Original Research Article

Combined Environment, Medium and Priming Treatments Significantly Accelerate Sweet Pepper Seed Germination

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**ABSTRACT**

Sweet pepper (*Capsicum annum* L.) is a fruit-vegetable of immense importance in terms of consumption in the world. Its richness in vitamins and minerals has resulted in increased utilization in dishes across the globe. However, there is a danger of not meeting its growing demand since production has been dwindling in some countries, partly due to challenges encountered during seed germination stage, yet the success of this early growth stage contributes to half of the overall crop production potential. Many factors including environmental conditions, growth substrate, and seed preconditioning contribute to the success of seed germination. Their mode of action is mostly integrated and hence consideration needs to be paid to all of them beginning at the early seed germination stage. This study, therefore, investigated the combined effects of growing environment, medium type, and priming proficiency on sweet pepper seed germination, with a view to contributing to overcoming seed germination failure. The research was conducted in two trials in a Completely Randomized Design with three replications. The factors were evaluated as 3 growing environments x 4 medium types x 3 priming proficiencies. Data values were collected on environmental conditions, media characteristics, sweet pepper seed germination rate and percentage. The data values were subjected to analysis of variance using SAS version 9.4. Significant means were separated using the LSD test at α=0.05. Results showed that prevailing environmental conditions and media characteristics varied across the treatments. More importantly, the effect of single factors of growing environment, medium type and priming proficiency, as well as their combinations on germination rate and percentage varied significantly across time and trials (*P*=0.0001). The HP1L gave the best germination percentage of 100% by 28 DAS, which indicated that the three factors interact while influencing sweet pepper seed germination. The present study, therefore, recommends use of halo-priming of sweet pepper seeds followed by sowing in hygromix under a lathhouse environment to accelerate and maximise germination rate and percentage.

***Keywords****: Seed dormancy, Environmental conditions, Propagation substrates, Solanaceae*

**1. INTRODUCTION**

One of the most highly cherished and consumed vegetable crops in the world is sweet pepper (*Capsicum annum* L.) (Edgar *et al*., 2016). In 2020, global production of sweet pepper attained 36 million tonnes, to which Kenya contributed only 2,271 tonnes (FAOSTAT, 2021). Sweet pepper is increasingly becoming cherished because of its richness in vitamins A, C, B1, B2, D and E (Muhamman and Auwal, 2008), calcium, phosphorus, potassium (Olatunji and Afolayan, 2018), pharmaceutical properties for treating hypertension, obesity, cardiovascular anomalies (Sun *et al*., 2016), and culinary uses as a spice or salad. This fact notwithstanding, sweet pepper export value in Kenya suffered a drop of 23% to US$1.27 million in 2021 (Tridge, 2022) due to reduced productivity. Reversing this trend calls for development of integrated technologies, starting at seed germination stage. The difficulty in sweet pepper seed germination justifies research to provide cheap and simple pretreatment techniques (Robledo, 2020).

Seed germination is the beginning of a plant life and a key phase for successful growth and yield (Carrera-Castaño *et al*., 2020). However, presence of allelopathic capsaicinoids in pepper suppresses germination (Barchenger and Bosland, 2016). As a result, sweet pepper seeds take on average 15-21 days (Mathowa *et al*., 2017) to germinate in the absence of any seed pretreatment, compared to the related tomato and brinjal species, which take 8-10 and 7-12 days, respectively. Acceleration of germination calls for manipulation of growing environment, media, and seed dormancy.

Growing environmental conditions that highly influence seed germination include humidity, moisture, light, temperature and oxygen (Nawaz *et al*., 2013). Without them being favourable, seed dormancy persists, thereby delaying germination (Nawaz *et al.,* 2013). 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 sweet pepper growth with less or no attention given to seed germination phase, yet it influences up to 50% of the subsequent growth of sweet pepper (Rajasekar *et al*., 2013; Ayyogari *et al*., 2014; Bisbis *et al*., 2018). There is therefore a need to investigate their influence on seed germination in an integrated set up.

Substrates are a modern technology in vegetable crop production that uses either inert organic or inorganic materials enriched with nutrients for proper plant growth (Sterrett, 2001; Nerlich and Danneh, 2021). Inorganic substrates include expanded clay, glass wool, perlite, pumice, rockwool, sand, vermiculite, sepiolite, volcanic tuff, foam mats, plastic foam, and hydrogel, among others. Organic substrates include coconut coir, bark, cocoa, fleece, marc, rice husk, sawdust, and wood chips (Olympios, 1999; Raviv *et al*., 2008). Although common (Gruda *et al*., 2019), peat usage is decreasing due to high costs (Jung and Yang, 2014; Anjichi and Odhiambo, 2021; Herrera *et al*., 2009), extreme degradation of peat lands coupled with emission of greenhouse gases (Barrett *et al*., 2016), and long renewal process of peatlands (Gruda, 2019). Consequently, other alternative organic materials are being used commercially (Gruda, 2011). Usage of hygromix is negated by its high costs (Taparia *et al*., 2021). Organic agricultural wastes with similar absorbent materials including maize cobs and ground nut shells can be used to produce soilless media rather than being burned or discarded in landfills (Oworu *et al*., 2010; Mohammadi *et al.,* 2015; Nalluri and Karri, 2018). However, their suitability has not been sufficiently established and application as a natural fertilizer additive to other growth mixtures, which justifies this research to fill the gap in knowledge.

Various conditioning treatments, including priming (Raj and Raj, 2019), stratification, chilling, light, hormones (Kucera *et al*., 2005), and smoke substances (Ahmad *et al*., 2022) have been tried to improve germination of sweet pepper seeds. Seed priming allows seeds to absorb water in the absence of roots and entering of the third stage of germination (Nawaz *et al*., 2013). It increases germination percentage (Hossseini and Koocheki, 2007), rate and uniformity (Adhikari *et al*., 2021; Singh *et al*., 2020). Seed priming techniques include halo-, hydro-, bio-, solid-matrix-, hormonal-, and chemical-priming (Adnan *et al*., 2020). The latter two though most effective are expensive and can cause death of seed embryos when inappropriately applied, thus calling for skilled personnel, which makes it rather unfit for small-scale farmers to use unless when trained, which further attracts financial input (Rhaman *et al*., 2020). Solid matrix priming is cheap, but it can deprive seeds of enough water to take it through stage II of germination, especially when it is hot and evaporation rate is high (Parera and Cantliffe, 1994). Bio-priming is ecofriendly, but it is relatively costly to obtain the microorganisms necessary for it, compared to hydro- and halo-priming (Mitra *et al*., 2021; Sime and Aune, 2020)). However, hydro- and halo-priming lack adequate information on their effects on Kenyan-based sweet pepper varieties. Owing to the limited information available on integration of important factors, this paper evaluated the potency of growing environment, cob-formulated medium, and seed priming proficiency on Kenyan-based sweet pepper seed germination.

**2. MATERIALS AND METHODS**

**2.1. Research Site and Arrangement**

The experiment was conducted on-farm in two trials from June 20-August 8, 2023 and August 19-October 6, 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 three-factor experiment was arranged in a Completely Randomized Design with 36 treatments, comprising 3 growing environments x 4 media x 3 priming proficiencies, replicated three times. Each treatment had five seedlings, but measurements were taken on the middle three, while the exterior two seedlings served as guard plants.

**2.2. Germination 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. Propagation pots measuring 7 cm × 7 cm ×6.5 cm and spaced at 10 cm were placed on a cleared area, measuring 5 m × 4 m × 0.5 m.

(b) Greenhouse set-up (G): The greenhouse measured 30 m x 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. Propagation pots of size 7 cm × 7 cm × 6.5 cm were placed on the benches at 10 cm spacing.

(c) Lathhouse set-up (L): A lathhouse, measuring 10 m x 10 m, with six 1 m x 1.5 m open-meshed windows, external gal sheet roofing, and internal net shading (75% light transmission), was used. Three wooden benches measuring 2 m x 1 m x 0.5 m with the top made of a net were constructed and placed inside the lathhouse. Propagation pots measuring 7 cm × 7 cm ×6.5 cm were placed on the benches at a spacing of 10 cm.

**2.3. Media Preparation**

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.

   

**Plate 1: Cob-formulated media preparation (CFM1= 2:1:1 and CFM2= 1:1:1 of ground cobs, groundnut shells and Tithonia leaves)**

**2.4. Seed Priming Procedures**

(a) Halo-priming (P1): Admiral F1 sweet pepper seeds were obtained from Syngenta Seed Company and 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. Cultural Practices**

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. Medium 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 chemical 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; Qiu *et al.,* 2015).

(b) Particle density: Approximately 25 g of each medium was placed in propagation pot and 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: It was calculated using the formulae: [1-(Bulk density/Particle density)] ×100 (Qiu *et al.,* 2015).

(d) Water holding capacity: Funnels lined with no. 1 filter papers were placed on 100 ml cylinders, 25 g of each medium 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, where 25 g medium was added to 50 ml of distilled water, 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 for oxidation. The solution was heated in a fume chamber for digestion and titrated against 50 ml HCl and results recorded.

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

(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 the neck of the flask to remove 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. Seed germination data:*** Two data sets were collected. The first set was germination rate obtained by counting over time. The interval used was 3 days until 27 DAS when there was no more germination. Thus the germination rate was monitored and recorded from 3 to 27 DAS. The second set was germination percentage at 28 DAS. It was calculated using the formula: (Total seeds germinated/Total seeds sown) x 100 (Scott *et al*., 1984).

**2.7. Data Analysis**

Seed germination rate and percentage 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, … Equation 1,

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. Environmental Conditions**

The environmental conditions (light intensity, relative humidity and temperature were recorded to help make inferences on the germination of sweet pepper (Table 1). Comparatively, light intensity, relative humidity and air temperature averages were higher in trial two than in trial one. In both trials, open field had highest light intensity (24.71 and 43.48 lux), followed by greenhouse (13.76 and 26.89 lux), and lathhouse (3.65 and 6.79 lux) in trial one and two, respectively. Highest and lowest weekly light intensity was recorded at 28 to 35 DAS and 42 to 49 DAS in trial one, respectively, while in trial two, it was at 7 to 14 DAS and 49 to 56 DAS, respectively.

**Table 1: Average environmental conditions over 28 and 56 days for trial 1 and trial 2**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Environment** | **Trial** | **Light intensity (lux)** | **Relative humidity (%)** | **Temperature (°C)** |
| First 28 days |  |  |  |  |
| Lathhouse | Trial 1 | 2.89 | 65.57 | 22.2 |
|  | Trial 2 | 7.07 | 53.89 | 25.6 |
| Greenhouse | Trial 1 | 11.24 | 59.64 | 25.6 |
|  | Trial 2 | 28.03 | 54.57 | 27.5 |
| Open-field | Trial 1 | 20.00 | 60.75 | 23.7 |
|  | Trial 2 | 51.84 | 50.96 | 26.2 |
| For 56 days |  |  |  |  |
| Lathhouse | Trial 1 | 3.69 | 66.21 | 22.2 |
|  | Trial 2 | 6.80 | 58.48 | 25.4 |
| Greenhouse | Trial 1 | 13.88 | 62.23 | 25.0 |
|  | Trial 2 | 26.89 | 57.77 | 27.5 |
| Open-field | Trial 1 | 24.56 | 63.18 | 23.4 |
|  | Trial 2 | 43.46 | 54.23 | 26.2 |

At 56 DAS, the lathhouse had the highest relative humidity of 66.21% and 58.48% in trial one and two, respectively. Greenhouse had the lowest relative humidity of 62.23% in trial one, while in trial two, it was lowest in open-field at 54.23%. The relative humidity in the greenhouse was not steady across the growing season. Highest weekly average temperature was recorded at 0-7 DAS in trial one and 42-49 DAS in trial two. Greenhouse had the highest mean air temperature of 25°C in trial one and 27.5°C in trial two, while lowest air temperature of 22.3°C and 25.3°C was recorded in the lathhouse in trial one and trial two, respectively. Mean weekly temperature was highest at 28-35 DAS in trial one and 7-14 DAS in trial two, and lowest at 42-49 DAS in trial one and 49-56 DAS in trial two. Medium was high (25°C and 28°C in trial one and two, respectively) in greenhouse and lowest (22°C and 25°C in trial one and two, respectively) in the lathhouse (Table 2). Apart from slight differences in some days, there were no differences in medium-temperature among media located in the same growing environment. However, occasionally, hygromix had slightly higher temperatures, while the soil had the lowest.

**Table 2: Average medium temperature (oC) over 56 days for trial 1 and trial 2**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Environment** | **Lathhouse** | | **Open-field** | | **Greenhouse** | |
| **Trial** | **Trial 1** | **Trial 2** | **Trial 1** | **Trial 2** | **Trial 1** | **Trial 2** |
| CFM1 | 22 | 25 | 23 | 26 | 25 | 28 |
| CFM2 | 22 | 25 | 23 | 26 | 25 | 28 |
| Hygromix | 22 | 25 | 23 | 26 | 25 | 28 |
| Soil | 22 | 25 | 23 | 26 | 25 | 28 |

It was also observed that medium temperatures were directly related to air temperature. Environmental factors such as light intensity, relative humidity and temperature are vital for germination of vegetable seeds. Depending on phototropism of a plant, light intensity can either enhance or hinder seed germination. Some seeds require light to trigger germination, while others germinate better in darkness (Chen *et al.,* 2023). Low light intensity results in lower survival rates, while higher light intensities promote better root length, stem diameter and biomass formation (Chen *et al.,* 2023). Light intensity is crucial in seedling growth as it triggers and interacts with hormones which enhance hypocotyl elongation and leaf formation (Gupta and Nath, 2020).

Optimal germination temperatures for most crops range from 20°C to 25°C (Sharma *et al.,* 2022). Some crops such as maize attain higher germination percentage at this range but germination and seedling growth is highly affected at temperatures above 30°C (Khaeim *et al.,* 2022). Temperature is critical in breaking seed dormancy and effectively initiating the germination process (Haj-Sghaier, 2022). It also affects the activities of germination enzymes such as catalase and peroxidase, as well as shoot and root development (Sharma *et al.*, 2022). Extremely higher temperatures beyond 32°C increase transpiration rates and heat stress, which reduces water availability, leading to reduced seedling establishment (Zakir *et al.,* 2024).

Relative humidity influences microclimate around germinating seeds, as well as water availability for growing seedling. High relative humidity regulates effects of high temperatures to reduce transpiration rates, thus preventing stress related damage of seeds (Zheng *et al.,* 2020). However, extremely high humidity under higher temperatures can promote early plant senescence and seedling susceptibility to diseases (Zheng *et al.,* 2020). Relative humidity is also crucial in preserving seed viability during storage, which has a direct correlation to germination percentage of vegetable seeds (Savaedy *et al.,* 2021).

**3.2. Media Characteristics**

None of the four media exhibited similar characteristics (Table 3). Forest soil had the highest bulk density of 0.55g/cm3, while CFM2 had the lowest (0.11 g/cm3). Texture varied across the media with soil having very fine texture followed by hygromix (fine), CFM2 (medium) and CFM1 (coarse). Hygromix had the highest porosity and water holding capacity (WHC) of 45.5% and 85%, respectively, while CFM1 had the lowest porosity (29.4%) and CFM2 the lowest WHC (20%). Hygromix had the highest pH (6.3), while CFM2 had the lowest pH (5.6). Nitrogen was highest in CFM2 (1.88%) and lowest in forest soil (0.03%). Hygromix had high phosphorus (12.22%/g) and calcium (7.55 ppm/g), while CFM2 had the lowest phosphorus (4.67%/g) and CFM1 had the lowest calcium (3.09 ppm/g). Potassium was highest in CFM2 (9.75 ppm/g) and lowest in soil (7.1 ppm/g).

Results for physico-chemical characteristics of the growing media are shown in Table 3. Growing media characteristics have numerous effects on seed germination (Plate 2). The bulk density of a growing media plays a major role by influencing the availability of oxygen, necessary for proper seed germination. When the bulk density is high, porosity of medium is low and this limits the space available for water and air, inhibits proper medium aeration, and constrains seed respiration (Qiu *et al.,* 2015). Temperature regulation and nutrient mobility in media is influenced by bulk density, where bulky media tends to warm up and cool down slowly, thereby potentially delaying germination. Bulky media experience slower nutrient diffusion, thus inhibiting the availability of nutrients, especially phosphorus that is immobile (Bengough and Mullins, 1990).

Enzymatic activities responsible for seed germination are pH sensitive with most of the seeds germinating better in a pH range of 5.5-7.5. After seed germination, pH influences nutritional balance around the root zone that in turn affect root and leaf development (Agić *et al.,* 2009). Growing media pH also affects the activity of microorganisms that play key roles in decomposition of organic matter and nutrient fixation (McCauley, 2009). Absorption of nutrients is also dependent on pH with the ideal pH for most nutrients being 6.0-6.5.

**Table 3: Physico-chemical growing medium characteristics**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **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 | 20 | 85 | 75 |
| Total N (%) | 1.45 | 1.88 | 0.38 | 0.03 |
| Total P (%) | 0.12 | 0.09 | 1.3 | 0.023 |
| Total K (mg/kg) | 8.76 | 9.75 | 7.96 | 7.1 |
| Ca (mg/kg) | 3.09 | 5.15 | 7.55 | 1.81 |

|  |  |  |
| --- | --- | --- |
| a) Algae development in hygromix media in the lathhouse | b) Shrinkage and hardening of CFM2 medium due to degradation in the greenhouse | c) Scorching effect on hygromix medium in the greenhouse |
| **Plate 2: Effect of growing environment on media characteristics** | | |

Water holding capacity plays a critical role in seed germination as it determines the availability of water in the growing media. Moisture availability is one of the factors affecting germination since it activates enzymatic processes that stimulate seed germination (Jethva *et al.,* 2022). Related to WHC is the texture of the media, which determines the WHC based on the ratio of soil particles. Growing media with higher clayey particles exhibit higher WHC (Das and Ghosh, 2023). However, a very fine texture lacking enough macropores promotes waterlogging and inhibits aeration which may ultimately lead to the suffocation of the seed embryo and root hairs.

The availability of essential nutrients, majorly N, P, K and Ca, is important in seed germination. Nitrogen is a key component of amino acids and proteins, which act as substrates for ATP synthesis, thus providing energy for enhancement of cell division and elongation. Phosphorus is a component of ATP, which is crucial for energy transfer in plants. It is important during the early stages by improving the ability to access nutrients (Khalofah *et al.,* 2022). Potassium is key in regulation of plant physiological processes such as enzyme activation, water uptake, maintenance of turgor pressure and osmotic balance. Calcium is key in the formation and strengthening of cell walls and membranes, as well as cell structural integrity, division and elongation (White and Broadley, 2003).

**3.3. Seed Germination Rate**

The germination rate over time was significantly (*P* < 0.0001) different in the two trials (Table 4). All the three factors individually and in combination had significant effects (*P* < 0.0001) across the assessment intervals. Seeds for most treatments germinated between 13 and 15 DAS, although trial one had poorer germination rate than trial two (Table 4). The highest treatments with zero germination were recorded at 15 DAS in both trials.

In trial two, whereas germination failures were high in the other growing environments, there was no germination failure in the lathhouse at 15 DAS when all the seeds had germinated, regardless of whether they were primed or not. Germination failures occurred in CFM2-based treatments in trial 1, as well as CFM1 and soil-based media in trial 2. Non-primed seeds germinated poorly compared to primed seeds at 15 DAS in trial one.

First sprout was observed in SP1G at 8 DAS in trial one and in HP1L at 7 DAS in trial two. First emergence was observed at 9 DAS in SPG and SP1G only. In trial two, first emergence was observed in HP1L and HP2L at 8 DAS. At 12 DAS, further emergence was observed in SP1L, CFM1P2G, CFM1PG, HP1G, HPG and SP1G in trial one, while in trial two it was observed in HPL. Highest germination was observed in HP1O at 89% in trial one, while in trial two, it was observed in HP1L and HPL both at 94.33%.

In trial one, slow germination rate was generally observed, with only three treatments (HP2G, HP1O, HPO) having surpassed 50% germination at 15 DAS (Table 4). In trial two, zero germination was highest in open field, with nine treatments, followed by seven treatments in the greenhouse failing to germinate. It is also worth noting that CFM2PL (83%) and CFM1P1L (77.67%), which consisted of the cob-formulated components recorded highly significant mean germination rates than seven treatments featuring the commercially made hygromix media (HP2L, HP2G, HPG, HP1G, HPO, HP1O, and HP2O) at 15 DAS in trial two. Additionally, the average germination rate of CFM1P2O was higher than that of HP2O.

At 18 DAS, germination rate was high in trial one with highest rate being for HP1O, HP2O, HPO and soil at 100%, while in trial two, it was highest for HP1L and HPL at 94.33% (Table 4). Six of the fifteen treatments in trial one and nine of the nineteen treatments in trial two that had not germinated after 15 DAS germinated after 18 DAS, and a majority of them comprised CFM-based treatments. However, in both trials, CFM2P1G, CFM2PG, CFM1P1O, CFM2P2O had zero germination rate. In both trials, there was no further change in the germination rate at 24 DAS, with the rate of germination remaining constant. Between 21 and 24 DAS, the rate of germination slowed down and between 24 and 27 DAS, there was no further change in the germination rate of most seeds in both trials. In some cases, germinated seeds died, leading to lower counts in subsequent DAS.

The fast germination occurring under greenhouse in trial one, and lathhouse in trial two can be attributed to the similarity of the prevailing environmental conditions, especially light intensity and medium temperature, which were 8.95 lux and 24°C in the greenhouse in trial one, compared to 8.95 lux and 26°C in the lathhouse in trial two. Previous studies have revealed that light and warmth are among the key factors affecting the germination of seeds (Javaid *et al.,* 2022). Light plays a key role in stimulating the biosynthesis and signaling of plant hormone gibberellin (GA), which not only induces radicle protrusion, thus weakening the tissues surrounding embryos, but also increases the growth potential of embryos, thus promoting faster germination of seeds (Jhanji *et al.,* 2024). Moreover, light cues antagonistically regulate seed dormancy as they suppress the action of ABA, which inhibits water uptake by embryo tissues (Yan and Chen, 2020). Temperature is critical in seed germination since the rate of water absorption is influenced by temperature.

**Table 4: Combined factor effect on germination rate of sweet pepper**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Treatment/ DAS** | **13-15 DAS** | | **16-18 DAS** | | **19-21 DAS** | | **22-24 DAS** | | **25-27 DAS** | |
| **T1** | **T2** | **T1** | **T2** | **T1** | **T2** | **T1** | **T2** | **T1** | **T2** |
| CFM1P1L | 33.33j | 77.67e | 66.67d | 83.33c | 89.00b | 83.33c | 100.0a | 83.33d | 100.0a | 83.33d |
| CFM1P2L | 11.00m | 59.67g | 66.67d | 72.00g | 77.67d | 72.00f | 100.0a | 72.00g | 78.00d | 72.00g |
| CFM1PL | 22.33k | 44.67h | 44.33f | 66.67h | 66.67e | 66.67g | 66.67g | 66.67i | 73.33f | 66.67i |
| CFM2P1L | 0.00n | 0.00n | 44.33f | 61.00i | 44.33h | 61.00i | 55.33h | 72.33f | 55.33i | 72.33f |
| CFM2P2L | 0.00n | 44.33i | 78.00c | 77.67e | 78.00c | 77.67e | 89.00b | 88.67c | 89.00b | 88.67c |
| CFM2PL | 0.00n | 83.00c | 22.33j | 83.00d | 22.00m | 83.00d | 22.00n | 83.00e | 33.33o | 83.00e |
| HP1L | 0.00n | 94.33a | 78.00c | 94.33a | 89.00b | 94.33a | 100.0a | 94.33b | 100.0a | 94.33b |
| HP2L | 11.00m | 72.00f | 55.33e | 88.67b | 55.33g | 88.67b | 66.33h | 88.67c | 66.33h | 88.67c |
| HPL | 0.00n | 94.33a | 33.00i | 94.33a | 38.67j | 94.33a | 72.33e | 94.33b | 83.33c | 94.33b |
| SP1L | 39.00i | 88.67b | 55.33e | 94.33a | 55.33g | 94.33a | 78.00c | 94.33b | 78.00d | 94.33b |
| SP2L | 22.00l | 88.67b | 78.00c | 88.67b | 66.67e | 88.67b | 77.67d | 88.67c | 77.67e | 88.67c |
| SPL | 11.00m | 78.00d | 100.0a | 94.33a | 100.0a | 94.33a | 100.0a | 100.0a | 100.0a | 100.0a |
| CFM1P1G | 44.33h | 0.00n | 66.67d | 22.00k | 78.00c | 27.67k | 89.00b | 39.00l | 89.00b | 39.00l |
| CFM1P2G | 0.00n | 5.67m | 44.33f | 22.00k | 66.33f | 50.33j | 89.00b | 50.33j | 0.00r | 50.33j |
| CFM1PG | 22.00l | 0.00n | 33.00i | 0.00o | 44.33h | 27.67k | 67.00f | 44.33k | 67.00g | 44.33k |
| CFM2P1G | 0.00n | 0.00n | 0.00m | 0.00o | 0.00o | 22.33l | 0.00p | 33.33m | 78.00d | 33.33m |
| CFM2P2G | 33.33j | 0.00n | 0.00m | 0.00o | 0.00o | 0.00r | 0.00p | 39.00l | 0.00r | 39.00l |
| CFM2PG | 0.00n | 0.00n | 0.00m | 0.00o | 0.00o | 0.00r | 0.00p | 11.33p | 0.00r | 11.33p |
| HP1G | 0.00n | 33.33k | 66.67d | 50.00j | 89.00b | 66.33h | 89.00b | 72.00g | 100.0a | 72.00g |
| HP2G | 55.33e | 44.33i | 55.33e | 66.67h | 55.33g | 72.00f | 55.33h | 72.00g | 55.33i | 72.00g |
| HPG | 33.33j | 39.00j | 33.33h | 72.33f | 33.33k | 83.33c | 33.33k | 83.33d | 44.33n | 83.33d |
| SP1G | 39.00i | 0.00n | 39.00g | 0.00o | 39.00i | 5.67q | 39.00j | 16.67o | 50.00k | 16.67o |
| SP2G | 11.00m | 0.00n | 11.00k | 16.67l | 11.00n | 27.67k | 28.00l | 33.33m | 44.67m | 33.33m |
| SPG | 50.00f | 0.00n | 44.33f | 0.00o | 44.33h | 0.00r | 44.33i | 22.33n | 49.67l | 22.33n |
| CFM1P1O | 0.00n | 0.00n | 0.00m | 0.00o | 0.00o | 0.00r | 22.00n | 5.67q | 44.67m | 5.67q |
| CFM1P2O | 44.67g | 5.67m | 0.00m | 5.67n | 0.00o | 5.67q | 11.00o | 16.67o | 22.00q | 16.67o |
| CFM1PO | 0.00n | 0.00n | 0.00m | 11.33m | 0.00o | 0.00r | 11.00o | 22.33n | 50.33j | 22.33n |
| CFM2P1O | 33.33j | 0.00n | 0.00m | 5.67n | 0.00o | 0.00r | 0.00p | 0.00r | 0.00r | 0.00r |
| CFM2P2O | 0.00n | 0.00n | 0.00m | 0.00o | 0.00o | 17.00m | 0.00p | 5.67q | 0.00r | 5.67q |
| CFM2PO | 0.00n | 0.00n | 5.67l | 0.00o | 22.33l | 0.00r | 22.33m | 5.67q | 22.33p | 5.67q |
| HP1O | 89.00a | 0.00n | 100.0a | 16.67l | 100.0a | 16.67n | 100.0a | 44.33k | 100.0a | 44.33k |
| HP2O | 44.67g | 0.00n | 100.0a | 5.67n | 100.0a | 11.00p | 100.0a | 33.33m | 100.0a | 33.33m |
| HPO | 78.00b | 16.67l | 100.0a | 16.67l | 100.0a | 22.33l | 100.0a | 67.00h | 100.0a | 67.00h |
| SP1O | 0.00n | 0.00n | 0.00m | 5.67n | 100.0a | 0.00r | 100.0a | 5.67q | 100.0a | 5.67q |
| SP2O | 0.00n | 0.00n | 100.0a | 0.00o | 100.0a | 0.00r | 100.0a | 0.00r | 100.0a | 0.00r |
| SPO | 22.00l | 0.00n | 89.00b | 11.33m | 89.00b | 11.33o | 89.00b | 0.00r | 89.00b | 0.00r |
| Mean (%) | 24.21 | 28.95 | 47.51 | 36.85 | 51.52 | 40.70 | 58.49 | 48.60 | 62.24 | 54.23 |
| *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 | 1.556 | 1.736 | 2.864 | 1.802 | 2.045 | 1.243 | 0.814 | 1.850 | 2.222 | 1.850 |
| CV % | 3.947 | 3.682 | 3.702 | 3.003 | 2.437 | 1.875 | 2.960 | 2.085 | 2.192 | 2.085 |

\* 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

Low temperatures below 21°C slow down food mobilization and reduce enzymatic activities, while high temperatures above the optimum 26°C denature enzymes and kill embryonic tissues, thus retarding germination rate (Guo *et al.,* 2020). These reasons also account for the higher germination rate in trial two compared to trial one at 15 DAS.

Fast cotyledon opening, sprouting and germination observed in treatments with soil can be attributed to its very fine texture that on one hand retains water around the seed and makes it easier for cell expansion after imbibition, and on the other hand, enhances faster radicle development, as well as promoting quicker upward growth of the hypocotyl. This finding was also reported by Naseer *et al.* (2024), who observed that germination was fast and high in loam treatments, while investigating the effect of various soil textures on the germination and growth parameters of *Luffa acutangula*, and linked it to its finer texture, which made it easier for plant seeds to penetrate through the soil without facing any resistance, as compared to sandy soils that had coarse textures.

HP1O had a higher germination rate of 89% in trial one, while HP1L and HPL had the highest in trial two of 94.33% at 15 DAS. Hygromix could have offered better medium characteristics, including 45.5% porosity, 0.18 g/cm3 bulk density, 85% WHC, a pH of 6.3, and fine texture, which highly contributed to hastening of sweet pepper seed germination rate, compared to the other media. Good porosity, which is determined by bulk density, enhances aeration around the seed, thereby providing the necessary oxygen for aerobic respiration from which energy is generated to hasten seed embryo growth and development (Ray *et al.,* 2016). Proper WHC, ranging from 75-85%, ensures readily available water, which is critical in protoplasm hydration, seed coat softening, seed permeability, and oxygen dissolution for the developing seed. Moreover, the rate of seed germination is highly influenced by the enzymatic activities carried out by enzymes such as amylase, protease, and lipase (Joshi, 2018). These enzymes, which are critical in solubilisation of proteaceous food material in sweet pepper seeds that in turn deliver requisite energy to the germinating embryo, thrive best at a pH range of 7.0-8.0 (Joshi, 2018). Good medium texture promotes quicker eF Apenotyl elongation during cell division, thus hastening seedling emergence.

Germination rate was significantly higher in halo-primed seeds than in hydro- and non-primed seeds in both trials and this is probably due to the effect of NaCl which activates water transporters and protein synthesis thus speeding the rate of germination. These results agreed with Byeong-Sung *et al.* (2006), who reported that halo-priming with deep sea water improved mean germination rate of sweet pepper, rice, and ginseng.

**3.4. Seed Germination Percentage**

The effect of growing environment, medium type, and priming proficiency, either singly or in combination on seed germination percentage was highly significant (*P* <0.0001) in both trials, with trial one having a higher germination percentage (62.24%) than trial two (54.23%) at 28 DAS (Table 5). There were more germination failures in trial one (5) compared to trial two (3), while only CFM2P1O failed to germinate in both trials. Out of the eight treatments which did not germinate in both trials, three were in the greenhouse, while five were in the open-field. The CFM1 treatments in the lathhouse performed better than those in the open-filed and greenhouse in both trials. Additionally for treatments that failed to elicit germination, five were CFM2-based, two were soil-based and one was CFM1-based. No hygromix-based treatment failed to promote germination. It was also observed that most of the CFM-based treatments were not significantly different in germination percentages compared to soil-based treatments. Four of those which did not germinate were hydro-primed, while both halo- and non-primed treatments had two each. In trial one, CFM1P1L, SPL, HP1L, HP1O, HP2O, HPO, SP1O and SP2O attained 100%, while only SPL attained 100% in trial two by 28 DAS. None of CFM2-based treatments attained 100% germination percentage by 28 DAS, and only SPL attained 100% in both trials (Table 5).

Germination percentage was high in the lathhouse environment in both trials. Seed germination is hinged on medium temperature, moisture content and light intensity (Atabaki *et al.,* 2023); thus prevailing environmental conditions have a significant impact on the final seed germination percentage. The lathhouse had standard ambient air temperature and light intensity that are critical in activating enzymatic activities considered vital in seed germination. In this study, hygromix in the greenhouse developed hard brownish crust probably due to the high temperature, which may have contributed to the low germination percentage.

The poor germination and high germination failure in the open-field can be attributed to the open exposure of seeds to extreme light intensity, especially in trial two, which may have dehydrated the medium, thereby reducing the available moisture content necessary for germination. Moreover, direct sun rays may have led to death of the embryo, thus making it impossible for the seeds to germinate.

**Table 5: Combined effect of environment, medium and priming proficiency on germination percentage at 28 DAS**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **SN** | **Treatment** | **Trial 1** | **Trial 2** | **SN** | **Treatment** | **Trial 1** | **Trial 2** |
| 1 | CFM1P1L | 100.0a | 83.33d | 22 | SP1G | 50.00k | 16.67o |
| 2 | CFM1P2L | 78.00d | 72.00g | 23 | SP2G | 44.67m | 33.33m |
| 3 | CFM1PL | 73.33f | 66.67i | 24 | SPG | 49.67l | 22.33n |
| 4 | CFM2P1L | 55.33i | 72.33f | 25 | CFM1P1O | 44.67m | 5.67q |
| 5 | CFM2P2L | 89.00b | 88.67c | 26 | CFM1P2O | 22.00q | 16.67o |
| 6 | CFM2PL | 33.33o | 83.00e | 27 | CFM1PO | 50.33j | 22.33n |
| 7 | HP1L | 100.0a | 94.33b | 28 | CFM2P1O | 0.00r | 0.00r |
| 8 | HP2L | 66.33h | 88.67c | 29 | CFM2P2O | 0.00r | 5.67q |
| 9 | HPL | 83.33c | 94.33b | 30 | CFM2PO | 22.33p | 5.67q |
| 10 | SP1L | 78.00d | 94.33b | 31 | HP1O | 100.0a | 44.33k |
| 11 | SP2L | 77.67e | 88.67c | 32 | HP2O | 100.0a | 33.33m |
| 12 | SPL | 100.0a | 100.0a | 33 | HPO | 100.0a | 67.00h |
| 13 | CFM1P1G | 89.00b | 39.00l | 34 | SP1O | 100.0a | 5.67q |
| 14 | CFM1P2G | 0.00r | 50.33j | 35 | SP2O | 100.0a | 0.00r |
| 15 | CFM1PG | 67.00g | 44.33k | 36 | SPO | 89.00b | 0.00r |
| 16 | CFM2P1G | 78.00d | 33.33m |  | Mean (%) | 62.24 | 54.23 |
| 17 | CFM2P2G | 0.00r | 39.00l |  | *P*-value | 0.0001 | 0.0001 |
| 18 | CFM2PG | 0.00r | 11.33p |  | LSD 0.05 | 2.222 | 1.850 |
| 19 | HP1G | 100.0a | 72.00g |  | CV % | 2.192 | 2.085 |
| 20 | HP2G | 55.33i | 72.00g |  |  |  |  |
| 21 | HPG | 44.33n | 83.33d |  |  |  |  |

\* 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

Similar results were reported by Das (2023), who observed significantly higher germination when *Spondias mombin* seeds were sown under 40% than under 60% and 100% light intensity. Although a temporal top shade net with 75% light transmission was constructed above the open-field set-up, most of the treatments thereunder did not germinate, suggesting that sweet pepper seeds may be very sensitive to high light cues during germination in the same way that sweet pepper plants do not thrive under high light intensity (Demers and Goselin, 2000). Thus, a slight increase in light intensity would negatively impact germination percentage. This scenario may have obtained under the open-field environment in the present study.

The fact that CFM1P1L was significantly different from CFM1P1G and CFM1P1O reveals that cob-formulated media can best serve seed germination under a lathhouse than in greenhouse and open-field environments. Moreover, since there was no significant difference between HP1L and CFM1P1L, it may be inferred that cob-formulated medium has a potency for use in horticultural nursery practices particularly if its physical properties, especially stability and texture are improved.

**4. CONCLUSIONS**

Lathhouse has great potential to reduce the number of days to germination of sweet pepper seeds. Media of ratio 2 ground cob-husks: 1 ground peanut husks: 1 ground Tithonia has a higher potential for application in sweet pepper seed germination compared to media of ratio 1:1:1. Halo-priming has potential to give better results in sweet pepper seed germination. A combined treatment of lathhouse environment, hygromix medium, and halo-priming reduce days taken to sweet pepper seed germination.

**5. RECOMMENDATIONS**

Further improvement on physical characteristics and formulation procedure for cob-based media for sweet pepper 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 is recommended for faster germination rate and increased germination percentage. Plant nursery growers and other small-scale farmers should adopt the lathhouse environment for faster and higher sweet pepper seed germination.

**DISCLAIMER (ARTIFICIAL INTELLIGENCE)**

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 obtained from the National Commission for Science, Technology and Innovation (NaCoSTI) after receiving approval of the Chuka University Ethics Committee. High standard of ethics and integrity were ensured in this research.

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.

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