

Influence of Different Compost-Based Growth Media for Germination and Early Seedling Growth of Three Leafy Vegetables

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Abstract

The growth medium significantly influences the growth and quality of leafy vegetables, as they are highly sensitive to soil composition, nutrient availability, and water-holding capacity. Considering their nutritional importance and sensitivity to growth media, a laboratory pot experiment was conducted in the Department of Crop Physiology and Ecology at Hajee Mohammad Danesh Science and Technology University from September to October 2024 to evaluate the effects of different compost-based growth media on the germination of three leafy vegetable taxa.

The experiment was arranged in a two-factor Completely Randomized Design (CRD) with three replications. Factor A consisted of three leafy vegetable taxa: T_1 = Indian spinach (*Basella alba* L.), T_2 = spinach (*Spinacia oleracea* L.), and T_3 = red amaranth (*Amaranthus cruentus* L.). Factor B comprised five growth media: G_1 = 100% soil (control), G_2 = 50% soil + 50% compost, G_3 = 50% soil + 50% poultry litter-based compost (PLBC), G_4 = 70% soil + 30% compost, and G_5 = 70% soil + 30% poultry litter-based compost (PLBC). During the experimental period, germination attributes, including Germination Percentage (GP), Mean Germination Time (MGT), Germination Rate Index (GRI), Coefficient of Velocity of Germination (CVG), and Timson Germination Index (TGI), together with seedling growth traits, namely shoot length (SL), root length (RL), and seedling dry weight (SDW), were measured to evaluate the effects of different growth media on the three taxa.

Spinach exhibited the highest overall germination performance, whereas Indian spinach showed the lowest germination percentage. Compost-based media, particularly G_4 (70% soil + 30% compost) and G_2 (50% soil + 50% compost), resulted in better germination and seedling growth, with G_4 producing the best overall performance. In contrast, poultry litter-based compost media resulted in comparatively poorer performance. Overall, the findings indicate that a growth medium consisting of 70% soil and 30% compost is more suitable than poultry litter-based compost for improving the germination and early seedling growth of leafy vegetables.

INTRODUCTION

Leafy vegetables play an essential role in human nutrition because they are rich sources of vitamins, minerals, dietary fiber, and natural antioxidants. Regular consumption of leafy vegetables contributes to improved immune function, bone health, digestive health, and reduced risks of several chronic diseases (Shahidi & Zhong, 2017). In Bangladesh, Indian spinach (*Basella alba* L.), spinach (*Spinacia oleracea* L.), and red amaranth (*Amaranthus cruentus* L.) are among the most widely cultivated leafy vegetables owing to their high nutritional value, short production cycle, and economic importance. Successful crop establishment largely depends on rapid and uniform seed germination, followed by vigorous early seedling growth, which ultimately influences crop productivity and marketable yield (Nonogaki et al., 2010).

Seed germination is a complex physiological process regulated by seed vigor and environmental conditions, including moisture, oxygen availability, temperature, and the physical and chemical properties of the growth medium (Bewley et al., 2013). Among these factors, the composition of the growth medium is particularly important because it influences water availability, aeration, nutrient supply, and microbial activity surrounding the germinating seed, all of which affect germination and early seedling establishment (Canali et al., 2004; Gruda et al., 2020).

Organic substrates such as compost and poultry litter-based compost (PLBC) have received increasing attention as sustainable alternatives to synthetic fertilizers because they improve soil fertility, enhance soil structure and water-holding capacity, stimulate beneficial microbial activity, and gradually release essential plant nutrients (Tiquia & Hodgkiss, 1996; Diacono & Montemurro, 2010). Compost provides balanced nutrient availability, improves aeration,

and enhances moisture retention, thereby promoting seed germination and early seedling development (Canali et al., 2004; Gruda et al., 2020). Poultry litter-based compost is also an important organic nutrient source because of its high nitrogen and mineral contents, which can enhance vegetative growth. However, its influence on seed germination and early seedling development varies depending on its chemical composition, maturity, application rate, and interactions with the growth medium (Kingery et al., 1994; Komilis & Tziouvaras, 2009).

Previous studies have demonstrated the benefits of compost-based substrates for improving seed germination and seedling growth. However, most studies have focused on individual crop species, field conditions, or a limited number of germination parameters. Comparative evaluations involving multiple leafy vegetable species under different compost-based growth media remain limited. Most previous studies have mainly reported germination percentage and seedling length, while other important germination indices, such as MGT, GRI, CVG, and TGI, have been less frequently evaluated (Bewley et al., 2013; Gruda et al., 2020).

Therefore, important knowledge gaps remain regarding the optimum proportions of soil, compost, and poultry litter-based compost required to maximize seed germination and early seedling growth of Indian spinach, spinach, and red amaranth. Addressing these gaps will provide valuable information for developing sustainable, low-cost growth media that can improve crop establishment and support economical vegetable production for smallholder farmers and commercial growers.

Objectives of the Study

Based on these gaps, this study aims to:

1. To evaluate the effects of compost and poultry litter-based compost in the seed germination and early seedling growth of Indian spinach (*Basella alba* L.), spinach (*Spinacia oleracea* L.), and red amaranth (*Amaranthus cruentus* L.).
2. To determine a suitable proportion of soil, compost, and poultry litter-based compost for improving seed germination and early seedling growth of Indian spinach, spinach, and red amaranth.

MATERIALS AND METHODS

Experimental Site and Period

The experiment was conducted in the laboratory of the Department of Crop Physiology and Ecology, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh (25.13°N, 88.23°E; 34.5 m above sea level). The study was carried out from September to October 2024.

Plant Materials and Growth Media

Seeds of three leafy vegetable taxa—Indian spinach (*Basella alba* L.), spinach (*Spinacia oleracea* L.), and red amaranth (*Amaranthus cruentus* L.)—were collected from Lal Teer Company. Compost (ACI Ltd.) and poultry litter-based compost (PLBC) were obtained from local sources and departmental composting units. Plastic pots (15 cm diameter × 6 cm depth) were used as experimental units.

Soil, compost, and PLBC differed in physico-chemical properties, particularly nutrient concentration and organic matter content (Table 1).

Table 1
pH and nutrient status of the soil, compost and PLBC sample used in the study

Sample	pH	Organic Carbon (%)	Organic Matter (%)	Total Nitrogen (%)	Phosphorous (µgm/gm soil)	Potassium (meq/100gm soil)	Sulfur (µgm/gm soil)	C:N Ratio
Soil	6.60	0.80	1.38	0.07	17.45	0.36	10.41	11.43:1.00
Compost	7.53	7.66	13.21	0.66	328.82	2.52	123.49	11.60:1.00
PLBC	7.85	20.13	36.52	1.13	3.51	2.14	1.02	17.81:1.00

Experimental Design and Treatments

The experiment followed a **two-factor Completely Randomized Design (CRD)** with three replications.

Factor A: Taxa

- T1: Indian spinach (*Basella alba* L.)
- T2: Spinach (*Spinacia oleracea* L.)
- T3: Red amaranth (*Amaranthus cruentus* L.)

Factor B: Growth media

- G1: 100% soil (control)
- G2: 50% soil + 50% compost
- G3: 50% soil + 50% PLBC
- G4: 70% soil + 30% compost
- G5: 70% soil + 30% PLBC

Each pot contained **800 g total substrate**, thoroughly mixed according to treatment composition.

Seed Preparation and Sowing

Seeds were pre-soaked in water for 48 hours, and floating or damaged seeds were discarded. Twenty-five seeds per pot were sown on 30 September 2024. Irrigation was applied every alternate day throughout the experiment.

Experimental Conditions and Data Collection

Germination was monitored for one month (30 September–30 October 2024). Germination observations were recorded until germination was complete for each taxon. Because the taxa differed in germination speed, germination traits were calculated at

- 18 DAS for Indian spinach.
- 10 DAS for spinach and red amaranth.

Seedling growth traits were recorded at 30 DAS.

A subset of seedlings (five per pot) was used for growth measurements

Measured Parameters

Data collection

Germination was recorded daily from 30 September to 30 October 2024. Germination percentage (GP) was calculated based on the total number of seeds sown per pot. Due to differences in germination duration among the taxa, germination parameters were assessed at 18 DAS for Indian spinach and 10 DAS for spinach and red amaranth. The parameters included germination percentage (GP), mean germination time (MGT), germination rate index (GRI), coefficient of velocity of germination (CVG), and Timson's germination index (TGI), calculated using standard formulas.

After germination assessment, excess seedlings were removed and 10 healthy seedlings were retained per pot. At 30 DAS, five randomly selected seedlings from each pot were used to measure shoot length (SL) and root length (RL). For seedling dry weight (SDW), the selected seedlings were oven-dried at 70°C for 72 h and weighed.

Germination percentage (GP)

Seeds were considered germinated when the radicle was ≥ 1 mm long and visible (Bewley and Black 2013). The germination percentage was calculated following El-Shaiey (2015) as follows

Germination percentage = (Germinated seeds / Total number of seeds) $\times$ 100

Mean germination time (MGT)

Mean germination time (MGT) represents the average time required for seed germination. (Soltani et al. 2015). Mean germination time was calculated following Al-Mudaris (1998).

Mean germination time (MGT) = $\Sigma Fx / \Sigma F$

Where F is the number of seeds germinated on day x.

Germination rate index (GRI)

The germination rate index is the speed and uniformity of seed germination over time. It was calculated using the following formula (Al-Mudaris 1998).

Germination rate index (GRI) = $G_1 / 1 + G_2 / 2 + \dots + G_i / i$

Where, G_1 = Number of seeds germinated on day 1, G_2 = Number of seeds germinated on day 2; and so on. i = Day of germination (counting from the start of germination)

Coefficient of Velocity of Germination (CVG)

Coefficient of velocity of germination is a measure of the speed of germination, indicating how quickly seeds germinate within a given time frame. The CVG of the three leafy vegetable taxa were calculated by using the following formulae (Al-Mudaris 1998).

$$\text{Co-efficient of velocity of germination (CVG)} = \{(A_1 + A_2 + \dots + A_n) / (A_1 T_1 + A_2 T_2 + \dots + A_n T_n)\} \times 100$$

Where, A = Number of seeds germinated, T = Time (days) corresponding to A, n = No of days to final count.

Timson germination index (TGI)

Many, including the Timson germination index, have been reported as a good indicator of seed germination rate (Al-Mudaris 1998). This index is calculated as the sum of percent germination of seeds at 2-day intervals by the total germination period (Khan and Ungar 1996). Timson's germination index was calculated using the formula reported by Ajmal Khan and Ungar (1998).

$$\text{Timson germination index (TGI)} = \Sigma G / T$$

Where, G = Cumulative germination percentage, T = Germination period (days counted from the seed sowing)

Shoot length (SL) and root length (RL)

On the 18th day after seed placement for germination, all other seedlings were removed from each plastic pot. After the germination assessment, 10 healthy seedlings were retained in each pot for subsequent growth. At 30 DAS, five seedlings were randomly selected from each pot for measurement of shoot length, root length, and seedling dry weight.

Seedling dry weight (SDW)

At 30 DAS, the uprooted fresh seedlings were taken in brown paper packs and placed into the electric oven (Model-E28# 03 – 54639, Binder, Germany) at 70°C for 72 hours to dry the samples. After three days, the samples were removed, and the dry weight was taken on an electronic balance.

Data analyses

The data were subjected to analysis of variance (ANOVA) using Statistix 10 to determine the effects of taxon, growth medium, and their interaction. When significant differences were detected, treatment means were separated using Tukey's honestly significant difference (HSD) test at $p \leq 0.05$.

RESULTS AND DISCUSSION

Germination traits

The seeds of Indian spinach, spinach, and red amaranth were sown in five growth media, and germination percentage (GP), mean germination time (MGT), germination rate index (GRI), coefficient of velocity of germination (CVG), and Timson germination index (TGI) were evaluated.

Table 2

Combined Interaction effects of compost and PLBC on Germination Percentage(GP), Mean germination time (MGT), and Germination rate index (GRI) of Indian spinach, spinach, and Red amaranth

Taxon	Growth medium	GP (%)	Relative Changes over Control (%)	MGT (days)	Relative Changes over Control (%)	GRI	Relative Changes over Control (%)
T ₁	G ₁	45.33	-	12.93 ^c	-	8.81 ^{abc}	-
	G ₂	54.67	+ 20.59	13.28 ^c	+ 2.68	9.70 ^{abc}	+ 10.11
	G ₃	4.00	-91.18	17.11 ^a	+ 32.31	0.22 ^e	-97.54
	G ₄	64.00	+ 41.18	12.85 ^c	-0.67	13.95 ^a	+ 58.35
	G ₅	6.67	-85.29	16.14 ^b	+ 24.82	0.44 ^e	-95.03
T ₂	G ₁	70.67	-	8.03 ^g	-	10.44 ^{abc}	-
	G ₂	76.00	+ 7.55	8.27 ^{fg}	+ 3.07	9.68 ^{abc}	-7.30
	G ₃	22.67	-67.92	9.11 ^{de}	+ 13.43	1.61 ^e	-84.60
	G ₄	89.33	+ 26.42	8.13 ^{fg}	+ 1.26	11.91 ^{ab}	+ 14.09
	G ₅	29.33	-58.49	9.01 ^{de}	+ 12.24	2.14 ^{de}	-79.55
T ₃	G ₁	70.67	-	7.88 ^g	-	11.47 ^{ab}	-
	G ₂	68.00	-3.77	8.43 ^{efg}	+ 6.99	7.54 ^{bcd}	-34.23
	G ₃	5.33	-92.45	9.17 ^d	+ 16.29	0.29 ^{be}	-97.43
	G ₄	53.33	-24.53	8.54 ^{d-g}	+ 8.30	5.44 ^{cde}	-52.54
	G ₅	13.33	-81.13	8.80 ^{def}	+ 11.59	1.14 ^e	-90.06
P-value		0.5431	-	< 0.001	-	0.0038	-
CV (%)		32.17	-	2.29	-	30.73	-
SE (±)		11.79	-	0.197	-	1.59	-

Here, T₁ = Indian spinach (*Basella alba* L.), T₂ = Spinach (*Spinacia oleracea* L.), T₃ = Red amaranth (*Amaranthus cruentus* L.), G₁ = 100% soil (Control), G₂ = 50% soil + 50% compost, G₃ = 50% soil + 50% poultry litter-based compost (PLBC), G₄ = 70% soil + 30% compost, G₅ = 70% soil + 30% poultry litter-based compost (PLBC), GP=Germination Percentage, MGT= Mean Germination Time and GRI = Germination Rate Index. Means followed by different superscript letters differ significantly at p < 0.05.

Germination percentage (GP)

Both vegetable taxon and growth medium significantly influenced germination percentage, whereas their interaction was not significant. Among the taxa, spinach recorded the highest mean GP (57.60%), followed by red amaranth (42.13%) and Indian spinach (34.93%). Across growth media, G₄ (70% soil + 30% compost) recorded the highest mean GP (68.89%), while G₃ and G₅ recorded markedly lower values (10.67% and 16.44%, respectively). Although

the taxon × growth-medium interaction was non-significant, spinach under G4 recorded the highest numerical GP (89.33%), whereas red amaranth under G3 recorded the lowest (5.33%).

The superior germination observed in G4 suggests that incorporating compost at a moderate proportion created a more favourable physical and chemical environment for seed germination. Compost incorporation can improve soil aggregation, aeration, water-holding capacity and nutrient availability, thereby creating favourable conditions for seed imbibition and the initiation of metabolic processes during germination (Insam and de-Bertoldi, 2007; Diacono and Montemurro, 2010; Gruda et al., 2020). The superior performance of G4 may therefore be attributed to the balanced proportion of soil and compost, which likely provided an adequate combination of moisture retention, aeration and nutrient supply. In contrast, increasing the compost proportion to 50% in G2 did not provide additional improvement over the control. The consistently poor performance of PLBC-based media may have been associated with elevated soluble salts, ammonia and incompletely stabilised organic compounds, which can induce osmotic stress or phytotoxicity and restrict water uptake and radicle emergence. Similar inhibitory effects of immature or poorly stabilised organic amendments have been reported by Tiquia et al. (1996), Luo et al. (2018) and Kebrom et al. (2019). Differences among taxa further indicate that seed characteristics contributed to germination performance, with spinach showing the highest overall GP and Indian spinach showing comparatively lower germination.

Mean germination time (MGT)

MGT was significantly affected by the interaction between taxon and growth medium. Indian spinach showed the longest MGT, particularly under G3 (17.11 days) and G5 (16.14 days), whereas the shortest MGT occurred in red amaranth under G1 (7.88 days), followed by spinach under G1 (8.03 days) and G4 (8.13 days). The relatively short MGT observed under G4 in spinach indicates favourable conditions for relatively rapid germination. Lower MGT reflects faster and more uniform seed emergence (Matthews and Hosseini, 2006; Soltani et al., 2015). The response may be associated with improved aeration, moisture retention and nutrient availability following compost incorporation (Insam and de-Bertoldi, 2007; Diacono and Montemurro, 2010; Gruda et al., 2020). Conversely, prolonged MGT under PLBC-amended media suggests less favourable physicochemical conditions; elevated soluble salts, ammonia and incompletely decomposed organic materials may reduce water uptake and delay radicle protrusion. Similar inhibitory responses have been reported by Tiquia et al. (1996), Mandal et al. (2013), Luo et al. (2018) and Kebrom et al. (2019).

Germination rate index (GRI)

The taxon × growth-medium interaction significantly affected GRI. The highest GRI was recorded in Indian spinach under G4 (13.95), whereas the lowest was observed under G3 (0.22). GRI integrates the speed and extent of germination and is therefore useful for evaluating seed vigour and establishment potential (Al-Ansari and Ksiksi, 2016; Jahanbin et al., 2012). The higher GRI under G4 indicates that 30% compost created favourable conditions for rapid germination, potentially through improved aggregation, aeration, moisture retention and gradual nutrient availability (Insam and de-Bertoldi, 2007; Diacono and Montemurro, 2010; Gruda et al., 2020). In contrast, the pronounced reduction under PLBC-based media suggests that insufficient stabilisation and associated soluble salts, ammonia or phytotoxic compounds may have suppressed germination vigour. Comparable responses have been documented for immature organic amendments (Tiquia et al., 1996; Luo et al., 2018; Kebrom et al., 2019).

Table 3

Interaction effects of compost and PLBC on the Co-efficient of Velocity of Germination (CVG) and Timson Germination Index (TGI) of Indian spinach, Spinach and Red amaranth

Taxon	Growth medium	CVG	Relative Changes over Control (%)	TGI	Relative Changes over Control (%)
T ₁	G ₁	7.73 ^f	-	35.23 ^{abc}	-
	G ₂	7.53 ^f	-2.62	38.79 ^{abc}	+ 10.11
	G ₃	5.84 ^g	-24.42	0.69 ^e	-98.04
	G ₄	7.79 ^f	+ 0.67	55.78 ^a	+ 58.35
	G ₅	6.20 ^g	-19.89	1.75 ^e	-95.03
T ₂	G ₁	12.46 ^{ab}	-	41.76 ^{abc}	-
	G ₂	12.09 ^{abc}	-3.01	38.71 ^{abc}	-7.30
	G ₃	10.99 ^e	-11.82	6.43 ^e	-84.60
	G ₄	12.30 ^{ab}	-1.27	47.64 ^{ab}	+ 14.09
	G ₅	11.11 ^{de}	-10.86	8.54 ^{de}	-79.55
T ₃	G ₁	12.69 ^a	-	45.71 ^{ab}	-
	G ₂	11.86 ^{a-d}	-6.52	30.17 ^{bcd}	-34.00
	G ₃	10.92 ^e	-13.96	1.18 ^e	-97.42
	G ₄	11.71 ^{b-e}	-7.67	21.77 ^{cde}	-52.36
	G ₅	11.39 ^{cde}	-10.19	3.49 ^e	-92.37
P-value		0.0101	-	0.0045	-
CV (%)		2.71	-	30.97	-
SE (±)		0.225	-	6.37	-
Here, T ₁ = Indian spinach (<i>Basella alba</i> L.), T ₂ = Spinach (<i>Spinacia oleracea</i> L.), T ₃ = Red amaranth (<i>Amaranthus cruentus</i> L.), G ₁ = 100% soil (Control), G ₂ = 50% soil + 50% compost, G ₃ = 50% soil + 50% poultry litter-based compost (PLBC), G ₄ = 70% soil + 30% compost, G ₅ = 70% soil + 30% poultry litter-based compost (PLBC), CVG = Co-efficient of Velocity of Germination and TGI= Timson germination index (TGI). Means followed by different superscript letters differ significantly at p < 0.05.					

Coefficient of velocity of germination (CVG)

CVG was significantly affected by the interaction between taxon and growth medium. The highest CVG was observed in red amaranth under the control (T₃ × G₁; 12.69), followed closely by spinach under G₁ (12.46) and G₄ (12.30). Indian spinach showed lower values overall, with the minimum under G₃ (5.84). The relatively high CVG observed under G₄ in spinach suggests that the 30% compost treatment provided favourable conditions for rapid

germination in this taxon, potentially through improved soil aeration, water availability and nutrient release (Insam and de-Bertoldi, 2007; Diacono and Montemurro, 2010; Gruda et al., 2020). In contrast, PLBC-based media reduced CVG across taxa, indicating slower germination. High soluble salts, ammonia and insufficiently decomposed organic materials may create osmotic or phytotoxic conditions that interfere with water uptake and physiological activation. Similar reductions have been reported for immature organic amendments (Tiquia et al., 1996; Luo et al., 2018; Kebrom et al., 2019).

Timson germination index (TGI)

TGI was significantly affected by the taxon × growth-medium interaction. The highest TGI was recorded in Indian spinach under G4 (55.78), followed by spinach under G4 (47.64) and red amaranth under the control (45.71). The lowest values occurred under PLBC-based media, particularly T1 × G3 (0.69) and T3 × G3 (1.18). TGI integrates germination speed and cumulative germination and therefore provides an overall measure of germination performance (Bewley et al., 2013; Al-Mudaris, 1998). The superior TGI under G4 indicates that a moderate compost proportion created favourable physical and biochemical conditions for sustained germination. Improved aeration, balanced moisture availability and gradual nutrient release may have supported seed metabolic activity throughout the germination period (Insam and de-Bertoldi, 2007; Diacono and Montemurro, 2010; Gruda et al., 2020). Conversely, the extremely low TGI under PLBC-amended media suggests adverse effects on both germination rate and final germination extent, potentially due to soluble salts, ammonia and incompletely stabilised organic compounds. Similar effects have been reported for immature composts and unstable organic amendments (Tiquia et al., 1996; Luo et al., 2018; Kebrom et al., 2019).

Overall interpretation

Taken together, the combined germination results consistently identify G4 (70% soil + 30% compost) as the most favourable compost-based growth medium. It produced the highest mean GP and favourable responses for several germination indices, particularly MGT, GRI, CVG and TGI, whereas PLBC-based media consistently reduced germination performance. The results therefore indicate that compost at 30% provided a more suitable balance of physical and chemical properties for germination, while poultry litter-based compost should be adequately matured and stabilised before incorporation into germination media.

Seedling Growth Traits

The seedling growth traits of Indian spinach, spinach and red amaranth were measured at the end of the experiment. After 30 DAS, the seedlings were uprooted carefully, and shoot length (SL) and root length (RL) were recorded separately for each replication, while the seedlings were oven-dried to determine seedling dry weight (SDW). The results for all seedling growth traits are presented together below.

Table 4

Combined interaction effects of compost and poultry litter-based compost (PLBC) on seedling growth traits of Indian spinach, spinach and red amaranth.

Taxon	Growth medium	SL (cm)	Relative Changes over Control (%)	RL (cm)	Relative Changes over Control (%)	SDW (g seedling ⁻¹)	Relative Changes over Control (%)
T ₁	G ₁	7.29	-	11.40 ^{ab}	-	0.093 ^{ab}	-
	G ₂	6.87	-5.76	10.93 ^{abc}	-4.15	0.121 ^a	+ 30.61
	G ₃	4.99	-31.47	6.92 ^{def}	-39.33	0.025 ^{bc}	-73.48
	G ₄	9.29	+ 27.45	13.13 ^a	+ 15.20	0.165 ^a	+ 77.49
	G ₅	5.80	-20.40	7.47 ^{cde}	-34.50	0.042 ^{bc}	-54.48
T ₂	G ₁	4.99	-	7.27 ^{de}	-	0.026 ^{bc}	-
	G ₂	5.92	+ 18.56	6.51 ^{d-g}	-10.37	0.024 ^{bc}	-7.47
	G ₃	4.26	-14.69	6.03 ^{d-g}	-16.97	0.022 ^{bc}	-15.72
	G ₄	6.50	+ 30.17	8.15 ^{bcd}	+ 12.20	0.031 ^{bc}	+ 18.56
	G ₅	4.66	-6.68	5.94 ^{d-g}	-18.26	0.026 ^{bc}	+ 1.80
T ₃	G ₁	3.21	-	4.12 ^{efg}	-	0.0013 ^c	-
	G ₂	3.56	+ 11.12	4.45 ^{efg}	+ 8.09	0.004 ^c	+ 226.32
	G ₃	3.17	-1.25	3.13 ^g	-23.95	0.001 ^c	-21.05
	G ₄	3.79	+ 18.30	4.57 ^{d-g}	+ 10.84	0.004 ^c	+ 178.95
	G ₅	3.21	0.00	3.60 ^{fg}	-12.62	0.002 ^c	+ 50.00
P-value		0.3583		0.0173	-	0.0004	-
CV (%)		22.90		17.29	-	61.35	-
SE (±)		0.966		0.975	-	0.020	-

Here, T₁ = Indian spinach (*Basella alba* L.), T₂ = Spinach (*Spinacia oleracea* L.), T₃ = Red amaranth (*Amaranthus cruentus* L.), G₁ = 100% soil (Control), G₂ = 50% soil + 50% compost, G₃ = 50% soil + 50% poultry litter-based compost (PLBC), G₄ = 70% soil + 30% compost, G₅ = 70% soil + 30% poultry litter-based compost (PLBC), SL = Shoot Length, RL= Root Length and SDW= Seedling Dry Weight. Means followed by different superscript letters differ significantly at p < 0.05.

Shoot Length (SL)

Shoot length (SL) was significantly influenced by both vegetable taxon and growth medium, whereas their interaction was not statistically significant. Indian spinach produced the longest shoots (6.85 cm), followed by spinach (5.27 cm) and red amaranth (3.39 cm). Among the growth media, G₄ (70% soil + 30% compost) recorded the greatest mean shoot length (6.53 cm), remaining statistically comparable to G₂ and G₁. In contrast, PLBC-

amended media reduced shoot growth, with G3 producing the lowest mean shoot length (4.14 cm). Although the interaction effect was non-significant, the numerical response showed that Indian spinach under G4 reached 9.29 cm, while spinach under G4 showed the greatest relative increase over its control (+ 30.17%).

Shoot length is an important indicator of early seedling vigour and reflects the suitability of the growth medium for supporting seedling establishment. The superior shoot growth observed with G4 suggests that incorporation of 30% compost improved the physical, chemical and biological properties of the growth medium. Compost can enhance soil aggregation, moisture retention, nutrient availability and microbial activity, thereby supporting cell division, cell elongation and early photosynthetic development (Diacono and Montemurro, 2010; Gruda et al., 2020; Kranz et al., 2020). In contrast, the reduced shoot length under PLBC-amended media may be associated with elevated soluble salts, ammonia toxicity and incompletely decomposed organic materials, which can restrict nutrient uptake and impair root function. Similar negative effects of immature organic amendments have been reported by Cayci et al. (2017), Luo et al. (2018) and Kebrom et al. (2019).

Indian spinach consistently produced longer shoots than the other taxa, which is likely associated with its larger seed size and greater food reserves supporting rapid early growth following germination (Saeed and Shaukat, 2000). Overall, the findings indicate that 70% soil + 30% compost provided a favourable medium for early shoot development, whereas PLBC should be adequately matured before use.

Root Length (RL)

Root length (RL) was significantly influenced by the interaction between vegetable taxa and growth media ($P = 0.0173$). The longest root length (13.13 cm) was recorded in Indian spinach grown in G4 (70% soil + 30% compost), whereas the shortest root length (3.13 cm) was observed in red amaranth grown in G3 (50% soil + 50% PLBC). Compared with the respective controls, G4 increased root length in all three vegetable taxa, while PLBC-based media (G3 and G5) consistently reduced root development. Indian spinach exhibited the greatest positive response to compost application, whereas red amaranth showed comparatively smaller improvements.

Root development plays a fundamental role in seedling establishment because an extensive root system enhances water absorption, nutrient acquisition and subsequent shoot growth. The significantly greater root length observed in G4 indicates that incorporating compost at an appropriate proportion improved the physical environment of the growth medium by increasing soil porosity, aggregation, moisture retention and nutrient availability. These improvements promote root elongation and facilitate early seedling establishment (Diacono and Montemurro, 2010; Gruda et al., 2020; Kranz et al., 2020).

In contrast, the marked reduction in root length under PLBC-amended media suggests that poultry litter-based compost created less favourable conditions for root growth. High soluble salt concentrations, ammonia toxicity and incompletely stabilised organic materials may have inhibited root cell division and elongation while reducing water and nutrient uptake. Similar inhibitory effects of immature organic amendments on seedling development have been reported by Cayci et al. (2017), Luo et al. (2018) and Kebrom et al. (2019).

Indian spinach consistently produced longer roots than spinach and red amaranth, probably because its larger seeds contain greater food reserves that support vigorous early root development (Saeed and Shaukat, 2000). A well-developed root system also contributes to improved shoot growth by enhancing nutrient and water absorption during early plant establishment. Overall, 70% soil + 30% compost was highly effective for promoting root

development, whereas poultry litter-based compost should be adequately matured before incorporation into growth media.

Seedling Dry Weight (SDW)

Seedling dry weight (SDW) was significantly influenced by both vegetable taxon and growth medium, whereas their interaction effect was not statistically significant. Among the vegetable taxa, Indian spinach produced the highest SDW, followed by spinach and red amaranth. Regarding the growth media, G4 (70% soil + 30% compost) resulted in the greatest mean SDW and remained statistically comparable to G2, whereas PLBC-amended media (G3 and G5) produced significantly lower dry weights. Although the interaction effect was not significant, Indian spinach grown in G4 achieved the highest numerical SDW (0.165 g seedling⁻¹), while seedlings grown in G3 consistently recorded very low biomass.

Seedling dry weight is a reliable indicator of biomass accumulation and reflects the combined effects of successful germination, nutrient uptake, and early seedling growth. The higher SDW observed with G4 indicates that incorporating compost at 30% created a favourable growth environment that enhanced biomass production. Compost improves soil physical structure, increases water-holding capacity, enhances nutrient availability and stimulates beneficial microbial activity. These improvements may have contributed to greater seedling biomass accumulation by creating more favourable conditions for photosynthesis, assimilate production, and dry matter accumulation during early plant development (Diacono and Montemurro, 2010; Gruda et al., 2020; Kranz et al., 2020). In contrast, seedlings grown in PLBC-based media accumulated less dry matter, suggesting that poultry litter-based compost was not sufficiently stabilised to support optimal seedling growth. Elevated soluble salt concentrations, ammonia toxicity and incompletely decomposed organic materials may have reduced nutrient uptake efficiency, inhibited root development and restricted photosynthetic activity, ultimately limiting biomass accumulation. Similar reductions in seedling dry matter caused by immature composts and unstable organic amendments have been reported by Tiquia et al. (1996), Cayci et al. (2017), Luo et al. (2018) and Kebrom et al. (2019).

Among the three vegetable taxa, Indian spinach consistently produced greater seedling dry weight than spinach and red amaranth, probably because its larger seeds contain greater carbohydrate and nutrient reserves that support sustained seedling growth before full photosynthetic capacity is established. The positive association observed between root length, shoot length and seedling dry weight further indicates that improved root development enhanced water and nutrient acquisition, which subsequently promoted shoot growth and biomass accumulation. Overall, 70% soil + 30% compost provided the most favourable conditions for early biomass production and vigorous seedling establishment, whereas poultry litter-based compost should be thoroughly matured before use.

Overall interpretation

Taken together, the seedling growth results consistently identify G4 (70% soil + 30% compost) as the most favourable growth medium. It promoted shoot and root development and produced the greatest biomass at the treatment level, while PLBC-based media consistently reduced seedling growth. The findings therefore indicate that a moderate compost proportion provided a more suitable balance of physical and chemical properties for early seedling establishment, whereas poultry litter-based compost should be adequately matured and stabilised before incorporation into growth media.

SUMMARY AND CONCLUSION

Leafy vegetables are important sources of vitamins, minerals, dietary fibre and other beneficial compounds and are widely consumed in Bangladesh. Indian spinach (*Basella alba* L.), spinach (*Spinacia oleracea* L.) and red amaranth (*Amaranthus cruentus* L.) are among the commonly cultivated leafy vegetables. Successful germination and early seedling establishment are essential for uniform crop establishment, and the composition of the growth medium can strongly influence these processes. Therefore, a pot experiment was conducted at the Department of Crop Physiology and Ecology, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur, Bangladesh, to evaluate the effects of five growth media on germination and early seedling growth of three leafy vegetables. Germination percentage (GP), mean germination time (MGT), germination rate index (GRI), coefficient of velocity of germination (CVG), Timson germination index (TGI), shoot length (SL), root length (RL), and seedling dry weight (SDW) were evaluated.

The results demonstrated clear differences among the three vegetable taxa and growth media. Spinach recorded the highest mean GP (57.60%), followed by red amaranth (42.13%), whereas Indian spinach showed the lowest mean GP (34.93%). Among the growth media, G4 (70% soil + 30% compost) produced the highest mean GP (68.89%), followed by G2 (50% soil + 50% compost), while the PLBC-based media showed markedly poorer germination performance. The highest numerical GP was recorded in spinach under G4 (89.33%), whereas the lowest was observed in red amaranth under G3 (5.33%). The interaction between taxon and growth medium was not significant for GP, although both main effects were significant.

Mean germination time was significantly affected by the taxon $\times$ growth-medium interaction. The longest MGT occurred in Indian spinach under G3 (17.11 days), followed by Indian spinach under G5 (16.14 days), whereas the shortest MGT was recorded in red amaranth under the control ($T3 \times G1$; 7.88 days). Germination rate index, coefficient of velocity of germination, and Timson germination index were also significantly influenced by the interaction. G4 generally provided favourable conditions for rapid and sustained germination, while G3 and G5 consistently reduced germination performance across the tested taxa. The highest GRI and TGI were recorded in Indian spinach under G4 (13.95 and 55.78, respectively), whereas the highest CVG was observed in red amaranth under the control (12.69). These results indicate that a moderate proportion of compost created a more favourable environment for germination than the tested PLBC-based media.

Seedling growth also varied considerably among taxa and growth media. Indian spinach produced the longest mean shoots (6.85 cm), followed by spinach (5.27 cm) and red amaranth (3.39 cm). At the growth-medium level, G4 produced the greatest mean shoot length (6.53 cm), while G3 recorded the lowest (4.14 cm). For the interaction, Indian spinach under G4 produced the longest shoot (9.29 cm). Root length was significantly affected by the interaction, with the longest root (13.13 cm) recorded in Indian spinach under G4 and the shortest root (3.13 cm) in red amaranth under G3. Seedling dry weight was significantly influenced by taxon and growth medium, with Indian spinach under G4 recording the highest numerical SDW (0.165 g seedling⁻¹). Overall, the compost-based media, particularly G4, supported better seedling growth than the PLBC-based media.

Taken together, the findings show that germination and early seedling growth of Indian spinach, spinach and red amaranth were strongly influenced by growth-medium composition. Spinach exhibited the highest overall germination performance, whereas Indian spinach showed comparatively lower germination but superior early seedling growth, particularly in shoot length, root length and biomass accumulation. The compost-based media performed better than the PLBC-based media, indicating that the tested poultry litter-based compost was less suitable under the experimental conditions. Among all treatments, G4 (70% soil + 30% compost) consistently provided the most favourable balance for germination and early seedling establishment. Therefore, G4 appears to be the most suitable growth medium among the tested treatments for successful germination and early

establishment of the three studied leafy vegetables under the conditions of this experiment. Further studies may evaluate compost maturity, physicochemical properties, and different application rates to optimise growth-media formulations for leafy vegetable production.

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