Using Date Palm Fibers and Banana Leaves Waste As an Alternative Growing Medium for Tomato, Cucumber and Lettuce Seedlings

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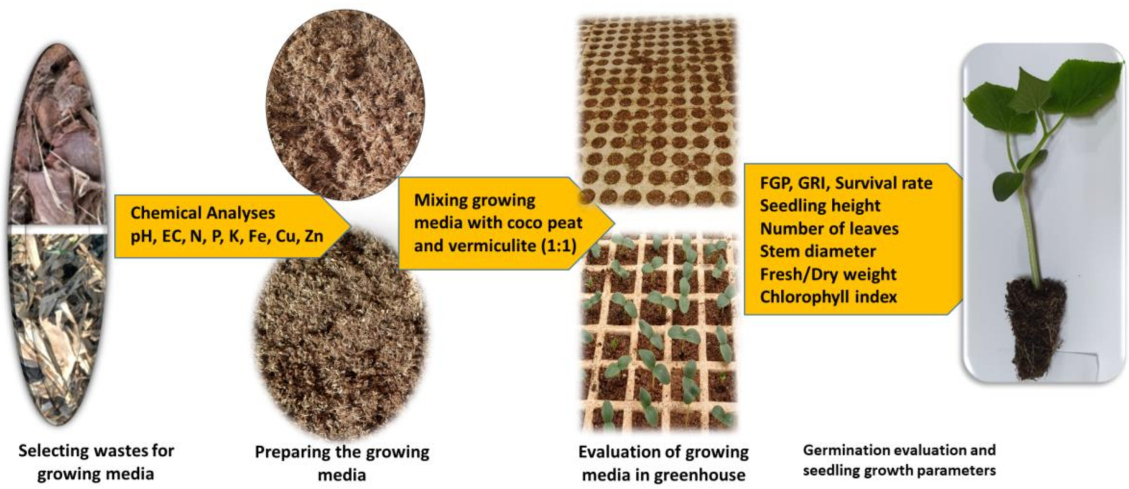
Graphical abstract



Abstract

Bananas and dates are commonly cultivated in Egypt, producing a large amounts of waste during and after processing. This waste requires sustainable management due to human health concerns. This study evaluated the potential use of banana leaf and date palm fiber waste, combined with peat moss or vermiculite as an alternative to peat substitute for producing tomato, cucumber, and lettuce seedlings under greenhouse as noticed in the studied parameters, including germination, biochemical, and seedlings growth. The main treatments included: (1) the control (traditional of peat moss and vermiculite growing medium at a ratio of 1:1); (2) a date palm fibers (DPF) growing medium, (3) a banana leaves (BL) growing medium, (4) a DPF and peat moss (1:1, v/v), (5) a mixture of BL and peat moss (1:1, v/v), (6) a mixture of DPF and vermiculite (1:1, v/v), and (7) a mixture of BL and vermiculite (1:1, v/v). The main findings of this study demonstrate the effectiveness of using such agro-wastes products in the germination and growth of the studied vegetable seedlings. Using DPF to prepare growing media, either alone or in combination with peat moss or vermiculite, produced the best results for the studied vegetable seedlings. The most obvious conclusion to be drawn from these results is that DPF is preferable to BL, as BL has higher values of pH and salinity levels than other mixed growing media. The results also confirm that BL waste can be improved by mixing it with vermiculite or peat moss to produce the required vegetable seedlings, such as tomatoes, cucumbers, and lettuces. The cheapest medium was found to be banana leaves alone or mixed with vermiculite. Further research is required to determine the optimal mixing ratio and explore the potential of utilizing other agro-wastes in horticultural nurseries.

Keywords: Agro-wastes, Bioactive compounds, Horticultural crop, Nursery, Peat moss

1. Introduction

Horticultural crops play a vital role in ensuring food and nutritional security. They are rich in vitamins, minerals, proteins, carbohydrates, and fiber, and have a high economic value (Manzoor et al., 2024). As the global population continues to grow, the daily demand for various horticultural crops is steadily increasing, thereby enhancing their economic and nutritional value (Shah et al., 2024). However, climate change poses a significant challenge to agriculture due to its social, economic, and environmental consequences, including increased stress on crops such as drought, high temperatures, salinity and other factors (Tang, 2024; Sayed et al. 2025). Alongside climate change, agricultural soils suffer from various forms of deterioration due to the depletion of soil organic matter (Pohanková et al., 2024), salinization (Han et al., 2024), desertification (Liu et al., 2024), accelerated soil erosion (He et al., 2024), drought (Patel and Patel 2024), water scarcity (Wahyono et al. 2024), pollution (Pathak et al., 2024), and imbalanced nutrients (Ma et al., 2024). Therefore, there is an urgent need for comprehensive and sustainable development, alongside increased horticultural crop production. It is also necessary to rely on hybrids and varieties, as well as improving technology and production systems for these crops (Shah et al., 2024; Al-Saedi et al. 2025).

Although many vegetable crops can be propagated from seeds, cultivating them as seedlings in a nursery has become the preferred method. The seedling stage is therefore fundamental to improving vegetable yield and quality, provided reasonable cultivation conditions are adopted (Liu et al., 2023). Numerous studies have confirmed the effectiveness of sustainable practices in the production of vegetable seedlings in nurseries (e.g., El-Ramady et al., 2022; Gallegos-Cedillo et al., 2024a; Fan et al., 2025). Therefore, the choice of growing medium is an important issue for horticultural nurseries, with alternatives to traditional soil media being preferable. This is due to the numerous benefits of such growing media, including their high nutrient content and the physical properties of the substrates used, which improve both soil health and fertility (Wu and Congreves, 2024). The selection of growing media and their constituents depends on environmental and ecological factors, particularly in the context of climate change. Concerns are growing about substrates used for horticultural crops, such as compost production (Vandecasteele et al., 2018; Bayoumi et al., 2008 & 2019), co-composted hydro-char substrates (Roehrdanz et al., 2019), spent growing media (Vandecasteele et al. 2023), substrate inoculated with beneficial microorganisms (Pokluda et al. 2023), and sustainable growing media (Gallegos-Cedillo et al., 2024b). The most important soil alternatives used in nurseries are peat moss and vermiculite, but these are as expensive as imported substrates in Egypt. Although vermiculite is an inexpensive local substrate, peat moss is expensive as an imported growth medium. Therefore, it is necessary to search for suitable alternatives that are locally produced and have good qualities, such as agro-wastes (e.g., rice straw, palm fibers, banana waste, cowpea pod waste, other vegetable and fruit waste, pruning waste, and grass cuttings). Using agro-waste, such as date palm fibers and banana leaves, has considerable potential as a soil substitute, and can positively affect seedling growth and crop production.

Globally, around 60% of banana biomass is wasted after harvesting, resulting in the production of almost 114.08 million tons of banana waste (Castillo et al., 2023), In contrast, date palms can generate approximately about 12 million tons of waste biomass annually (Khoshnodifar et al., 2023). In Egypt, both date palms and bananas are commonly cultivated producing around 0.66 and 1.7 million tons of residues, respectively (Moawad and Moussa, 2023). The justifications behind using such agro-wastes in the current study can be summarized in the following points: (1) Egypt produces several million tons of the studied agro-wastes every year, and these residues represent a serious environmental problem, especially when they are managed by burning. (2) The common growing media used in vegetable nurseries, including peatmoss are expensive as imported materials require hard currency. (3) There is an urgent need to find alternative growing media using such local agro-wastes and to save the hard currency. (4) Reducing the total costs of the studied vegetable seedlings, this in turn will reflect on the economic evaluation of the production of such crops. These crops produce vast amounts of fibers and leaves annually, which can be converted into high-value products through in many industries, such as paper production and growing media (Aydi et al. 2023a,b; Qaryouti et al. 2023). As growing media are an important constituent of vegetable seedling nurseries, finding cheap, effective alternatives is crucial. Therefore, a recent study was conducted to evaluate the use of date palm fibers and banana leaves as an alternative to traditional growing media (peat moss or coco peat) for growing lettuce, tomato, and cucumber seedlings. Could these alternative growth media be a sustainable solution for vegetable seedling nurseries? What is the economic value of such alternative growth media?

2. Materials and Methods

2.1 Experimental layout and treatments

The experiment was conducted on the farm of the Horticulture Department at the Faculty of Agriculture, Kafrelsheikh University, in August 2023. It was carried out under a greenhouse; temperature 26 ± 4 °C, light 14:10 h L/D photocycle, and humidity 72 ± 5%. The study examined the use of some plant waste from two horticultural crops (i.e., banana leaves and date palm fibers) as an alternative growing medium for plants. The plant waste was collected and placed in a ventilated area to complete the drying process (Figure 1). The banana leaves and date palm fibers were collected from different two locations: (i) an orchard farm at the Faculty of Agriculture, Kafr El-Sheikh University, and (ii) the cities of Baltim and Rashid. The waste was crushed using a grinding machine and then mixed by volume to create the desired treatments (Figure 2; six replicates (trays) for each treatment) as follows:

1- Control, traditional growing medium (peat moss: vermiculite; 1:1)

2- Medium of date palm fibers (DPF) waste (100%)

3- Medium of banana leaves (BL) waste (100%)

4- Medium of date palm fibers (DPF) and peat moss (1:1)

5- Medium of banana leaves (BL) and peat moss (1:1)

6- Medium of date palm fibers (DPF) and vermiculite (1:1)

7- Medium of banana leaves (BL) and vermiculite (1:1)

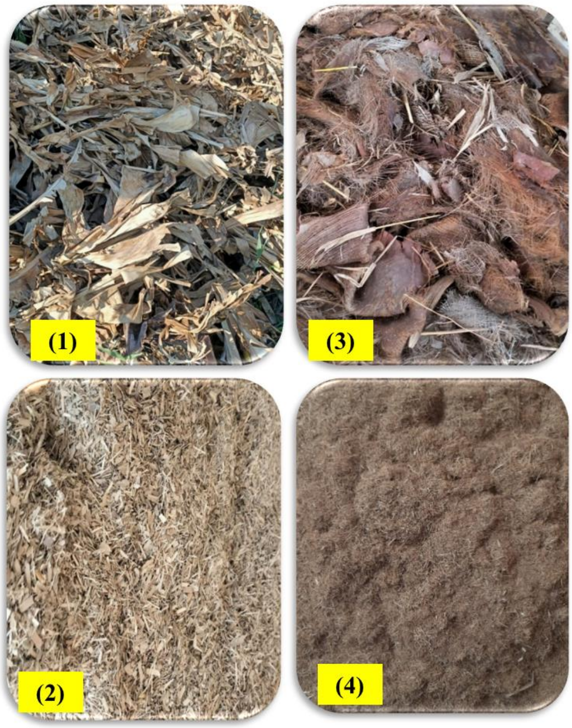


Figure 1. Agro-waste in the form of raw materials of banana leaves and date palm fibers (photos 1 and 3) as well as their crushed forms (photos 2 and 4, respectively)

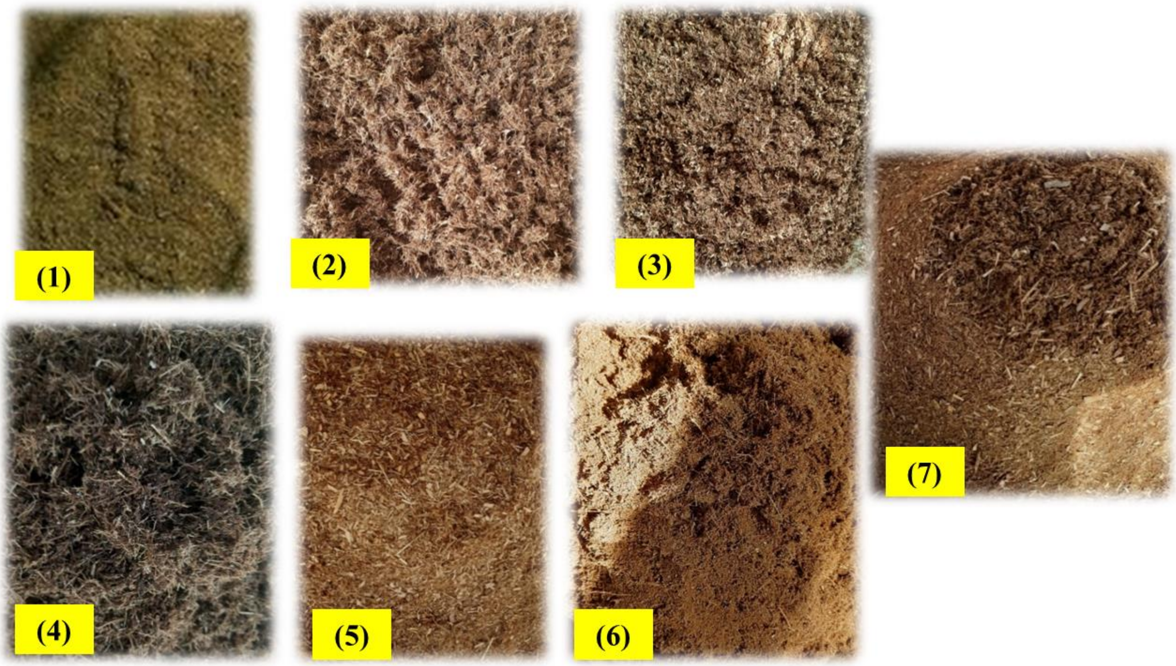


Figure 2. Treatments of the prepared growing media. The photos 1 to 7 represent the following, respectively: control medium (peat moss: vermiculite), date palm fibers alone, banana leaves alone date palm fibers with peat moss (1:1), banana leaves with peat moss (1:1), date palm fibers with vermiculite (1:1), and banana leaves with vermiculite (1:1).

2.2. Analyses of the growing media

Basic analyses were performed on all the agro-waste materials studied (i.e., date palm fibers and banana leaves), as well as on the studied media after mixing and before planting (see Table 1). The analyses included the nutritional value besides the pH and salinity (EC). The following practices were added to each growing medium during the mixing and before sowing the seeds: 50 g of fungicide (uniform) per carton of peat moss and its equivalent in other mixtures, adding 300 g of N:P:K fertilizer (19:19:19), and samples were taken from the growing medium mixtures after homogenization to analysis both the pH and EC values. A peat moss and vermiculite substrate (1: 1 v/v) was used as the control substrate due to its widespread use in vegetable crop nurseries worldwide, despite being the most expensive component (1810 LE/100 trays) compared to the other substrates studied. The chemical characteristics (i.e., pH and EC values) of all the growing media were measured according to Sparks et al., (2020) using a pH meter (model 3510, Jenway, Staffordshire, UK) and an EC meter (model MI 170, Italy), respectively (see Table 2).

Table 1. Basic analyses of date palm fibers and banana leaves.

Chemical analysis	Banana leaves	Date palm fibers
pH (in extract 1:10)	7.38	5.82
EC (in extract 1:20), dS m^{-1}	4.36	5.23
Nitrogen content (%)	1.544	0.64
K (ppm)	24918	6831
P (ppm)	1058	421
Mn (ppm)	281.2	48.0
Fe (ppm)	425	206
Cu (ppm)	7.40	6.75
Zn (ppm)	20.30	54.40

Table 2. Basic analyses using mixed growing media before sowing.

Samples	pH value	EC (ppm)
Control	6.98 ± 0.08	1283 ± 47.2 d
Date palm fibers	7.57 ± 0.12	1670 ± 48.1 c
Banana leaves	8.71 ± 0.11	2501 ± 51. 8 a
Date palm fibers + peatmoss	6.72 ± 0.06	1543 ± 44.3 c
Banana leaves + peatmoss	7.63 ± 0.07	1856 ± 48.6 b
Date palm fibers + vermiculite	7.20 ± 0.10	1002 ± 36.8 ef
Banana leaves + vermiculite	8.59 ± 0.13	1098 ± 37.2 e

The composition of each nursery medium, along with the cost of filling 100 Styrofoam seedling trays (209 cells) is shown in Table 3. Peat moss and vermiculite (1:1) was the most expensive growing medium (1810 LE), followed by date palm fibers and peat moss (1100 LE). The cheapest medium was for banana leaves alone or mixed with vermiculite (320 LE).

Table 3. Description of the composition of the growing media used in the experiments, alone with their relative cost (LE/100 trays)

Growing media	Growing media composition (as a volume)	Relative cost (LE/100 trays)
Control	Peatmoss: vermiculite (1:1)	1810
Date palm fibers	Date palm fibers ground only (100% only)	400
Banana leaves	Banana leaves ground only (100% only)	320
Date palm fibers + peatmoss	Date palm fibers ground : peatmoss (1:1)	1010
Banana leaves + peatmoss	Banana leaves ground : peatmoss (1:1)	970
Date palm fibers + vermiculite	Date palm fibers ground : vermiculite (1:1)	360
Banana leaves + vermiculite	Banana leaves ground : vermiculite (1:1)	320

Note: 1 USD ≈ 50.5 LE by the first of January 2025

2.3.Sowing the seeds in the trays

Styrofoam trays (209 for lettuce and tomatoes and 104 for cucumbers) were prepared, treated with 39% formalin to sterilize them and then placed in the sun to dry. After filling the trays with the studied medium, the cucumber, tomato and lettuce seeds were sown and then all trays were appropriately irrigated. As tomatoes and cucumbers are summer crops, the cultivated seeds were covered and placed in an incubator to increase their germination rate. However, this practice was not necessary for lettuce seeds as they are a winter crop. Irrigation was carried out at two-day intervals or as needed. Regarding the agrochemicals, a solution of 1.5 g N:P:K (19.19.19) in 1.0 L was added to each tray for fertilization 12 days after sowing, 1.0 g of fungicide (Uniform) per liter was added eight days after sowing, and 1.0 g of insecticide (Abamectin) per liter was applied one week after germination. Seed sowing began on 18 October 2023, with daily monitoring involving counting the number of germinated seeds each day until the germination rate stabilized (after 20 days), in order to calculate the germination parameters (Esechie, 1994). Seeds were considered germinated when the hypocotyls appeared above the surface of the medium. We did not identify any pathogens during the study period for these seedlings. The following germination parameters were recorded:

1- Final germination percent (FGP, %) = $= \frac{\text{Number of germinated seeds}}{\text{Total number of tested seeds}} \times 100$

2- Germination rate index (GRI) = $\left(\frac{G1}{1}\right) + \left(\frac{G2}{2}\right) \ldots \ldots + \left(\frac{Gx}{x}\right)$

Where: G = germination on each subsequent day after placement,

1, 2; x = corresponding day of germination

3- Survival rate (%) =

$(\text{number of germinated seeds} - \text{number of seedlings that died after germination}) \times 100$

2.4.Seedlings growth

Thirty-five days after sowing the tomato and lettuce seeds, and twenty-five days after sowing the cucumber seeds, the following vegetative growth traits were measured:

- Seedling height (cm), measured from the surface of the growing medium to the shoot apex,
- Number of leaves (excluding cotyledons),
- Stem diameter (mm), measured with a caliper,
- Fresh masses of shoots and roots (per seedling),
- Dry masses of shoots and roots (recorded after drying at 70 °C for 48 hours).

2.5.Chlorophyll content and photosynthesis efficiency

The chlorophyll content (SPAD) or chlorophyll index was measured using the chlorophyll-meter (Minolta, Tokyo, Japan), according to Yadava, (1986), after 35 days for tomato and lettuce seedlings and after 25 days for cucumber seedlings. The seedlings were kept in a dimly lit place for 30 min before measurement. Photosynthetic efficiency (Fv/Fm) was recorded using a portable chlorophyll fluorometer (OS-30p, Opti-Sciences, Hudson, NH, USA). The lowest fluorescence (F_0) for photosynthetic photon flux density values were measured after 30 min in the dark for the same leaves, and the maximal fluorescence (Fm) values were measured using light of < 0.1 and 3500 µmol m^{-2} s^{-1} for the same leaves. According to Dewir et al. (2005), the variable fluorescence value ($Fv = Fm - F_0$) and photochemical efficiency of PSII (Fv/Fm) were also recorded. The previous parameters were recorded using three seedlings and were taken from the leaves under the leaf chamber. Each treatment included three single leaves as three replications.

2.6.Statistical analyses

The data were tabulated in randomized complete block design (RCBD) and statistically analyzed using the one-way-ANOVA of the CoStat package program (Computer

Program Analysis, Version 6.303; CoHort Software, CA, USA). Duncan's multiple range test at a 5% level of probability was employed to identify significant differences in the means of the treatments (Snedecor and Cochran 1989).

3. Results

3.1 Germination traits

All germination indices were significantly influenced by the different growing media under studied conditions (Table 4). These indices included the final germination percentage (FGP), the germination rate index (GRI), and the survival rate of the studied crops. Using date palm fibers media alone or mixed with peat moss or vermiculite significantly increased the FGP in all crop seeds. The highest FGP was recorded by date palm fibers alone or in combination with peat moss or vermiculite media in most cases for all crops, with no significant difference from the common medium (control) for the three vegetables. Conversely, using media of banana leaf substrate alone severely reduced the FGP of tomato, lettuce and cucumber seeds as compared to the control substrate, while banana leaves mixed with peat moss or vermiculite produced intermediate results in most cases (Table 4). The lowest GRI values were obtained by applying a mixture of date palm fibers and vermiculite to cucumber (2.82) and lettuce (4.01), with no statistical difference to the control substrate (2.86 and 3.88 for cucumber and lettuce, respectively). However, the highest GRI value was by using a banana leaf substrate for tomato (5.02). The highest GRI values were obtained using a medium of banana leaves, resulting in values of 5.16, 6.84, and 6.37 for cucumber, tomato, and lettuce, respectively. In most cases, the lowest GRI values were observed when using the date palm fiber medium alone or mixed with peat moss or vermiculite, with insignificant differences compared to the control treatment. The maximum survival rate (100%) was observed when the date palm fiber medium was mixed with peat moss or vermiculite, followed by the control medium. Meanwhile, the banana leaf substrate, either alone or combined with peat moss or vermiculite, showed the lowest survival rates in all crops.

Table 4. Effect of different growing substrates on the germination parameters of the studied seedlings

Growing media	Final germination percent (FGP, %)	Germination rate index (GRI, day)	Survival rate (%)
	Cucumber seedlings		
Control	85.83 ± 2.92 a	2.86 ± 0.07 e	95.00 b
Date palm fibers	90.92 ± 3.14 a	3.09 ± 0.11 de	98.00 ab

Banana leaves	26.19 ± 0.42 c	5.16 ± 0.24 a	80.88 e
Date palm fibers + peatmoss	90.36 ± 2.85 a	2.99 ± 0.08 e	100.00 a
Banana leaves + peatmoss	40.47 ± 1.95 b	4.28 ± 0.22 c	85.50 de
Date palm fibers + vermiculite	88.99 ± 2.78 a	2.82 ± 0.10 e	100.00 a
Banana leaves + vermiculite	39.52 ± 1.28 b	4.92 ± 0.23 b	88.00 cd
F – test	**	**	*
	Tomato seedlings		
Control	94.65 ± 3.03 a	5.20 ± 0.22 c	97.00 b
Date palm fibers	90.52 ± 2.25 ab	5.55 ± 0.25 bc	97.00 b
Banana leaves	60.33 ± 1.67 d	6.84 ± 0.31 a	88.00 d
Date palm fibers + peatmoss	94.52 ± 2.88 a	5.59 ± 0.15 bc	99.50 a
Banana leaves + peatmoss	71.78 ± 2.16 c	5.91 ± 0.26 b	90.00 cd
Date palm fibers + vermiculite	93.29 ± 2.91 a	5.30 ± 0.25 c	100.00 a
Banana leaves + vermiculite	88.88 ± 2.77 b	5.02 ± 0.18 d	92.00 c
F- test	**	*	*
	Lettuce seedlings		
Control	96.08 ± 2.99 a	3.88 ± 0.11 e	94.00 b
Date palm fibers	95.65 ± 3.12 a	4.21 ± 0.34 d	95.00 b
Banana leaves	29.76 ± 2.06 c	6.37 ± 0.25 a	75.00 d
Date palm fibers + peatmoss	97.06 ± 2.95 a	4.02 ± 0.12 de	100.00 a
Banana leaves + peatmoss	79.45 ± 3.22 b	5.78 ± 0.27 b	85.00 c
Date palm fibers + vermiculite	98.03 ± 3.22 a	4.01 ± 0.13 de	99.00 a
Banana leaves + vermiculite	75.66 ± 2.20 b	5.05 ± 0.11 c	88.00 c
F- test	**	**	**

Different letters in the same column show significant differences among each group of treatments according to Duncan's test at $p \leq 0.05$.

3.2. *Seedling growth traits*

Seedling growth traits (i.e., seedling length, number of leaves, stem diameter, shoot fresh and dry weights, and roots fresh and dry weights) differed significantly in relation to different growing media sources in most cases, as presented in Tables 5 and 6. The tallest tomato and lettuce seedlings resulted the from control growing medium, followed by the date palm fibers substrate combined with peat moss and vermiculite, while the longest cucumber seedlings were obtained using the substrate of date palm fibers combined with peat moss

(18.7 cm), followed by date palm fibers combined with vermiculite (16.6 cm) and the control substrate (15.2 cm). The number of leaves per seedling did not differ significantly in relation to the growing medium, except for tomato seedlings. The highest values were obtained by the control treatment (4.5) and the treatment combining date palm fibers with peat moss (4.4). Seedlings grown in a date palm fibers and peat moss medium had the thickest stem diameter of all seedlings, with no significant difference compare to the control substrate for tomato and lettuce seedlings. However, cucumber seedlings with the highest thickness resulted from the substrate composed of date palm fibers combined with peat moss, followed by the control and the combination of date palm fibers and vermiculite.

Table 5. Effect of different growing substrates on some vegetative growth traits of the studied seedlings.

Growing media	Seedling length (cm)	No. of leaves	Stem diameter (mm)
Tomato seedlings after 35 days from sowing			
Control	21.6 a	4.5 a	3.51 a
Date palm fibers	8.8 e	2.8 c	2.69 b
Banana leaves	5.9 f	2.2 cd	2.05 d
Date palm fibers + peatmoss	16.9 b	4.4 a	3.36 ab
Banana leaves + peatmoss	11.4 d	3.3 bc	2.67 c
Date palm fibers + vermiculite	14.2 c	3.8 b	3.22 b
Banana leaves + vermiculite	9.7 e	3.5 b	2.83 c
F – test	**	*	**
Cucumber seedlings after 25 days from sowing			
Control	15.2 bc	3.0 a	3.26 b
Date palm fibers	10.3 d	2.2 a	2.91 c
Banana leaves	9.5 d	2.2 a	2.58 e
Date palm fibers + peatmoss	18.7 a	3.3 a	3.76 a
Banana leaves + peatmoss	15.1 bc	2.6 a	2.98 c
Date palm fibers + vermiculite	16.6 b	2.7 a	3.19 b
Banana leaves + vermiculite	13.3 c	2.4 a	2.75 de
F – test	**	NS	**
Lettuce seedlings after 35 days after sowing			

Control	24.1 a	4.7 a	2.16 ab
Date palm fibers	11.4 d	4.4 a	1.58 d
Banana leaves	10.5 e	4.2 a	1.99 b
Date palm fibers + peatmoss	15.8 b	4.9 a	2. 28 a
Banana leaves + peatmoss	12.4 cd	5.2 a	2.02 b
Date palm fibers + vermiculite	13.7 c	4.8 a	2.15 ab
Banana leaves + vermiculite	11.8 d	5.3 a	1.76 c
F – test	**	NS	**

Different letters in the same column show significant differences among each group of treatments according to Duncan's test at $p \leq 0.05$, NS: non-significant means treatments have the same letter.

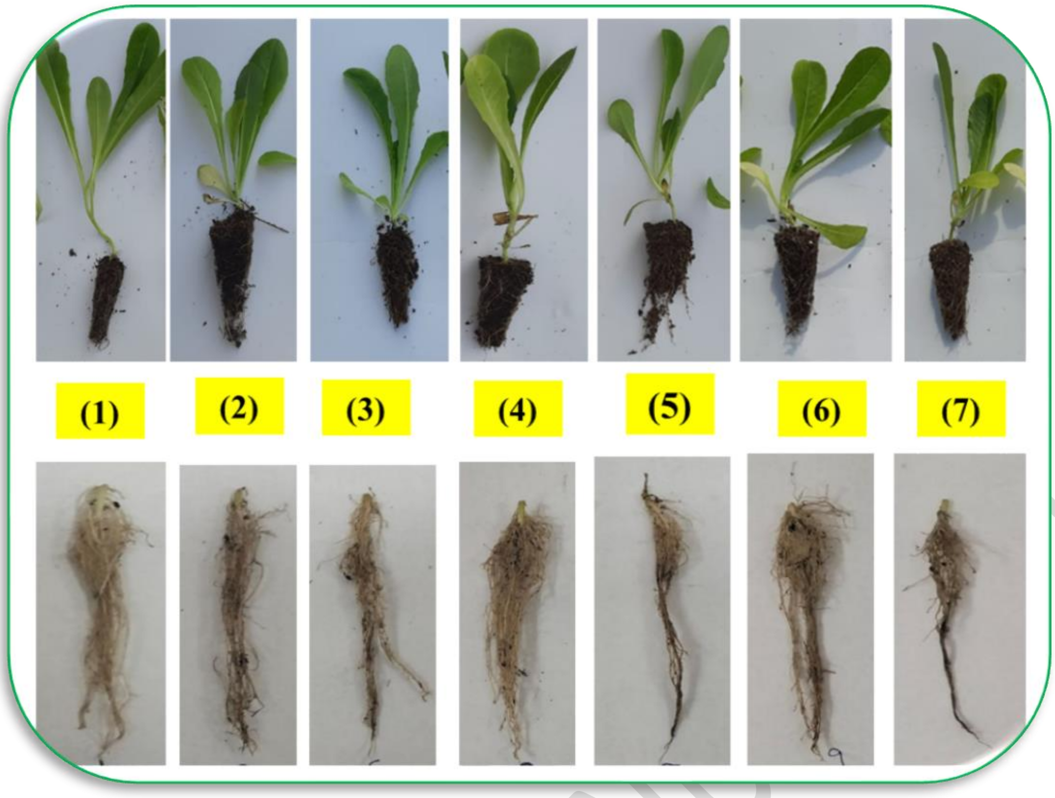
For the fresh and dry weights of tomato and lettuce seedlings, the control substrate produced the highest values, followed by the date palm fibers and peat moss substrate (Table 6). In contrast, the highest fresh and dry weights of cucumber seedlings were recorded for those grown on a date palm fibers and peat moss substrate, followed by those grown on a control substrate or a date palm fibers and vermiculite substrate. Similarly, seedlings grown in the control treatment showed the highest root fresh and dry weights in all crops. Conversely, using a substrate of banana leaves had a negative effect on all growth parameters of vegetable crop seedlings. Figure 3 provides an overview of various vegetable seedlings studied, including the shoot and root growth.

Table 6. Effect of different growing substrates on the fresh and dry weights of shoots and roots in the studied seedlings.

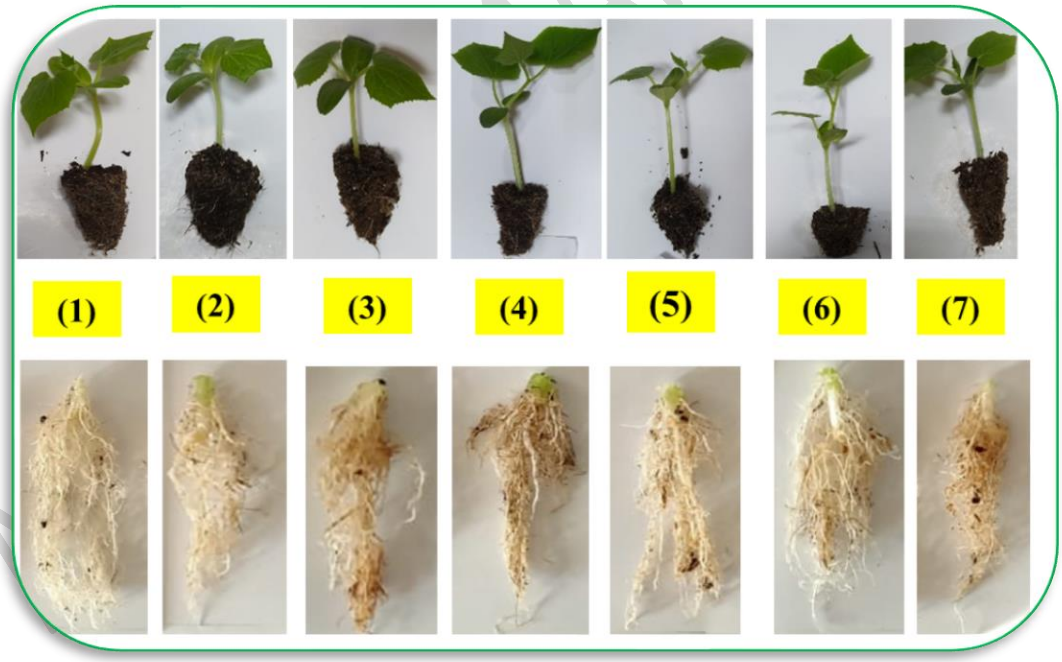
Growing media	Shoot fresh weight (g)	Shoot dry weight (g)	Root fresh weight (g)	Root dry weight (g)
Tomato seedlings after 35 days from sowing				
Control	1.48 a	0.115 a	0.325 a	0.028 a
Date palm fibers	0.58 f	0.045 d	0. 167 d	0.015 c
Banana leaves	0.36 g	0.026 e	0.129 e	0.011 d
Date palm fibers + peatmoss	1.18 b	0.093 b	0.269 bc	0.024 b
Banana leaves + peatmoss	0.91 d	0.069 c	0.238 c	0.020 b
Date palm fibers + vermiculite	1.05 c	0.089 b	0.258 bc	0.023 b
Banana leaves + vermiculite	0.66 e	0.051 d	0.179 d	0.016 c
F-test	**	**	**	**

Cucumber seedlings after 25 days from sowing				
Control	3.12 b	0.14 a	0.96 a	0.042 a
Date palm fibers	1.96 e	0.09 a	0.45 cd	0.022 a
Banana leaves	1.68 f	0.08 a	0.38 d	0.019 a
Date palm fibers + peatmoss	3.45 a	0.16 a	0.88 a	0.040 a
Banana leaves + peatmoss	2.72 c	0.13 a	0.62 b	0.028 a
Date palm fibers + vermiculite	3.04 b	0.14 a	0.85 a	0.036 a
Banana leaves + vermiculite	2.18 d	0.11 a	0.55 c	0.024 a
F. test	**	NS	**	NS
Lettuce seedlings after 35 days after sowing				
Control	3.28 a	0.183 a	0.541 a	0.025 a
Date palm fibers	1.66 d	0.094 e	0.266 d	0.015 c
Banana leaves	1.68 d	0. 098 e	0.311 cd	0.016 c
Date palm fibers + peatmoss	2.15 b	0.121 bc	0.485 b	0.024 a
Banana leaves + peatmoss	1.86 c	0.104 d	0.368 c	0.018 b
Date palm fibers + vermiculite	2.02 bc	0.113 c	0.456 b	0.023 a
Banana leaves + vermiculite	1.85 c	0.110 c	0.344 c	0.018 b
F. test	**	**	**	*

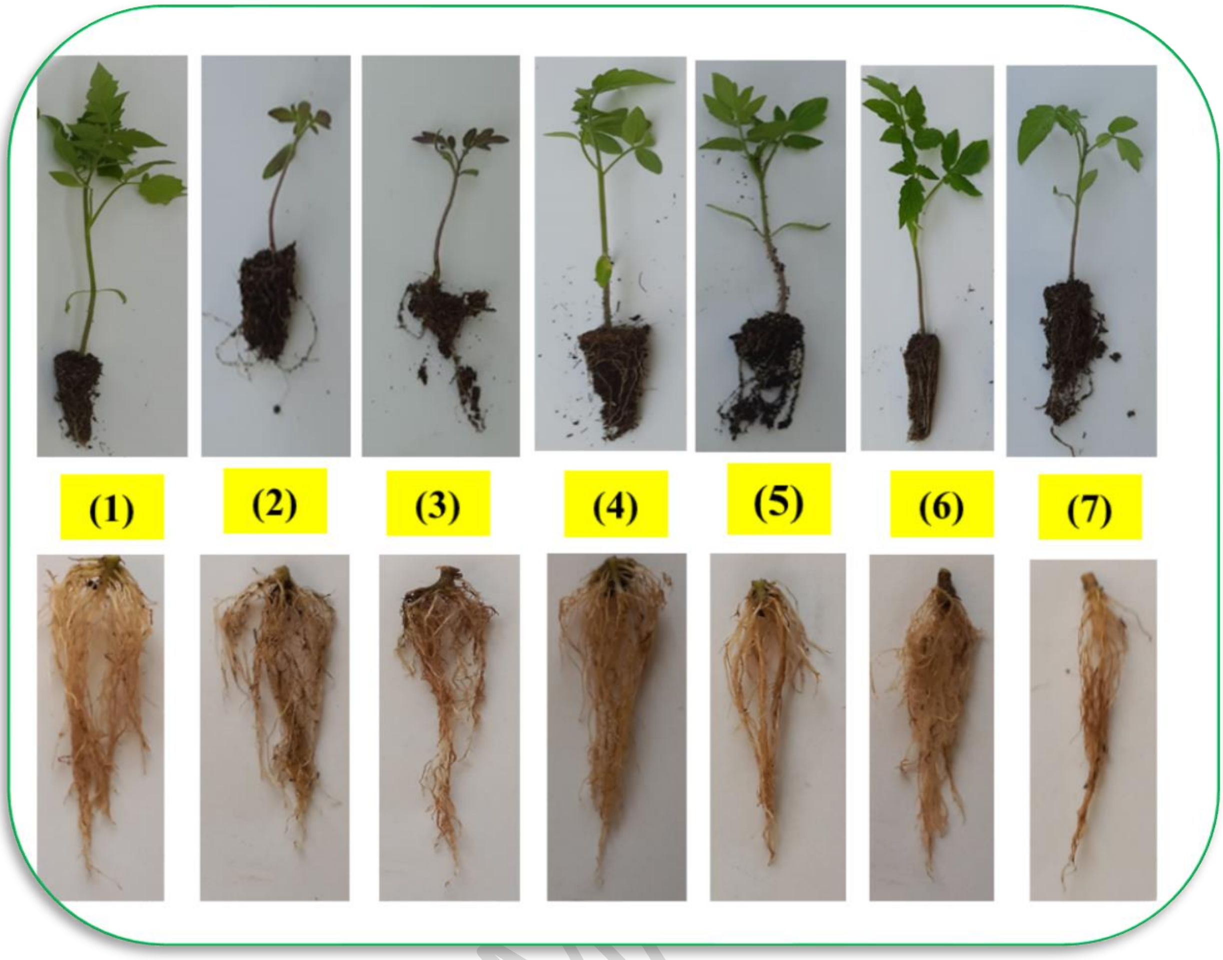
Different letters in the same column show significant differences among each group of treatments according to Duncan's test at p ≤ 0.05, NS: non-significant means treatments have the same letter.



Lettuce seedlings, 35 days after sowing date



Cucumber seedlings, 25 days after sowing date



Tomato seedlings 35 days after sowing date

Figure 3. An overview of the seedlings of the studied crops and their growth in different growing media. The numbers represent the following media: 1 (control), 2 (date palm fibers), 3 (banana leaves), 4 (date palm fibers + peatmoss), 5 (banana leaves + peatmoss), 6 (date palm fibers + vermiculite), and 7 (banana leaves + vermiculite).

3.3. Total chlorophyll and photosystem efficiency

As shown in Table 7, chlorophyll content (SPAD) and photosystem efficiency (Fv/Fm) in various vegetable seedlings differed significantly according to the growing media used. The highest chlorophyll content (14.56 SPAD) was recorded in lettuce seedlings grown in banana leaf substrate, whereas the lowest value (4.92 SPAD) was found in tomato seedlings grown in the same substrate. Generally, using date palm fibers or banana leaves alone resulted in the lowest chlorophyll values in tomato and cucumber crops, but not in lettuce seedlings. The same trend was observed for photosystem efficiency (Fv/Fm) values was noticed, with the lowest results (0.611 and 0.653) obtained from using only date palm fibers or banana leaves in tomato and cucumber seedlings compared to other growing substrates. However, there was no significant difference in lettuce seedlings. Mixing palm fibers or banana leaves with peat moss or vermiculite increased the (Fv/Fm) values in the studied crop seedlings.

Table 7. Effect of different growing substrates on chlorophyll content and photosynthesis efficiency in seedlings.

Growing media	Chlorophyll content (SPAD)	Photosynthesis efficiency (Fv/Fm)
Tomato seedlings after 35 days from sowing		
Control	8.42 a	0.706 ab
Date palm fibers	5.36 c	0.611 c
Banana leaves	4.92 d	0.653 bc
Date palm fibers + peatmoss	8.38 a	0.739 a
Banana leaves + peatmoss	8.74 a	0.748 a
Date palm fibers + vermiculite	7.98 b	0.728 a
Banana leaves + vermiculite	7.74 b	0.711 ab
F. test	**	*
Cucumber seedlings after 25 days from sowing		
Control	11.37 a	0.736 a
Date palm fibers	9.65 bc	0.699 c
Banana leaves	8.96 c	0.714 bc
Date palm fibers + peatmoss	11.89 a	0.733 a
Banana leaves + peatmoss	11.31 a	0.705 bc
Date palm fibers + vermiculite	11.57 a	0.735 a
Banana leaves + vermiculite	10.45 b	0.716 b
F. test	*	*
Lettuce seedlings after 35 days after sowing		
Control	12.22 b	0.749 a
Date palm fibers	9.76 c	0.744 a
Banana leaves	14.56 a	0.767 a
Date palm fibers + peatmoss	12.53 b	0.752 a
Banana leaves + peatmoss	11.18 bc	0.757 a
Date palm fibers + vermiculite	11.09 bc	0.751 a
Banana leaves + vermiculite	12.88 b	0.746 a
F. test	**	NS

Different letters in the same column show significant differences among each group of treatments according to Duncan's test at $p \leq 0.05$, NS: non-significant means treatments have the same letter.

4. **Discussion**

Agro-waste is a significant environmental issue that requires sustainable management. The cultivation of banana and date palm is a major contributor to the large-scale production of agro-waste in Egypt and many other countries worldwide. Growing media is essential to controlling production in horticultural nurseries. The current study evaluated some agro-wastes from bananas and date palms in producing alternative growing media. To distinguish between these two agro-wastes individually and/or in combination with the common growing media of peat moss and vermiculite, the economic evaluation was performed by tabulating the cost price of the studied combinations. This study aims to evaluate these agro-wastes, in the form of banana leaves and date palm fibers to be used as an alternative growing medium in vegetable nurseries. This section will present different perspectives on using such agro-waste as a growing medium for cultivating tomato, cucumber, and lettuce seedlings.

4.1 Salinity and pH on growing media

The first question will address the characterization of the growing media used before sowing the seeds of the studied vegetable crops. The mixture of applied ago-wastes with vermiculite produced lower salinity content (1002.27 and 1098.52 ppm) compared to the mixture with peatmoss (1543.68 and 1856.62 ppm for DPF and BL, respectively). The higher salinity content values (1856.62 and 2501.76 ppm) were noticed for growing media of BL + peatmoss and BL alone. It seems that vermiculite, as a local and inexpensive substrate, was preferable in the growing media compared to peatmoss. Concerning the physiological reasoning of salinity and pH effects on seedling root growth, salinity (EC) and pH significantly influence seedling root development, nutrient uptake, and overall plant health. Date palm fibers and vermiculite recorded the lower salinity value (1002 ppm) and neutral pH value (7.20). These values of EC supported the seedling growth through the physiological mechanisms through reducing the osmotic stress, ion toxicity and nutrient imbalance (Mimoun et al. 2024). The value of pH (7.20) is not low (< 5.5) or higher (> 8.00), but neutral supporting the bioavailability of nutrients to uptake by seedlings roots (Marschner, 2012). The other growing media suffer from higher salinity and/or higher alkalinity (higher pH), which cause a real stress on the uptake of nutrients by seedling roots (Turner et al. 2020).

4.2 Economic value of growing media

Growing media made from DPF and BL offer significant economic advantages, particularly in regions where these materials are abundant as agricultural byproducts. Utilizing these organic wastes reduces production costs compared to conventional peat-based or synthetic substrates, while also promoting sustainable farming practices. DPF and BL are lightweight, biodegradable, and locally available, lowering transportation and processing expenses. Their use in horticulture and hydroponics can enhance crop yields by improving aeration and water retention, leading to higher profitability for growers. Furthermore, repurposing these agricultural residues creates additional income streams for farmers and supports circular economy initiatives by converting waste into valuable resources. Therefore, the hypothesis of our study was confirmed through the economic evaluation of all studied growing media, which reported that the price of growing media from vermiculite was cheaper than that of peatmoss (Table 3). With respect to the first research question, it was found that growing media made from vermiculite with DPF and/or BL may be better than those made with peatmoss. As sources of peatmoss are limited and inappropriate in Egypt due to its high cost and imported growing media, DPF or BL wastes can be considered proper substrates as an alternative to peatmoss. As demand for eco-friendly growing media increases, date palm and banana-based substrates present a cost-effective and sustainable alternative with strong market potential. Future research should explore optimized processing techniques and economic scalability to maximize their commercial viability.

4.3 Vegetative growth of seedlings and growing media

The second question may include the possible impacts of mixed agro-wastes on the germination of studied vegetable seedlings. The germination process is a crucial stage of the production of studied seedlings. A strong relationship between germination parameters and the production of vegetable seedlings has been reported in the literature (Gallegos-Cedillo et al., 2024; Ullah and Jan, 2024). In general, the best survival rate (100%) was recorded by DPF growing media compared to BL growing media for the studied vegetable seedlings. This may be due to the lower salinity content (EC), particularly when mixed with vermiculite. On the other hand, applying BL to different growing media resulted in the lowest germination percentage for different mixed growing media. The reason for this feature may be the physical structure and nutritional value of DPF in supporting germination, although the nutrient content in BL was higher compared to DPF. However, the higher pH (8.71) and EC (2501.76 ppm) values may be are significant constraints for germination. This may also be due to the high content of bioactive compounds in date palm wastes (Zahid et al., 2024). Furthermore, salinity is a crucial constraint for seed germination due to osmotic stress and Na^+ ion-toxicity (Singh et al., 2021). The low density of DPF, along with low pH and EC values compared to other growing media, can be noticed. On the other hand, it could be noticed that the germination rate index for the studied seedlings was lower when using the DPF, which recorded fewer days. This finding is very important for seedling production in the nursery. It allows the production of earlier seedlings for earlier harvesting and saves production costs in the nursery stage of studied crops.

The third question includes the impacts of studied agro-wastes on the growth parameters of seedlings of tomato, cucumber, and lettuce. The same behavior of DPF on growth parameters can be noticed, as mentioned in the previous part concerning germination indices. The main reason for this action could be interpreted through the previous studies, which have demonstrated that DPF is rich in carotenoids, fibers, phenolics, and tocopherols (Maou et al. 2021; Manai et al. 2024). It could be noticed that the preferable seedling length is medium (around 10 cm), as recorded by DPF, rather than the higher length obtained with the common growing media (peat moss + vermiculite) for the studied vegetable seedlings (15-20 cm). In general, seedling stem diameter values are better in growing media containing DPF, while a lower stem diameter is observed in growing media with BL. A similar effect of DPF can be seen on the dry weight of seedling roots and shoots. It is important to note that seedling quality may depend on root growth and stem diameter, which are preferable in the growing media containing DPF.

4.4 Photosynthesis efficiency of seedlings and growing media

The last question may include the impacts of mixed agro-wastes on the chlorophyll content and photosynthesis efficiency in the studied vegetable seedlings. These parameters also follow the same trend as the previous parameters of the studied vegetable seedlings. The waste of DPF alone or mixed with vermiculite or peatmoss presented better results compared to the waste of BL. This combination of findings provides some support for the conceptual premise that using the waste of DPF has a promising application in preparing growing media for vegetable seedlings compared to the waste of BL. Chlorophyll content and photosynthesis efficiency are closely linked to root growth, as both depend on nutrient uptake, photosynthesis, and stress responses. Chlorophyll content is a key indicator of photosynthetic potential and overall seedling vigor. Growing medium of date palm fibers and vermiculite was recorded higher values of chlorophyll and photosynthesis efficiency. The suggested mechanism may back to forming non-saline medium and neutral pH, which enhances light absorption and energy conversion as well as nutrient uptake (Marschner, 2012). This reflects the high photosynthetic efficiency of growing medium of date palm fibers and vermiculite comparing with control due to stronger seedlings. The slight salinity under this growing medium synergizes the nutrient uptake and the photosynthetic efficiency of seedlings comparing with higher salinity levels of other growing media. This result is in agreements with Li et al. (2024).

As far as we know, few publications exist on the use of DPF in growing media, such as Gomis et al., (2022), although many articles discussed using ago-wastes in producing the growing media (e.g., Abid et al. 2018, Jayaprakash et al. 2022; EL-Mously et al. 2023; Aydi et al. 2023a,b; Bhatia and Sindhu 2024). Additionally, these agro-wastes need further investigation under different mixing rates with different substrates.

5. Conclusions

The purpose of this investigation was to explore the relationship between the studied agro-waste (DPF and BL) and the production of different vegetable seedlings of tomato, cucumber, and lettuce. Different mixing ratios of DPF and BL wastes were used as alternative growing media to peatmoss, an imported material, to save hard currency. The main findings of the current study confirm the possible mixing of DPF with vermiculite to overcome the high cost of common growing media like peatmoss. This proof can be noticed from the preferable results in germination parameters, growth, and biochemical properties of the studied vegetable seedlings (tomato, cucumber, and lettuce). This study raises important economic and environmental issues that require further research in the future, particularly regarding different mixing ratios in vegetable nurseries. It could summarize the main highlighted points from the current study as follows:

- Date palm fibers (DPF) and banana leaves (BL) are common agro-wastes
- DPF promising growing media alone or mixed with vermiculite or peatmoss for vegetable seedlings production
- BL waste rich in many nutrients, but higher values in pH and salinity
- BL can't use alone as a growing media but by mixing with vermiculite or peatmoss
- Optimal mixing ratio is a crucial for utilizing agro-wastes in horticultural nurseries

Future studies should explore microbial community dynamics in these growth media to assess their role in nutrient cycling and seedling health. Additionally, investigating the long-term stability and scalability of these systems could provide valuable insights for practical applications.

Acknowledgments: Authors extend their gratefulness to the Deanship of Scientific Research, Vice Presidency for Graduate Studies and Scientific Research, King Faisal University, Saudi Arabia, for supporting this research work through the grant number (KFU251153)

Funding: Deanship of Scientific Research, Vice Presidency for Graduate Studies and Scientific Research, King Faisal University, Saudi Arabia, Grant number (KFU251153)

References

Abid, W., Magdich, S., Mahmoud, I.B., Medhioub, K., Ammar, E. (2018). Date Palm Wastes Co-composted Product: An Efficient Substrate for Tomato *(Solanum lycopercicum* L.) Seedling Production. *Waste Biomass Valor* 9, 45–55. https://doi.org/10.1007/s12649-016-9767-y

Al-Saedi, T.K., Sayed, K., Syakir, M.I., Umar, Y., Azhar, B., Tohiran, K.A., Nobilly, F., Rahmat, S. R. (2025). Enhancing soil quality and economic value in oil palm plantations: Effects of livestock integration on earthworm abundance and ecosystem services. *Journal for Nature Conservation*, 86, 126939. https://doi.org/10.1016/j.jnc.2025.126939.

Aydi, S.; Sassi Aydi, S.; Marsit, A.; El Abed, N.; Rahmani, R.; Bouajila, J.; Merah, O.; Abdelly, C. (2023a). Optimizing Alternative Substrate for Tomato Production in Arid Zone: Lesson from Growth, Water Relations, Chlorophyll Fluorescence, and Photosynthesis. *Plants*, *12*, 1457. https://doi.org/10.3390/plants12071457

Aydi, S.; Sassi Aydi, S.; Rahmani, R.; Bouaziz, F.; Souchard, J.P.; Merah, O.; Abdelly, C. (2023b) Date-Palm Compost as Soilless Substrate Improves Plant Growth, Photosynthesis, Yield and Phytochemical Quality of Greenhouse Melon (*Cucumis melo* L.). *Agronomy*, *13*, 212. https://doi.org/10.3390/agronomy13010212

Bayoumi, Y. A., El-Henawy, A. S., A. Abdelaal, Kh. A., Elhawat, N. (2019). Grape Fruit Waste Compost as a Nursery Substrate Ingredient for High-Quality Cucumber (*Cucumis sativus* L.) Seedlings Production. *Compost Science & Utilization*, 27 (4):205–216.

Bayoumi, Y.A., El-Mahrouk, M.E., El-Aidy, F., Pap, Z. (2008). Using compost of grape manufacture and farm wastes as growing media in vegetable and ornamental nurseries. *International Journal of Horticultural Science*, 14 (3): 45-50.

Bhatia, T., Sindhu, S.S. Sustainable management of organic agricultural wastes: contributions in nutrients availability, pollution mitigation and crop production. *Discov Agric* **2**, 130 (2024). https://doi.org/10.1007/s44279-024-00147-7

Castillo, M., de Guzman, M.J.K., Aberilla, J.M. (2023). Environmental sustainability assessment of banana waste utilization into food packaging and liquid fertilizer. *Sustainable Production and Consumption*, 37: 356-368.

Dewir, Y.H., Chakrabarty, D., Ali, M.B., Hahn, E.J., Paek, K.Y. (2005). Effects of hydroponic solution EC, substrates, PPF and nutrient scheduling on growth and photosynthetic competence during acclimatization of micropropagated Spathiphyllum plantlets. *Plant Growth Regul*., 46: 41–251.

EL-Mously, H., Midani, M., Darwish, E.A. (2023). Date Palm Byproducts in Organic Fertilizers, Compost, Soil Amendment and Coal. In: Date Palm Byproducts: A Springboard for Circular Bio Economy. Materials Horizons: From Nature to Nanomaterials. Springer, Singapore. https://doi.org/10.1007/978-981-99-0475-4_8

El-Ramady, H., Prokisch, J., El-Baily, S., Elasawi, T., Elmahrouk, M., Omara, A. E., Elsakhawy, T., Amer, M., Brevik, E. (2022). Biological Nanofertilizer for Horticultural Crops: A Diagrammatic Mini-Review. *Environment, Biodiversity and Soil Security*, 6: 339-348.

Esechie, H. (1994). Interaction of salinity and temperature on the germination of sorghum. *Journal of Agronomy and Crop Science* 172 (3):194–9.

Fan, X., Wei, Y., Song, D., Zhou, T., Li, R., Su, X., Zhang, T., Cheng, S., Xiao, R. (2025). Biochar enhanced co-composting for peat-free seedling substrate: A win-win solution for sustainable development of modern vegetable industry. *Process Safety and Environmental Protection*, 194: 1504-1514.

Gallegos-Cedillo VM, Nájera C, Signore A, Ochoa J, Gallegos J, Egea-Gilabert C, Gruda NS, Fernández JA. (2024b). Analysis of global research on vegetable seedlings and transplants and their impacts on product quality. *J Sci. Food Agric*., 104(9):4950-4965.

Gallegos-Cedillo, V.M., Nájera, C., Gruda, N.S., Signore, A., Gallegos, J., Rodríguez, R., Ochoa, J., Egea-Gilabert, C., Fernández, J.A. (2024a). An in-depth analysis of sustainable practices in vegetable seedlings nurseries: A review. *Scientia Horticulturae*, 334: 113342.

Gomis, M. P., Pérez-Murcia, M. D., Barber, X., Martínez-Sabater, E., Moral, R., Bustamante, M. Á. (2022). Development and Validation of Alternative Palm-Derived Substrates for Seedling Production. *Agronomy*, 12(6): 1377.

Han, J., Kim, M., Mammadov, Z., Lee, S., Elzinga, E.J., Mammadov, G., Hwang, W., Ro, H.M (2024). Synergistic effect of climate change and water management: Historical and future soil salinity in the Kur-Araz lowland, Azerbaijan. *Sci Total Environ*., 907:167720.

He, X., Miao, Z., Wang, Y., Yang, L., Zhang, Z (2024). Response of soil erosion to climate change and vegetation restoration in the Ganjiang River Basin, China. *Ecological Indicators*, 158: 111429.

Jayaprakash, K.; Osama, A.; Rajagopal, R.; Goyette, B.; Karthikeyan, O.P. (2022). Agriculture Waste Biomass Repurposed into Natural Fibers: A Circular Bioeconomy Perspective. *Bioengineering 9*, 296. https://doi.org/10.3390/bioengineering9070296

Khoshnodifar, Z., Ataei, P., Karimi, H. (2023). Recycling date palm waste for compost production: A study of sustainability behavior of date palm growers. *Environmental and Sustainability Indicators*, 20: 100300.

Li, J., Wu, Y., Feng, X., Hussain, T., Guo, K., Liu, X. (2024). Nonuniform salinity regulate leaf characteristics and improve photosynthesis of cherry tomatoes under high salinity. *Environmental and Experimental Botany*, 217, 105565. https://doi.org/10.1016/j.envexpbot.2023.105565.

Liu, X., Shi, R., Gao, M., He, R., Li, Y. Liu, H. (2023). Growth of tomato and cucumber seedlings under different light environments and their development after transplanting. *Front. Plant Sci.* 14:1164768.

Liu, Z., Si, J., Jia, B., He, X., Zhou, D., Wang, C., Zhu, X., Qin, J., Ndayambaza, B., Bai, X (2024). The dominant influencing factors of desertification and ecological risk changes in Qinghai Area of Qilian Mountains National Park: Climate change or human activity? *J Environ Manage*., 362:121335.

Ma, B., Karimi, M.S., Mohammed, K.S., Shahzadi, I., Dai, J (2024). Nexus between climate change, agricultural output, fertilizer use, agriculture soil emissions: Novel implications in the context of environmental management. *Journal of Cleaner Production*, 450: 141801.

Manai, S., Boulila, A., Silva, A.S., Barbosa-Pereira, L., Sendón, R., Khwaldia, K. (2024). Recovering functional and bioactive compounds from date palm by-products and their application as multi-functional ingredients in food. *Sustainable Chemistry and Pharmacy*, 38, 101475.

Manzoor, M.A., Xu, Y., Lv, Z., Xu, J., Shah, I.H., Sabir, I.A., Wang, Y., Sun, W., Liu, X., Wang, L., Liu, R., Jiu, S., Zhang, C. (2024). Horticulture crop under pressure:

Unraveling the impact of climate change on nutrition and fruit cracking. *J Environ Manage.*, 357:120759.

Maou, S., Meghezzi, A., Grohens, Y., Meftah, Y., Kervoelen, A., Magueresse, A. (2021). Effect of various chemical modifications of date palm fibers (DPFs) on the thermo-physical properties of polyvinyl chloride (PVC)–high-density polyethylene (HDPE) composites. *Industrial Crops and Products*, 171: 113974.

Marschner, P. (2012). Mineral Nutrition of Higher Plants (3rd ed.). Academic Press.

Mimoun, A., Rey, H., Jourdan, C., Banamar, H., Yakoubi, F., Babou, F., Bennaceur, F. (2024). Moderate salinity stimulates root plasticity and growth parameters of date palm seedlings (*Phoenix dactylifera* L.). *Rhizosphere*, 30, 100876. https://doi.org/10.1016/j.rhisph.2024.100876.

Moawad, D.R.M., Moussa, R.R (2023). The effect of using data palm waste fibers in plain concrete mixture by comparing three pre-treatment techniques. *Sci Rep* 13: 12032.

Qaryouti, M., Osman, M., Alharbi, A., Voogt, W., Abdelaziz, M.E. (2023). Using Date Palm Waste as an Alternative for Rockwool: Sweet Pepper Performance under Both Soilless Culture Substrates. Plants (Basel). 13(1):44. doi: 10.3390/plants13010044.

Patel, R.; Patel, A. (2024). Evaluating the impact of climate change on drought risk in semi-arid region using GIS technique. *Results in Engineering*, 21: 101957.

Pathak, H.K., Chauhan, P.K., Seth, C.S., Dubey, G., Upadhyay, S.K. (2024). Mechanistic and future prospects in rhizospheric engineering for agricultural contaminants removal, soil health restoration, and management of climate change stress. *Sci Total Environ.*, 927:172116.

Pohanková, E.P., Hlavinka, K.C., Kersebaum, C., Nendel, A., Rodríguez, J., Balek, M., Dubrovský, A., Gobin, G., Hoogenboom, M., Moriondo, E.J., Olesen, R., Rötter, M., Ruiz-Ramos, V., Shelia, T., Stella, M.P., Hoffmann, J., Takáč, J., Eitzinger, C., Dibari, R., Ferrise, J., Bohuslav, M., Bláhová, Trnka, M. (2024). Expected effects of climate change on the soil organic matter content related to contrasting agricultural management practices based on a crop model ensemble for locations in Czechia. *European Journal of Agronomy*, 156:127165.

Pokluda, R., Ragasová, L.N., Jurica, M., Kalisz, A., Komorowska, M., Niemiec, M., Caruso, G., Gąstoł, M., Sekara, A. (2023). The shaping of onion seedlings performance through substrate formulation and co-inoculation with beneficial microorganism consortia. *Front Plant Sci.*, 14:1222557.

Roehrdanz, M., Greve, T., de Jager, M., Buchwald, R., Wark, M (2019). Co-composted hydrochar substrates as growing media for horticultural crops. *Scientia Horti*., 252: 96-103.

Sayed, K., Syakir, M. I., Othman, A. A., Azhar, B., Tohiran, K. A., & Nobilly, F. (2025). Introducing the RICE framework in paddy-duck farming: a novel approach to enhance the adaptive capacity of paddy farmers among asnaf community in managing the risk of climate change. *Archives of Agronomy and Soil Science*, *71*(1), 1–16. https://doi.org/10.1080/03650340.2025.2465744

Shah, I.H., Manzoor, M.A., Jinhui, W., Li, X., Hameed, M.K., Rehaman, A., Li, P., Zhang, Y., Niu, Q., Chang, L (2024). Comprehensive review: Effects of climate change and greenhouse gases emission relevance to environmental stress on horticultural crops and management. *J Environ Manage*., 351:119978.

Singh, M., Nara, U., Kumar, A., Choudhary, A., Singh, H., Thapa, S. (2021). Salinity tolerance mechanisms and their breeding implications. *Journal of Genetic Engineering and Biotechnology*, 19 (1): 173.

Snedecor, G.W., Cochran, W.G. (1989). Statistical Methods, eight edition. Iowa State University Press, Ames, IA, USA.

Sparks, D.L., Page A.L., Helmke P.A., Loeppert, R.H. (2020). Methods of Soil Analysis, Part 3: Chemical Methods (Vol. 14). New York: John Wiley & Sons

Tang, K. (2024). Agricultural adaptation to the environmental and social consequences of climate change in mixed farming systems: Evidence from North Xinjiang, China. *Agricultural Systems*, 217: 103913.

Turner, A.J., Arzola, C.I., Nunez, G.H (2020). High pH Stress Affects Root Morphology and Nutritional Status of Hydroponically Grown Rhododendron (*Rhododendron* spp.). *Plants* (Basel). 9(8):1019. doi: 10.3390/plants9081019.

Ullah, H., Jan, T. (2024). Germination test, seedling growth, and physiochemical traits are used to screen okra varieties for salt tolerance. *Heliyon*, 10,(13): 34152.

Vandecasteele, B., Debode, J., Willekens, K., Delm, T.V (2018). Recycling of P and K in circular horticulture through compost application in sustainable growing media for fertigated strawberry cultivation. *European Journal of Agronomy*, 96: 131-145.

Vandecasteele, B., Van Waes, C. (2023). Fast screening of total nutrient contents in strawberry leaves and spent growing media using NIRS. *Front Plant Sci*., 14:1210791.

Wahyono, Y., Sasongko, NA., Trench, A., Anda, M., Hadiyanto, H., Aisyah, N., Ariyanti, D (2024). Assessing the impact of climate change and water scarcity of ferronickel production in Indonesia: A life cycle assessment approach. *Sustainable Energy Technologies and Assessments*, 67: 103835.

Wu, Q., Congreves, K.A (2024). Soil health benefits associated with urban horticulture. *Science of The Total Environment*, 912: 168852.

Yadava, U.L (1986). A rapid and nondestructive method to determine chlorophyll in intact leaves. *HortScience*, 21: 1449–1450.

Zahid, I., Nazir, M.H., Javed, M.A. (2024). Extraction of bioactive components from date palm waste, various extraction processes and their applications: A review. *Biomass and Bioenergy*, 190: 107433.