | 0.67i | 0.00m | 0.00k | 0.00l | 0.00m |
| CFM2P2O | 0.00f | 0.00e | 0.00g | 0.00i | 0.00h | 0.00j | 0.00m | 0.00k | 0.00l | 0.00m |
| CFM2PO | 0.00f | 0.00e | 0.00g | 1.13g | 0.00h | 0.00j | 0.67l | 0.67j | 0.67k | 0.67l |
| HP1O | 3.33a | 0.67d | 4.00a | 2.67e | 4.00b | 4.67d | 6.00b | 6.00c | 6.67b | 6.67d |
| HP2O | 3.33a | 0.67d | 4.00a | 0.00i | 4.67a | 1.33h | 7.33a | 2.67g | 7.33a | 3.33h |
| HPO | 2.67b | 0.67d | 3.33b | 2.67e | 3.33c | 3.33e | 6.00b | 5.33d | 7.33a | 5.33f |
| SP1O | 0.00f | 0.00e | 2.00d | 1.13g | 2.00e | 1.33h | 4.00e | 2.00h | 4.00ef | 2.67i |
| SP2O | 2.00c | 0.67d | 2.00d | 0.67h | 2.00e | 2.00g | 2.67h | 2.67g | 2.00j | 2.67i |
| SPO | 2.00c | 0.00e | 2.00d | 1.13g | 2.00e | 2.00g | 3.33f | 2.67g | 2.00j | 2.67i |
| Mean | 0.87 | 0.63 | 1.07 | 1.65 | 1.30 | 2.06 | 2.27 | 2.73 | 2.49 | 3.04 |
| *P*-value | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| LSD0.05 | 0.238 | 0.180 | 0.224 | 0.31 | 0.232 | 0.323 | 0.324 | 0.361 | 0.405 | 0.331 |
| CV% | 16.8 | 17.6 | 12.8 | 11.6 | 11.0 | 9.6 | 8.8 | 8.1 | 10.0 | 6.7 |

\* Means followed by the same letter in a column are not significantly different at α = 0.05.

LSD = Least Significant Difference, CV = Coefficient of Variation, T1 = Trial 1, T2 = Trial 2

Hygromix-based seedlings in the lathhouse recorded higher number of leaves in both trials and this could be due to the excellent water retention and aeration properties which promote better nutrient uptake for use in carrying out the metabolic activities necessary for leaf formation. Hygromix medium could also have promoted higher levels of cytokinins because of its boost on development of roots, which are the locations where cytokinins are synthesized. This effect, in addition to the nutritional strength of hygromix, especially richness in nitrogen and calcium (Table 1), which promote proper growth and development in plants, could explain why HPL and HP2L in trail 1 had the highest number of leaves. These results were in agreement with those reported by Oagile *et al.* (2016) that the number of leaves were significantly high in kales grown in hygromix compared to coco-peat and germination mix. The absence of more than four leaves in CFM1, CFM2 and soil-based treatments can be because of poor root development that inhibits absorption of water and nutrients necessary for plant growth (Plate 4). The absence of leaf increase after 49 DAS can be due to depletion of the available nutrients in the media components.

The highest number of leaves featured halo-primed treatments, and this could be as a result of the osmotic balance created when plants take up chloride ions and stimulate proper uptake of calcium ions, which are key in proper cellular functions such as primordial initiation that is a basis for leaf formation. Similar results were reported by Okello *et al.* (2022), who linked an increase in the number of leaves in *Aspilia africana* to halo-priming.

**3.2.4. Seedling fresh and dry weights**

Seedling fresh and dry weights were higher in trail 2 than in trail 1 (Table 8). All the three factors tested (environment, medium, and priming) had significant (*P*<0.0001) effects on seedling fresh and dry weights (Table 8). The effect of growing environment on seedling weight was not consistent (Table 8).

**Table 8: Main factor effect of environment, medium, and priming on seedling weight**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Seedling fresh weight (g)** | | **Seedling dry weight (g)** | |
| **Factor** | **Trial 1** | **Trial 2** | **Trial 1** | **Trail 2** |
| Growing Environment | | | | |
| Lathhouse (L) | 2.06a | 2.49a | 0.235b | 0.57b |
| Open-field (O) | 1.41b | 0.45c | 0.308a | 0.23c |
| Greenhouse (G) | 0.66c | 2.08b | 0.121c | 0.65a |
| *P-*value | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| LSD 0.05 | 0.195 | 0.174 | 0.040 | 0.060 |
| Growing Medium | | | | |
| CFM1 (2:1:1) | 0.17bc | 0.19c | 0.016b | 0.00c |
| CFM2 (1:1:1) | 0.03c | 0.12c | 0.002b | 0.00c |
| Hygromix (H) | 4.99a | 5.93a | 0.934a | 1.80a |
| Soil (S) | 0.31b | 0.45b | 0.045b | 0.08b |
| *P-*value | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| LSD 0.05 | 0.226 | 0.17 | 0.046 | 0.069 |
| Priming Proficiency | | | | |
| Halo (P1) | 1.47a | 1.80a | 0.224ab | 0.57a |
| Hydro (P2) | 1.58a | 1.69a | 0.234a | 0.45b |
| None (P) | 1.07b | 1.52b | 0.192b | 0.43b |
| *P-*value | 0.0001 | 0.0070 | 0.4256 | 0.0001 |
| LSD 0.05 | 0.195 | 0.174 | 0.040 | 0.060 |
| CV% | 30.2 | 22.1 | 38.0 | 26.2 |

\* Means followed by the same letter in a column are not significantly different at α = 0.05.

LSD = Least Significant Difference, CV = Coefficient of Variation, T1 = Trial 1, T2 = Trial 2

Hygromix had highest weights that were significantly different from those of other media in both trials. In both trials, soil had a higher fresh weigh compared to both CFM1 and CFM2, which had no significant differences between them. There was no significant difference in dry weight for soil, CFM1 and CFM2, as well as fresh weight for halo and hydro-primed seedlings. Mean dry weight was higher in hydro-primed treatments in trail 1, but it was not significantly different from halo-primed ones. In trail 2, halo-priming had a higher dry weight that was significantly different from that for hydro and no priming, which had no significant difference between them.

The combined factor effect was significant (*P*<0.0001) on both fresh and dry weights of sweet pepper seedlings. Highest fresh weight of 8.15 g and 9.60 g was recorded for HP1L and HP2L in trials one and two, respectively. Fresh weight of HP1L was not significantly different compared to that of HP2L and HP2O in trail 1. In trail 2, the fresh weight of HP2L was significantly different compared to that of the rest of the combinations. The highest dry weight of 1.62 g was for HP2O in trail 1, while it was 2.87 g for HP1G in trail 2. Lowest dry weight of 0.0 g was for most of the CFM1, CFM2 and soil-based treatments (Table 9) in both trials.

**Table 9: Combined effect of environment, medium, and priming on seedling weight**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Treatment** | **Fresh weight (g)** | | **Dry weight (g)** | | **Treatment (continued)** | **Fresh weight (g)** | | **Dry weight (g)** | |
| **T1** | **T2** | **T1** | **T2** | **T1** | **T2** | **T1** | **T2** |
| CFM1P1L | 0.29efg | 0.33ghi | 0.01g | 0.03h | SP1G | 0.26efg | 0.47fghi | 0.04g | 0.09gh |
| CFM1P2L | 0.31efg | 0.42ghi | 0.01g | 0.02h | SP2G | 0.20efg | 0.44ghi | 0.03g | 0.04h |
| CFM1PL | 0.24efg | 0.29ghi | 0.02g | 0.02h | SPG | 0.16efg | 0.40ghi | 0.06g | 0.05gh |
| CFM2P1L | 0.11efg | 0.25ghi | 0.02g | 0.02h | CFM1P1O | 0.03g | 0.07i | 0.01g | 0.00h |
| CFM2P2L | 0.12efg | 0.20ghi | 0.00g | 0.02h | CFM1P2O | 0.19efg | 0.12hi | 0.00g | 0.00h |
| CFM2PL | 0.04fg | 0.22ghi | 0.00g | 0.01h | CFM1PO | 0.05efg | 0.05i | 0.00g | 0.00h |
| HP1L | 8.15a | 8.00b | 0.97cd | 1.90cd | CFM2P1O | 0.00g | 0.00i | 0.05g | 0.00h |
| HP2L | 7.79a | 9.60a | 0.86d | 2.30b | CFM2P2O | 0.00g | 0.00i | 0.00g | 0.00h |
| HPL | 6.74b | 8.00b | 0.65e | 1.80cd | CFM2PO | 0.00g | 0.00i | 0.00g | 0.00h |
| SP1L | 0.47efg | 1.05ef | 0.05g | 0.26g | HP1O | 5.30b | 2.70d | 1.04c | 1.50e |
| SP2L | 0.72def | 0.78efg | 0.08h | 0.15gh | HP2O | 8.08a | 1.07ef | 1.62a | 0.63f |
| SPL | 0.71de | 0.70efgh | 0.11h | 0.12gh | HPO | 2.84c | 1.17e | 1.21b | 0.67f |
| CFM1P1G | 0.23efg | 0.15hi | 0.02g | 0.00h | SP1O | 0.11efg | 0.07i | 0.03g | 0.00h |
| CFM1P2G | 0.09efg | 0.14hi | 0.00g | 0.00h | SP2O | 0.09efg | 0.11hi | 0.00g | 0.00h |
| CFM1PG | 0.11efg | 0.12hi | 0.00g | 0.00h | SPO | 0.07efg | 0.06i | 0.03g | 0.00h |
| CFM2P1G | 0.00g | 0.16hi | 0.00g | 0.01h | Mean | 1.37 | 1.67 | 0.22 | 0.48 |
| CFM2P2G | 0.00g | 0.12hi | 0.00g | 0.00h | *P*-value | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| CFM2PG | 0.00g | 0.13hi | 0.00g | 0.00h | LSD 0.05 | 0.677 | 0.601 | 0.138 | 0.208 |
| HP1G | 2.69c | 8.37b | 0.49f | 2.87a | CV% | 30.2 | 22.1 | 38.0 | 26.2 |
| HP2G | 1.39d | 7.33c | 0.26g | 2.01c |  |  |  |  |  |
| HPG | 2.80c | 7.10c | 0.52ef | 2.43b |  |  |  |  |  |

\* Means followed by the same letter in a column are not significantly different at α = 0.05.

LSD = Least Significant Difference, CV = Coefficient of Variation, T1 = Trial 1, T2 = Trial 2

Seedling fresh weight is determined by the succulent levels of the plant and the amount of plant biomass. The lathhouse environment had reduced transpiration probably due to controlled light intensity, relative humidity and air temperature, which promote water retention that results in high fresh weight values (Figures 1-3). The open-field environment in trail 1 had relatively lower temperatures and relative humidity, which could have contributed a significant effect on fresh weight. The high temperatures in the greenhouse promoted rapid transpiration of the seedlings leading to reduced fresh weight (Figure 3). Similar explanation was reported by Savvas and Passsam (2008), who related higher above-ground biomass in pepper to high humidity.

In another research, Homma *et al*. (2023) pointed out that total dry matter content fluctuated due to outside solar radiation and light intensity. The study found that there was an increase in the dry matter content in warm, sunny days and a decrease in cold, rainy days. It can be inferred that environmental conditions, especially air temperatures and light intensity have a significant effect on plant dry matter content. Therefore, the high dry weight observed in the open-field and greenhouse for trail 1 and trail 2, respectively, can be due to the high light intensity and air temperatures that promoted high photosynthesis and hence dry weight in HP2O and HP1G (Figures 1 and 3). However, the lathhouse also had significant effect on dry weight in both trials and this can be due to the microclimate created which reduced plant stress, making seedlings accumulate high nutrients even if weight was lower compared to the other environments due to the reduction of photosynthesis by the less amount of light.

Hygromix’s good water retention could have sustained water supply for seedlings regardless of the environmental conditions, thereby increasing the water levels in the seedlings (Table 1). Similar findings were reported by Mathowa *et al.* (2017), who observed significant effect of growing medium on seedling fresh weight. In another study, it was also found that a mixture of hygromix and compost increased the fresh and dry weights of lettuce (Adediran, 2005). Both halo and hydro-priming promote water uptake in seedlings, which could be the reason for their significant effect on seedling fresh weight. Thus an environment with a combination of low temperatures (Figure 3), relative humidity (Figure 2), good water holding capacity medium (Table 1), and either halo or hydro-priming produce seedlings with high fresh weight, as was observed for HP1L, HP2O and HP2L.

Seedlings with many leaves inevitably have high fresh weight; consequently, HP1L, HP2O and HP2L that had higher number of leaves recorded higher fresh weight. Similar findings were reported by Abbaspour *et al.* (2012) who observed that plant height, branches and leaf number increase the fresh and dry weight content in pistachio. A notable exception to this was HP1G, which had the highest number of leaves in trail 2, but did not have the highest fresh weight probably due to the high rate of transpiration that was observed in the greenhouse.

Dry weight is recorded after drying plant tissues at temperatures higher than the ambient temperature. Plants are majorly 90% dry matter content comprising of mostly carbon, hydrogen and oxygen, which constitute about 89%; nitrogen and potassium take up 4% each of the dry matter (Evans, 2024). Thus, it can be deduced that seedling dry matter is highly influenced by nutrient availability and this could explain the high level of dry matter in hygromix-based treatments since hygromix had better nutritional levels compared to the other media (Table 1).

**3.2.5. Seedling Dickson Quality Index**

All the three factors (environment, medium and priming) tested had significant (*P*<0.0001) effects on DQI in both trials (Table 10). Open-field environment had the highest DQI in both trials. Hygromix had the highest DQI, followed by soil, and lastly CFM-based media in both trials. Hydro-priming had the highest DQI in trail 1, while in trail 2 both hydro and halo-priming had highest DQI. No priming had the lowest DQI in both trials (Table 10).

**Table 10: Main factor** **effect on DQI of sweet pepper seedlings at 56 DAS**

|  |  |  |
| --- | --- | --- |
| **Factor** | **Trial 1** | **Trial 2** |
| Growing Environment | | |
| Lathhouse (L) | 0.022c | 0.106b |
| Open-field (O) | 0.134a | 0.134a |
| Greenhouse (G) | 0.040b | 0.059c |
| *P-*value | 0.0001 | 0.0001 |
| LSD 0.05 | 0.005 | 0.009 |
| Growing Medium | | |
| CFM1 (2:1:1) | 0.009b | 0.003c |
| CFM2 (1:1:1) | 0.000c | 0.000c |
| Hygromix (H) | 0.243a | 0.380a |
| Soil (S) | 0.009b | 0.014b |
| *P-*value | 0.0001 | 0.0001 |
| LSD 0.05 | 0.006 | 0.011 |
| Priming Proficiency | | |
| Halo (P1) | 0.061b | 0.107a |
| Hydro (P2) | 0.073a | 0.107a |
| None (P) | 0.061b | 0.083b |
| *P-*value | 0.0001 | 0.0001 |
| LSD 0.05 | 0.005 | 0.009 |
| CV% | 15.8 | 19.5 |

\* Means followed by the same letter in a column are not significantly different at α=0.05. LSD = Least Significant Difference, CV = Coefficient of Variation.

The DQI values were higher in trail 2 than in trail 1; trail 2 posted higher average DQI of 0.09 compared to 0.06 for trail 1 (Table 11). Highest DQI in trail 1 was recorded for HP2O (0.64), followed by HP1O (0.46), and HPO (0.45). In trail 2, HP2O had the highest DQI of 0.64, followed by HP1O (0.46), HPO/HP2L (0.45), HP1G/HP1L (0.38) and HPL (0.35). In soil-based treatments, highest DQI was for SP1L (0.04) and SPG (0.03) in trials one and trail 2, respectively. CFM1P2L (0.03) and CFM1P2O (0.008) had the highest DQI in CFM1-based treatments in trials one and trail 2, respectively, whereas all of the CFM2-based treatments had 0.000 DQI in both trials (Table 11).

**Table 11: Combined factor effect on DQI of sweet pepper seedlings at 56 DAS**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Treatment** | **Trial 1** | **Trial 2** | **Treatment (continued)** | **Trial 1** | **Trial 2** |
| CFM1P1L | 0.011kl | 0.003g | SP1G | 0.006kl | 0.000g |
| CFM1P2L | 0.031hi | 0.002g | SP2G | 0.003l | 0.000g |
| CFM1PL | 0.0007l | 0.002g | SPG | 0.028ij | 0.000g |
| CFM2P1L | 0.000l | 0.000g | CFM1P1O | 0.009kl | 0.009g |
| CFM2P2L | 0.000l | 0.000g | CFM1P2O | 0.009kl | 0.009g |
| CFM2PL | 0.000l | 0.000g | CFM1PO | 0.006kl | 0.006g |
| HP1L | 0.046gh | 0.375cd | CFM2P1O | 0.000l | 0.000g |
| HP2L | 0.107e | 0.448b | CFM2P2O | 0.000l | 0.000g |
| HPL | 0.059g | 0.351d | CFM2PO | 0.000l | 0.000g |
| SP1L | 0.004l | 0.041f | HP1O | 0.456b | 0.456b |
| SP2L | 0.00l | 0.028fg | HP2O | 0.638a | 0.452b |
| SPL | 0.002l | 0.021fg | HPO | 0.452b | 0.638a |
| CFM1P1G | 0.012ijk | 0.000g | SP1O | 0.014jkl | 0.014fg |
| CFM1P2G | 0.000l | 0.000g | SP2O | 0.006kl | 0.006g |
| CFM1PG | 0.000l | 0.000g | SPO | 0.022ijk | 0.015fg |
| CFM2P1G | 0.000l | 0.000g | Mean | 0.0654 | 0.0994 |
| CFM2P2G | 0.000l | 0.000g | *P*-value | 0.0001 | 0.0001 |
| CFM2PG | 0.000l | 0.000g | LSD 0.05 | 0.017 | 0.032 |
| HP1G | 0.182c | 0.388c | CV% | 15.8 | 19.45 |
| HP2G | 0.089f | 0.166e |  |  |  |
| HPG | 0.164d | 0.145e |  |  |  |

\* Means followed by the same letter in a column are not significantly different at α = 0.05.

LSD = Least Significant Difference, CV = Coefficient of Variation, T1 = Trial 1, T2 = Trial 2

Growing environment, medium type, and priming proficiency had significant effects on Dickson Quality Index and this was so because DQI is derived from variables such as seedling height, collar diameter, number of leaves, and plant dry matter (Binotto *et al.,* 2010), which were found to be significantly influenced by the three factors. The findings of this study revealed that the open-field environment had a higher influence on the DQI in both trials and this was due to the higher influence of the open-field conditions on root development (Plate 5), which is a significant aspect in determination of DQI. The least DQI in greenhouse environment was due to the harsh greenhouse conditions, leading to plant stress that affected general plant growth (Plates 1 and 2).

It can be deduced from these results that although a seedling may possess desirable height, diameter, and number of leaves, it may fail to obtain a 0.2 or higher DQI value because DQI is highly correlated with dry matter content (Binotto *et al.,* 2010). This explains the relatively lower DQI values in the lathhouse, which had predominantly better seedling plant height, collar diameter, and number of leaves (Plates 3 and 5). As a result, partial hardening of the lathhouse seedlings would be key in enhancing their quality and performance in the field.

Hygromix had significant effects on seedling characteristics through its physico-chemical properties (Table 1), which were favourable and this could have translated to its significant effect on DQI. Due to poor plant performance in cob-formulated and soil media, none of them had a desirable DQI, and this was attributed to their physico-chemical characteristics that were poor (Table 1). Both halo and hydro-priming had significant effects on DQI and this was attributed to the significant influence they had on seedling height, collar diameter, and number of leaves.

**4. CONCLUSIONS**

The fact that trail 1 values were lower than trail 2 demonstrated that seedling establishment varies by season, owing to impact of environmental factors. Lathhouse environment has great potential to hasten time taken for sweet pepper seedling to get ready for transplanting. Cob-formulated media of a ratio 2:1:1 has a higher potential for use in horticultural application compared to cob-formulated media of a ratio 1:1:1. Halo-priming has potential to give better results in sweet pepper seedling establishment. A combination of halo-priming, hygromix medium, lathhouse environment hasten establishment of seedlings, making them ready for transplanting by 35 days post-sowing.

**5. RECOMMENDATIONS**

Plant nursery growers and small-scale farmers should adopt the lathhouse for sweet pepper seedling establishment and partial hardening a few days to enhance quality before transplanting or selling. Further improvement on physical characteristics and formulation procedure for cob-based media earmarked for adoption in horticultural nursery seedling production is recommended. Adoption of halo-priming of sweet pepper seeds with 4 g/L NaCl for 24 hours as a pre-treatment procedure for better seed germination, seedling establishment and ultimate high-quality seedlings is recommended.

**DISCLAIMER OF ARTIFICIAL INTELLIGENCE USE**

Authors hereby declare that no generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

**ETHICAL CONSIDERATION**

A research permit was sought from the National Commission for Science, Technology and Innovation (NaCoSTI) after receiving approval of the Chuka University Ethics Committee. High standard of integrity were ensured in the research through citing and referencing other people’s work.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

**REFERENCES**

Abbaspour, H. (2012). Influence of salt stress on growth, pigments, soluble sugars and ion accumulation in three pistachio cultivars. *Journal of Medicinal Plants Research*, *6*(12), 2468-2473.

Adediran, J. A. (2005). Growth of tomato and lettuce seedlings in soilless media. *Journal of Vegetable Science*, *11*(1), 5-15.

Adhikari, B., Dhital, P. R., Ranabhat, S., & Poudel, H. (2021). Effect of seed hydro-priming durations on germination and seedling growth of bitter gourd (*Momordica charantia*). *PLOS ONE*, *16*(8), e0255258.

Adnan, M., Rehman, H. A., Asif, M., Hussain, M., Bilal, H. M., Adnan, M., & Khalid, M. (2020). Seed priming; an effective way to improve plant growth. *EC Agriculture*, *6*(6), 01-05.

Adondakis, S., & Venable, D. L. (2004). Dormancy and germination in a guild of sonoran desert annuals. *Ecology*, *85*(9), 2582-2590.

Ahmad, B., Qadir, S. U., Dar, T. A., Alam, P., Yousuf, P. Y., & Ahmad, P. (2023). Karrikins: Smoke-derived phytohormones from stress alleviation to signaling. *Journal of Plant Growth Regulation*, 42(8), 4784-4796.

Aloui, H., Mohamed Aymen, E., & Chérif, H. (2017). Seed priming to improve seedling growth of pepper cultivars exposed to salt concentrations. *International Journal of Vegetable Science*, *23*(6), 489-507.

Anjichi, V. E., & Odhiambo, K. (2021). Use of locally constituted environmentally sustainable seedling growing media to raise commercial seedlings. Directorate of Research and Innovation. University of Eldoret.

Ayyogari, K., Sidhya, P., & Pandit, M. K. (2014). Impact of climate change on vegetable cultivation-A review. *International J. Agric., Envir. Biotech.*, *7*(1), 145-155.

Barchenger, D. W., & Bosland, P. W. (2016). Exogenous applications of capsaicin inhibits seed germination of Capsicum annum. *Scientia Horticulturae*, *203*, 29-31.

Barrett, G. E., Alexander, P. D., Robinson, J. S., & Bragg, N. C. (2016). Achieving environmentally sustainable growing media for soilless plant cultivation systems: A review. *Scientia Hortic*, *212*, 220-234.

Binotto, A. F., Lúcio, A. D. C., & Lopes, S. J. (2010). Correlations between growth variables and Dickson quality index in forest seedlings. *CERNE*, *16*(4), 457-464.

Bisbis, M. B., Gruda, N., & Blanke, M. (2018). Potential impacts of climate change on vegetable production and product quality: A review. *Journal of Cleaner Production*, *170*, 1602–1620.

Blake, G. R. and Hartge, K. H. 1986. Bulk density, Chapter 13. In: Klute, A. Ed.). Methods of Soil Analysis: Part 1-Physical and Mineralogical Methods, 5.1. Second Edition. SSSA Book Series.

Carrera-Castaño, G., Calleja-Cabrera, J., Pernas, M., Gómez, L., & Oñate-Sánchez, L. (2020). An updated overview on the regulation of seed germination. *Plants*, *9*(6), 703.

Dickson, A., Leaf, A. L., & Hosner, J. F. (1960). Quality appraisal of white spruce and white pine seedling stock in nurseries. *The Forestry Chronicle*, *36*(1), 10-13.

Dong, J., & Huang, H. (2018). Auxin polar transport flanking incipient primordium initiates leaf adaxial-abaxial polarity patterning. *Journal of Integrative Plant Biology*, *60*(6), 455-464.

Edgar, O., Gweyi-Onyango, J., & Korir, N. (2016). Influence of mulching materials on the growth and yield components of greenhouse pepper at Busia in Kenya. *Asian Research Journal of Agriculture*, *2*(2), 1-10.

El-Sanatawy, A. M., Ash-Shormillesy, S. M. A. I., Qabil, N., Awad, M. F., & Mansour, E. (2021). Seed halo-priming improves seedling vigour, grain yield, and water use efficiency of maize under varying irrigation regimes. *Water*, *13*(15), 2115.

Evans, M. (2024). *Mineral Nutrition*. Uark.Edu; University of Arkansas.

FAO. 2021. Standard Operating Procedure for Soil Available Phosphorus: Olsen Method. FAO, pp. 1-18

FAOSTAT, (2021). FAOSTAT: Food and agriculture data. Rome, Italy.

Gordon, S. P., Chickarmane, V. S., Ohno, C., & Meyerowitz, E. M. (2009). Multiple feedback loops through cytokinin signaling control stem cell number within the Arabidopsis shoot meristem. *Proceedings of the National Academy of Sciences*, *106*(38), 16529-16534.

Gruda, N. (2011). Current and future perspective of growing media in Europe. In *V Balkan Symposium on Vegetables and Potatoes 960*, 37-43.

Gruda, N. S. (2019). Increasing sustainability of growing media constituents and stand-alone substrates in soilless culture systems. *Agronomy*, *9*(6), 298.

Haluschak, P. 2006. Laboratory Methods of Soil Analysis. Canada, Manitoba Soil Survey.

Herrera, F., Castillo, J. E., López-Bellido, R. J., & Bellido, L. L. (2009). Replacement of a peatlite medium with municipal solid waste compost for growing melon (*Cucumis melo* L.) transplant seedlings. *Compost Science & Utilization*, *17*(1), 31-39.

Homma, M., Tadahisa Higashide, & Ahn, D.-H. (2023). Modeling short-term yield changes in sweet pepper based on dry matter production and fruit growth. *Journal of American Society for Horticultural Science*, *148*(6), 292–303.

Hosseini, A., & Koocheki, A. (2007). The effect of different priming treatments on germination percent and mean germination time of four varieties of sugar beet. *Journal of Agronomic Research*, *5*(1), 69-76.

Hwang, H., An, S., Pham, M. D., Cui, M., & Chun, C. (2020). The combined conditions of photoperiod, light intensity, and air temperature control the growth and development of tomato and red pepper seedlings in a closed transplant production system. *Sustainability*, *12*(23), 9939.

Jaetzold, R., Schmidt, H., Horne, B. and Shisanya, C. (2006). *Farm Management Handbook of Kenya*. Volume 2; Natural Conditions and Farm Management Information. 2nd Edition, Part C, East Kenya, Eastern Province.

Julė Jankauskienė, & Laužikė, K. (2023). Effect of sweet pepper (*Capsicum annum* L.) seedling age and cultivation method on seedling quality, photosynthetic parameters and productivity. *Agronomy*, *13*(9), 2255–2255

Jung, J. Y., & Yang, J.-K. (2014). The suitability evaluation of lignocellulosic substrate as growing media substitute. *African Journal of Biotechnology*, *13*(14). 1541-1549.

Kalve, S., De Vos, D., & Beemster, G. T. S. (2014). Leaf development: A cellular perspective. *Frontiers in Plant Science*, *5*, 362.

Kato-Noguchi, H., & Tanaka, Y. (2003). Effects of capsaicin on plant growth. *Biologia Plantarum*, *46*(1), 157-159.

Kheloufi, A., & Mansouri, L. M. (2020). Effect of seawater irrigation on germination and seedling growth of Carob tree (*Ceratonia siliqua* L.) from Gouraya National park (Béjaïa, Algeria). *Reforesta*, *10*, 1-10.

Kinyanjui, H. (1979). Soils of Tatton Farm, Egerton College, Njoro. National Agricultural Laboratories, Kenya Soil Survey, Ministry of Agriculture, Republic of Kenya, Nairobi. https://search.worldcat.org/en/title/12238656

Kucera, B., Cohn, M. A., & Leubner-Metzger, G. (2005). Plant hormone interactions during seed dormancy release and germination. *Seed Science Research*, *15*(4), 281-307.

Llanderal, A., García-Caparrós, P., Lao, M. T., & Segura, M. L. (2021). DRIS norms and sufficiency ranges for pepper grown under greenhouses conditions in the southeast of Spain. *Agronomy*, *11*(5), 837-845.

Maboko, M. M., & DuPlooy, C. P. (2015). Effect of plant growth regulators on growth, yield, and quality of sweet pepper plants grown hydroponically. *HortScience*, *50*(3), 383-386.

Manjaiah, K. M., Mukhopadhyay, R., Paul, R., Datta, S. C., Kumararaja, P., & Sarkar, B. (2019). *Chapter 13: Clay minerals and zeolites for environmentally sustainable agriculture*. In: M. Mercurio, B. Sarkar, & A. Langella (Eds.). ScienceDirect; Elsevier.

Manyasha L. L. Ntsoane, Manhivi, V. E., Tinotenda Shoko, Seke, F., Maboko, M. M., & Sivakumar, D. (2023). The phytonutrient content and yield of brassica microgreens grown in soilless media with different seed densities. *Hortic.*, *9*(11), 1218-1218.

Mathowa, T., Tshipinare, K., Mojeremane, W., Legwaila, G. M., & Oagile, O. (2017). Effect of growing media on growth and development of sweet paper seedlings. *Journal of Applied Horticulture*, *19*(3), 200-204.

Miao, C, Yang, S., Xu, J, Wang, H., Zhang, Y., Cui, J., Zhang, H., Jin, H., Lu, P., He, L., Yu, J., Zhou, Q, and Ding, X. 2023. Effect of light intensity on growth and quality of lettuce and spinach cultivars in a plant factory. *Plants,* *12*(18), 3337-3355.

Minami, K. (2001, May). High quality of seedling in vegetable production. In: *IX International Symposium on Timing of Field Production in Vegetable Crops 607*, 63-66.

Miodek, A., Gizińska, A., Włoch, W., & Kojs, P. (2021). What do we know about growth of vessel elements of secondary xylem in woody plants? *Biological Rev.*, *96*(6), 2911-2924.

Mitra, D., Mondal, R., Khoshru, B., Shadangi, S., Das Mohapatra, P. K., & Panneerselvam, P. (2021). Rhizobacteria mediated seed bio-priming triggers the resistance and plant growth for sustainable crop production. *Current Research in Microbial Sci.*, *2*, 100071-100076.

Muhammad, S., Joergensen, R., Mueller, T., & Muhammad, T. (2007). Priming mechanism: Soil amended with crop residue. *Pak. J. Bot*, *39*, 1155-1160.

Nalluri, N., & Karri, V. R. (2018). Use of groundnut shell compost as a natural fertilizer for the cultivation of vegetable plants. *Int. J. Adv. Res. Sci. Eng*, *7*(1), 1-8.

Nerlich, A., & Dannehl, D. (2021). Soilless cultivation: Dynamically changing chemical properties and physical conditions of organic substrates influence the plant phenotype of lettuce. *Frontiers in Plant Sci.*, *11*, 601455.

Novikova, T. P., Paweł Tylek, Clíssia Barboza Mastrangelo, Drapalyuk, M. V., Kharin, S. V., & Novikov, A. I. (2023). The root collar diameter growth reveals a strong relationship with the height growth of juvenile scots pine trees from seeds differentiated by spectrometric feature. *Forests*, *14*(6), 1164-1164.

Nyoka, B. I., Kamanga, R., Njoloma, J., Jamnadass, R., Mng’omba, S., & Muwanje, S. (2018). Quality of tree seedlings produced in nurseries in Malawi: Assessment of morphological attributes. *Forests, Trees and Livelihoods*, *27*(2), 103-117.

Oagile, O. and Ramalekane, O., Mojeremane, W., Matsuane, C. and Legwaila, G. M. 2016. Growth and development of kale (*Brassica oleracea var. acephala* L.) seedlings to different commercial growing media. *International Journal of Plant and Soil Science,* *12*(4), 1-7.

Okello, D., Komakech, R., Gang, R., Endang, R., Chung, Y., Omujal, F., & Kang, Y. (2022). Influence of various temperatures, seed priming treatments and durations on germination and growth of medicinal plant *Aspilia africana*. *Scientific Reports*, *12*(1), 14180-14191.

Olatunji, T. L., & Afolayan, A. J. (2018). The suitability of chili pepper (*Capsicum annum L*.) for alleviating human micronutrient dietary deficiencies: A review. *Food Science & Nutrition*, *6*(8), 2239-2251.

Olympios, C.M. & Choukr-Allah, R. (1999). Overview of soilless culture: Advantages, constraints, and perspectives. *Protected cultivation in Mediterranean region*, *31*, 307-324.

Oworu, O. O., Dada, O., & Majekodunmi, O. E. (2010). Influence of compost on growth, nutrient uptake and dry matter partitioning of grain amaranths (*Amaranthus hypochondriacus L*.). *Libyan Agriculture Research Center Journal International*, *1*(6), 375-383.

Pandiyaraj, P. (2017). Modern nursery raising systems in vegetables. *International Journal of Agricultural Sciences, 9*(52), 4889-4992.

Pascual, J. A., Ceglie, F., Tuzel, Y., Koller, M., Koren, A., Hitchings, R., & Tittarelli, F. (2018). Organic substrate for transplant production in organic nurseries. A review. *Agronomy for Sustainable Dev.*, *38*(3), 35-58.

Paul, L. C., & Metzger, J. D. (2005). Impact of vermicompost on vegetable transplant quality. *HortScience*, *40*(7), 2020-2023.

Rajasekar, M., Arumugam, T. & Kumar, S. (2013). Influence of weather and growing environment on vegetable growth and yield. *J. of Horticulture and Forestry*, *5*(10), 160-167.

Raviv, M. (2005). Production of high-quality composts for horticultural purposes: A mini-review. *HortTechnology*, *15*(1), 52-57.

Raviv, M. (2013). Compost in growing media: What is new and what is next? *Acta Horticulturae,* *982*(982), 39-52.

Raviv, M., Lieth, J. H., & Bar-Tal, A. (2008). Significance of soilless culture in agriculture, p. 1-14. In: Raviv, M., Lieth, J. H., & Bar-Tal, A. (Eds.). Soilless Culture: Theory and Practice. Academic Press. Elsevier. 713 pp.

Reis, M., & Coelho, L. (2007). Compost mixes as substrates for seedling production. In: *VIII International Symposium on Protected Cultivation in Mild Winter Climates: Advances in Soil and Soilless Cultivation, 747*, 283-292.

Rhaman, M. S., Imran, S., Rauf, F., Khatun, M., Baskin, C. C., Murata, Y., & Hasanuzzaman, M. (2020). Seed priming with phytohormones: An effective approach for the mitigation of abiotic stress. *Plants*, *10*(1), 37.

Savvas, D., Ntatsi, G., & Passam, H. C. (2008). Plant nutrition and physiological disorders in greenhouse grown tomato, pepper and eggplant. *European Journal of Plant Science and Biotechnology*, *2*(1), 45-61.

Sime, G., & Aune, J. (2020). On‐farm seed priming and fertilizer micro‐ dosing: Agronomic and economic responses of maize in semi‐ arid Ethiopia. *Food and Energy Security*, *9*(1), 1-13.

Singh, V. K., Singh, R., Tripathi, S., Devi, R. S., Srivastava, P., Singh, P., Kumar, A., & Bhadouria, R. (2020). Seed priming: State of the art and new perspectives in the era of climate change *Chapter 6.* In: M. N. V. Prasad & M. Pietrzykowski, Eds.). Climate Change and Soil Interactions. Elsevier.

Spicer, R., & Groover, A. (2010). Evolution of development of vascular cambia and secondary growth. *New Phytologist*, *186*(3), 577-592.

Sterrett, S. B. (2001). Compost as horticultural substrates for vegetable transplant production, p. 227-240. In: Stoffella, P. J. and Kahn, B. A. (Eds.). *Compost Utilization in Horticultural Cropping Systems*, CRC Press.

Sun, F., Xiong, S., & Zhu, Z. (2016). Dietary capsaicin protects cardiometabolic organs from dysfunction. *Nutrients*, *8*(5), 174-187.

Tania, S. S., Rhaman, M. S., & Hossain, Md. M. (2020). Hydro-priming and halo-priming improve seed germination, yield and yield contributing characters of Okra. *Tropical Plant Research*, *7*(1), 86-93.

Taparia, T., Hendrix, E., Nijhuis, E., de Boer, W., & van der Wolf, J. (2021). Circular alternatives to peat in growing media: A microbiome perspective. *Journal of Cleaner Production*, *327*, 129375.

Tian, T., Ma, L., Liu, Y., Xu, D., Chen, Q., & Li, G. (2020). Arabidopsis far-red elongated hypocotyl3 integrates age and light signals to negatively regulate leaf senescence. *The Plant Cell*, *32*(5), 1574-1588.

Torkashvand, M., Alidoust, M., & Mahboub Khomami, A. (2015). The reuse of peanut organic wastes as a growth medium for ornamental plants. *International J. Recycling of Organic Waste in Agriculture*, *4*(2), 85-94.

White, P. J., & Bradley, M. R. (2003). Calcium in plants. *Annals of Botany*, *92*(4), 487–511.

Wu, C., Wang, M., Dong, Y., Cheng, Z., & Meng, H. (2015). Growth, bolting and yield of garlic (*Allium sativum* L.) in response to clove chilling treatment. *Scientia Hortic*, *194*, 43–52.

Xiong, Y., & Jiao, Y. (2019). The diverse roles of auxin in regulating leaf development. *Plants*, *8*(7), 243.

Xu, N., Meng, L., Tang, F., Du, S., Xu, Y., Kuang, S., Lv, Y., Song, W., Li, Y., Qi, W., & Zhang, Y. (2023). Plant spacing effects on stem development and secondary growth in *Nicotiana tabacum*. *Agronomy*, *13*(8), 2142.