Assessing Food Waste Compost as a Substrate Amendment for Tomato and Watermelon Seedlings

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Abstract. A greenhouse study investigated the influence of various food waste compost (FWC) and potting mix (PM) blends on germination, growth, and nutrient uptake of tomato (*Solanum lycopersicum*) and watermelon (*Citrullus lanatus*) seedlings. Source material for the FWC included food scraps from a commercial partner and wood chips from a local tree service company. The FWC was prepared in a controlled environment and combined with wood chips to create experimental substrates. After composting, substrate blends were prepared by mixing FWC with a peat-based PM to create five volume:volume (v:v) ratios of FWC:PM comprising 100:0 (FWC alone), 75:25, 50:50, 25:75, and 0:100 (PM alone). Tomato and watermelon growth characteristics were assessed during separate trials in the same greenhouse. For each trial, one seed was sown into each cell of a 72-cell tray filled with a corresponding substrate. Plant growth assessments included emergence rates, plant height, stem diameter, biomass, leaf area, and nutrient content. Tomato emergence was reduced to 67% and 77% in 75:25 (FWC:PM) and FWC alone, respectively; however, higher PM substrate blends had 88% to 92% tomato emergence. Watermelon emergence was 62% in FWC alone, whereas all other substrate blends had ≥81% watermelon emergence. The results indicated that substrate mixes with ≤50% (v:v) FWC produced superior seedling emergence, growth, and biomass accumulation. Importantly, no FWC:PM substrate blend produced higher emergence or growth than PM alone. Although leaf properties in FWC:PM mixtures were comparable to or better than those in a commercial PM standard, the observed reduction in uniform and rapid seedling emergence is a more critical factor for commercial production. Thus, FWC may be a suitable material for substrate blends, but it should not serve as a standalone alternative to PM.

Food waste is the fourth largest contributor of municipal solid waste in the United States, accounting for 57.2 million metric tons or 21% of the total solid waste generated (US Environmental Protection Agency 2018). Although the US Environmental Protection Agency Wasted Food Scale prioritizes upstream efforts to prevent food waste, such as producing or buying only food items that are needed (US Environmental Protection Agency 2024), some amount of downstream food waste will still be produced. In the United States, 31% of the food supply, amounting to 60 billion kg, is wasted at retail and consumer levels either because of culling and spillage at the retail level or because of being discarded by consumers as plate scraps or expired and spoiled items (Buzby et al. 2014). From the perspective of a specialty crop producer, market prices and food quality determine whether a crop can be sold profitably or will become food waste (Johnson et al. 2019). Fortunately, composting is an effective method of recapturing food waste at any stage and repurposing solid waste into materials suitable for use as soil amendments that add organic matter or soil nutrients (Ozores-Hampton 2017; Ozores-Hampton et al. 1994). However, the relatively low nutrient density of many compost materials makes it most appropriate as a soil amendment for small farms or certified organic farms (Gaskell and Hartz 2011) and should be complemented with other fertility sources such as cover crops and organic or inorganic fertilizers (Ozores-Hampton 2012). In soilless production of organic vegetables, compost is considered a substitute for peatmoss or other substrates rather than a fertility source (Rogers 2017). In container production, bell pepper (*Capsicum annuum*) and marigold (*Tagetes patula*) transplants grow well in substrate blends with compost substituted for the standard peat-perlite commercial substrate; however, compost sources had disparate effects on plant growth responses (Hummel et al. 2014). For example, elevated sodium (Na) ion levels in compost derived from food waste is well-documented, and these Na levels can be influenced by the food waste type, bulking agent type, and ratio of food waste to bulking agent (Lee et al. 2019, 2020; Yang et al. 2021). As reported by Lee et al. (2016), food waste compost (FWC) application to soil often results in both increased electrical conductivity (EC) and pH, which is a direct effect of the elevated Na ion levels in the FWC. These higher Na levels can also impact both the composition and activity of the soil microbial community (Lee et al. 2019). Overall, compost can serve as a suitable substrate for seedling propagation because it typically has a suitable bulk density and can be blended with other commercial substrates (Dekalb et al. 2014; Díaz-Pérez and Camacho-Ferre 2010; Herring et al. 2018).

Although compost has many utilities from container to field production, compost varies in its chemical and physical characteristics depending on the source material or feedstock (Costello et al. 2019; Sikora and Szmidt 2001). Carbon sources from many industries, such as grape (*Vitis vinifera*) fruit waste (El-Mahrouk et al. 2017), mushroom compost (Fidanza et al. 2010), swine lagoon compost (Herring et al. 2018; Noah et al. 2022), and others such as paper fiber, food waste, or gelatin

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manufacturing waste (Long et al. 2017), have been composted and tested for their utility as substrates or soil amendments. Because compost is so variable, it is critical to understand and test the physical and chemical properties to determine its suitability as a soil amendment or substrate for specialty crop production (Gaskell and Hartz 2011; Ozores-Hampton 2017). Regulatory agencies treat compost as a municipal solid waste; therefore, testing is only required for potential environmental hazards of the material rather than its utility as an agricultural product. In Arkansas, the Department of Environmental Quality stipulates that compost must be tested for contamination with pathogens or heavy (trace) metals (Arkansas Department of Environmental Quality 2007), but there is no requirement for nutrient testing. Fortunately, tomatoes (*Lycopersicon esculentum*) and squash (*Cucurbita maxima*) grown in composted materials did not bio-accumulate harmful trace elements, despite their presence in the media (Ozores-Hampton et al. 1997). Additional federal regulations outlined in the Final Rule on Produce Safety (US Food and Drug Administration 2015) aim to address potential food safety risks associated with the use of both treated and untreated biological soil amendments of animal origin during the production of crops that are generally consumed raw; in this regard, "farms can use any treatment process or processes that have been validated to meet the relevant microbial standard in [21 CFR] § 112.55 without the need to test the end products." Thus, regulatory agencies are generally not concerned with the suitability of compost as a useful soil amendment or substrate for specialty crop production regarding nutrient composition (Li et al. 2010).

The present study aimed to characterize the nutrient status of FWC and the suitability of the material as a substrate for tomato and watermelon (*Citrullus lanatus*) seedling propagation. Tomatoes and watermelons have different seed sizes and emergence patterns; therefore, an assessment of each species will determine the suitability of a given substrate blend for use in seedling propagation. The objectives of this study were to assess each compost–peat substrate blend to determine the substrate nutrient composition, seedling emergence and plant growth response of tomato and watermelon seedlings, and nutrient concentration in plant tissues of emerged tomato and watermelon seedlings.

Materials and methods

In-vessel composting of food waste was conducted within a climate-controlled greenhouse environment at Arkansas System Division of Agriculture Milo J. Shult Agricultural Research and Extension Center in Fayetteville, AR, USA (lat. 36.09962°N, long. 94.17194°W). The food waste was sourced from a local enterprise based in Benton County (Food Loops, Rogers, AR, USA) dedicated to the development of efficient and consistent in-vessel composting technologies for organic wastes. This company collects food waste from various restaurants and institutions within the Northwest Arkansas region and transports it to their facility in Rogers, AR, USA, where it undergoes a grinding process to achieve a particle size of 3 to 4 cm. The composition of the food waste varies per collection, but it typically includes a mixture of vegetables, fruits, grains, legumes, and animal-based proteins. Wood chips, which are used as a bulking agent, were supplied by Monster Tree Service (Springdale, AR, USA).

Composting was performed in a mix of food waste and wood chips in an 80:20 (v:v) ratio initially created by layering food waste and bulking agent inside each 208-L vessel to a capacity equating to 70% of the total volume. Barrels were steel drums with food-grade lining that were maintained on their sides during composting. Barrels were not air-tight, but they had duplicate sets of four 1-cm holes covered with mesh screen, were rotated daily, and were periodically opened to aerate the materials. The drums were maintained under controlled conditions for 50 d. Temperature increased rapidly to achieve thermophilic conditions (>45 °C) in 6 to 7 d. After peaking at temperatures between 58 and 62 °C between days 10 and 12, the temperature declined slowly until remining steady at 28 to 30 °C after day 44. Compost was stored in-vessel for further curing for approximately 16 months before the start of this greenhouse study.

Finished FWC was used in the preparation of five experimental blends to evaluate their effects on the growth of tomato and watermelon seedlings. Composted material was coarsely screened through a 1.27-cm screen before mixing as woody fragments in the composted material were too large to serve as a seedling substrate. Substrate blends were prepared by mixing screened FWC with a peatmoss-based potting mix (PM) (Proline C/GP; Jolly Gardener, Poland, ME, USA) at five v:v ratios of FWC to PM comprising 0:100 (PM alone), 25:75, 50:50, 75:100, and 100:0 (FWC alone) and homogenizing in a 113-L concrete mixer (Model SGY-CM1; Kobalt Tools, Mooresville, NC, USA). Substrate blends were prepared separately using compost from separate vessels for experimental runs 1 and 2 in this trial. Within each experimental run, a bulk volume of each substrate blend was prepared and then placed into corresponding 72-cell square plug trays (cell height, 5.7 cm; cell width, 3.9 cm; 720469C plug trays; T.O. Plastics, Clearwater, MN, USA) approximately 1 h before sowing seed across all replications for a given treatment. Table 1 summarizes the nutrient content, pH, EC, and nutrient analysis of FWC:PM blends for each experimental run.

Greenhouse trials were initiated 21 Apr 2021 and repeated 16 Jun 2021 at the University of Arkansas System Division of Agriculture Milo J. Shult Agricultural Research and Extension Center in Fayetteville, AR, USA. Concurrent trials were conducted for tomato and watermelon using the same greenhouse for each species on separate propagation benches. The greenhouse was a Quonset-style structure with a double layer of inflated clear greenhouse plastic (GT4 6 mL; Stuppy Inc., North Kansas City, MO, USA) with two exhaust fans and an evaporative cooling wall outfitted with 10-cm evaporative cooling pads (Greenhouse Megastore, Danville, IL, USA). Trials were conducted during the summer; therefore, supplemental lighting and heating were not used. Temperature and relative humidity were logged every hour over the course of each experimental run (Table 2) using an Onset HOBO logger (Model MX1101; Onset Computer Corporation, Bourne, MA, USA) positioned 15.2 cm above the 72-cell plug trays in the experiment.

For tomato ('Big Beef') and watermelon ('Crimson Sweet') trials, one seed was sown per cell into 72-cell square plug trays containing the substrate blend.

Table 1. Media analysis of substrate blends of food waste compost (FWC) and peat-based potting mix (PM) from experimental runs 1 and 2 of greenhouse trials located at the Milo J. Shult Research and Experiment Station in Fayetteville, AR, USA.[i]

							Saturation extract analysis ($mg \cdot mL^{-1}$)										
Experimental run	FWC:PM[ii] (%, v:v)	C (%)	N (%)	C:N	pH	EC ($dS \cdot m^{-1}$)	NO_3-N	P	K	Ca	Mg	S	Na	Fe	Mn	Zn	Cu	B
1	100:0	39.4	2.81	14.0	6.9	7.58	137	47.6	1052	25.6	10.6	61.2	888	4.7	0.17	0.80	0.16	0.50
1	75:25	35.2	2.33	15.1	6.7	6.24	147	38.6	793	29.9	18.2	81.1	651	2.5	0.18	0.90	0.09	0.38
1	50:50	38.2	1.43	26.7	6.5	3.36	n.a.[iii]	24.5	418	26.2	20.1	90.5	316	1.7	0.19	0.99	0.06	0.29
1	25:75	34.9	1.26	27.7	6.0	2.67	126	20.1	278	55.4	48.3	111.0	178	1.6	0.34	1.17	0.04	0.23
1	0:100	35.4	1.05	33.7	5.7	1.42	112	12.7	108	75.6	68.8	103.0	22	1.6	0.51	0.85	0.08	0.16
2	100:0	35.5	2.87	12.0	7.5	6.90	126	27.8	1167	59.3	13.7	58.7	592	n.a.	0.33	0.46	0.17	0.40
2	75:25	32.3	2.10	15.0	7.3	6.28	146	10.0	942	45.6	18.2	90.0	552	2.9	0.22	0.34	0.09	0.21
2	50:50	33.2	1.57	21.0	6.6	3.27	134	9.6	457	61.3	37.4	84.7	212	1.2	0.31	0.93	0.04	0.15
2	25:75	30.1	1.28	24.0	6.4	2.36	86	9.7	311	48.8	37.0	71.6	134	1.1	0.33	0.84	0.04	0.14
2	0:100	32.2	1.03	31.0	5.5	1.63	87	9.1	113	78.9	48.5	110.0	30	1.3	0.56	0.82	0.05	0.11

[i] A media analysis was conducted at the Fayetteville Agricultural Diagnostic Laboratory in Fayetteville, AR, USA. Analytical methods included a Mehlich-3 protocol for saturation extract analysis for nutrients, 1:2 mixture:water (w/v) ratio measurement for pH, electrical conductivity (EC), and combustion analysis of the total C and N concentrations.

[ii] FWC and PM substrates were prepared on a volume:volume basis.

[iii] Two values were missing from the substrate analysis and are not available for disclosure and are reported as n.a. (not available).

B = boron; C = carbon; Ca = calcium; Cu = copper; Fe = iron; K = potassium; Mg = magnesium; Mn = manganese; N = nitrogen; Na = sodium; P = phosphorus; S = sodium; Zn = zinc.

Tomato seeds were sown to a depth of 0.6 cm, and larger-seeded watermelons were sown to a depth of 1.9 cm. Sown seeds were loosely covered with the respective substrate blend and watered in with a water breaker nozzle (1000PL; Dramm Corporation, Manitowoc, WI, USA) to provide sufficient and uniform initial moisture for seeds to imbibe and initiate germination. Over the course of the experiment, watering needs differed among treatments because emerged seedlings required heavier watering than seeds that had not yet emerged, and substrate blends had varying levels of water-holding capacity. Therefore, watering was conducted as needed according to a watering scale (Healy 2020) based on visible characteristics of the substrate and free release of moisture. To minimize substrate displacement, all flats were watered by hand using a Fogg-It mist nozzle (3.78 L per minute; Fogg-It Nozzle Co. Inc., Belmont, CA, USA).

Plant growth characteristics for watermelons and tomatoes were assessed at 14 d and 21 d after sowing, respectively. This timing coincided with seedlings in the best-performing substrate blend reaching a growth stage suitable for hardening-off before field transplanting. Seedling emergence was calculated as a percentage of the sown seed in each 72-cell tray that germinated and emerged:

$$\textit{Seedling emergence} = \left(\frac{e}{72}\right) \times 100$$

where e represents the number of emerged seedlings with cotyledons expanded. Plant growth characteristics, including plant height, stem diameter, and leaf number, of 16 representative plants per experimental unit (i.e., 72-cell plug tray) were measured. Plant growth responses of 16 individual plants were collected and averaged for each treatment before the statistical analysis. Plant height was measured from the substrate line to the apical meristem of each plant. Leaf number included all fully expanded leaves. Stem diameters were recorded as two perpendicular measurements 2.5 cm above the substrate line using an electronic digital caliper (CID Bio-Science Inc., Camas, WA, USA) and averaged for each plant.

Leaf area, leaf biomass, total biomass, and nutrient status were assessed using 16 destructively harvested plants at 14 d and 21 d after sowing for

Table 2. Ambient temperature and relative humidity during 21-d experimental runs 1 and 2 of greenhouse trials assessing germination and plant growth response of tomato and watermelon in substrate blends of food waste compost and commercial potting mix. The greenhouse was located at the Milo J. Shult Research and Experiment Station in Fayetteville, AR, USA.[i]

	Temp (°C)			Relative humidity (%)		
	Minimum	Maximum	Avg	Minimum	Maximum	Avg
Experimental run 1[ii]	20.0	40.8	28.3	21.5	98.9	57.3
Experimental run 2	19.7	36.5	27.4	42.6	100	84.3

[i] Temperature and relative humidity were logged every hour over the course of each experimental run using an Onset HOBO logger (Model MX1101; Onset Computer Corporation, Bourne, MA, USA) positioned 15.2 cm above the 72-cell plug trays in the experiment.

[ii] Experimental runs 1 and 2 occurred from 21 Apr 2021 to 12 May 2021 and from 16 Jun 2021 to 7 Jul 2021, respectively.

watermelon and tomato, respectively. Leaf area was measured by detaching leaves and feeding them into a conveyor-driven leaf area scanner (LI-3100C; LI-COR Environmental, Lincoln, NE, USA). Plant tissues were dried in an oven for 72 h at 60 °C in a forced air incubator (Catalogue No. 10029-048; VWR International, Radnor, PA, USA) and ground using a benchtop mill grinder with a 1-mm screen (Cyclone Sample Mill; UDY Corporation, Fort Collins, CO, USA) before submission for nutrient analysis at the Fayetteville Agricultural Diagnostic Laboratory (Fayetteville, AR, USA). The Mehlich-3 method was applied for nutrient extraction (Mehlich 1984; Zhang et al. 2014). Total carbon and nitrogen were measured using a combustion method described by Provin (2014). Leaf biomass and total biomass were determined by cutting seedlings at the substrate line, detaching leaves, recording the biomass for each sample using the same protocol for the plant nutrient analysis (72 h at 60 °C), and using an analytical laboratory balance to obtain weights (BP61S; Sartorius, Goettingen, Germany).

Additional plant growth characteristics, including the specific leaf area [SLA, the ratio of leaf area (cm^2) to leaf biomass (g)], leaf area to dry matter ratio [LADMR, the ratio of leaf area (cm^2) to total biomass (g)], and etiolating ratio (the ratio of plant height to stem diameter converted to the same unit of measure) were calculated. The chlorophyll content of the youngest fully expanded leaf of 16 plants was measured for each treatment using a soil plant analysis development (SPAD) chlorophyll meter (SPAD-502Plus; Konica Minolta, Ramsey, NE, USA).

All data were subject to an analysis of variance (ANOVA) as a randomized complete block design using the GLIMMIX procedure in SAS (version 9.4; SAS Institute Inc., Cary, NC, USA). An analysis was conducted and reported separately for tomato and watermelon trials. The main effect of the substrate blend was analyzed as a fixed effect, while the experimental run and block (nested with the experimental run) were treated as random effects. Studentized residual plots were assessed for each response variable to ensure homoscedasticity, and means were separated using Tukey's honestly significant difference (HSD) multiple comparisons adjustment ($\alpha = 0.05$). Several substrates resulted in ≥99% watermelon germination, which violated the ANOVA assumption of equal variance. In this case, a nonparametric Kruskal-Wallis test was conducted using the NPAR1WAY procedure in SAS version 9.4, and pairwise comparisons were assessed using the Dwass, Steel, Critchlow-Fligner method for multiple comparisons ($\alpha = 0.05$). Statistical groupings were identical for the final tomato germination percentage whether using GLIMMIX or NPAR1WAY procedures; therefore, values in the tables reflect the GLIMMIX output.

Results

Substrate chemical properties. Across both experimental runs, substrate blends with higher concentrations of FWC contained higher nitrogen (N), NO_3, phosphorus (P), potassium (K), copper (Cu), and boron (B) concentrations along with higher pH and EC (Table 1). Thus, increasing concentrations of PM coincided with decreases in those specific nutrients and decreases in pH and EC. In run 1 and run 2, FWC had pH of 6.9 and 7.5, respectively, and was generally more alkaline than PM, which had pH of 5.7 and 5.5 in run 1 and run 2, respectively (Table 1). In contrast, substrate blends with higher concentrations of PM had higher C:N ratios and higher concentrations of calcium (Ca), magnesium (Mg), sodium (S), manganese (Mn), and zinc (Zn). A minor decrease in carbon (C) was observed as PM represented a larger portion of substrate blends; however, the disparity was more prominent when C was compared with N in the C:N ratio. Disparities in the Na concentration and EC value among substrate compositions were dramatic. In experimental run 1 and run 2, FWC alone had Na concentrations of 888 and 592 mg·mL^{-1}, respectively. These Na concentrations in FWC were substantially higher than those in PM alone, with Na levels of 22 mg·mL^{-1} and 30 mg·mL^{-1} in experimental run 1 and run 2, respectively.

Seedling emergence. Seedling emergence was reduced for both tomato and watermelon when sown into FWC alone (Tables 3 and 4). In the tomato trial, seedling emergence was 91%, 92%, and 88% for FWC:PM substrate blends of 50:50, 25:75, and 0:100 (PM alone), respectively (Table 3). Tomato emergence was reduced in FWC alone and in the 75:25 (FWC:PM) blend with only 67% and 77% of tomato seeds emerging at 21 d after sowing, respectively. In the watermelon trial, 62% of seed emerged in FWC alone; this reduction was relative to all other substrate blends ($P < 0.001$) (Table 4). Watermelon emergence was ≥99% for substrate blends containing ≥50% (v:v) PM; however, means separation determined that these values did not differ from the 82% emergence of the 75:25 (FWC:PM) substrate blend. Watermelon emergence was reduced in FWC alone, whereas tomato emergence was reduced in FWC alone and in 75:25 (FWC:PM) substrate blends.

Seedling growth characteristics. Tomato seedlings exhibited reduced height in substrate blends with the highest concentrations of FWC (Table 3). Tomato heights were 8.7 cm and 12.2 cm in FWC alone and 75:25 (FWC:PM) substrate blend, respectively.

Table 3. Seedling emergence, height, stem diameter, and etiolating ratio of tomato seedlings (21 d after sowing) in response to prepared blends of food waste compost (FWC) and peatmoss-based potting mix (PM) in 2021 greenhouse trials conducted in Fayetteville, AR, USA. The germination rate was calculated as a percentage of seeds to germinate and emerge with fully expanded cotyledons from each 72-cell plug tray. Seedling height, stem diameter, and etiolating ratio were collected from or calculated based on 16 plants per experimental unit from four replications in each of the two experimental runs.[i]

Substrate FWC:PM[ii] (%, v:v)	Emergence (%)[iii]	Seedling growth parameters		
		Height (cm)[iv]	Stem diam (mm)[v]	Etiolating ratio[vi]
100:0	67 b	8.7 c	1.85 b	47 c
75:25	77 b	12.2 b	2.32 a	56 bc
50:50	91 a	16.5 a	2.73 a	65 ab
25:75	92 a	17.9 a	2.65 a	74 a
0:100	88 a	15.9 a	2.46 a	68 ab
P value	<0.001	<0.001	<0.001	<0.001

[i] Means were separated using Tukey's honestly significant difference at a significance level of $\alpha = 0.05$. Means followed by the same letter are not significantly different.

[ii] FWC and PM substrates were prepared on a volume:volume basis.

[iii] Germination rate was calculated as a percentage of seeds to successfully germinate and emerge within each 72-cell tray and expressed as a percentage of a total of 72 seeds sown per tray.

[iv] Plant heights were measured from the substrate to the apical meristem.

[vi] Etiolating ratio is the ratio of the plant height (cm) to the stem diameter (cm).

All substrate blends of ≥50% (v:v) PM produced tomato seedlings of a similar height, ranging from 15.9 to 17.9 cm. The tomato stem diameter was 1.85 mm in FWC alone, which was significantly reduced relative to all other substrate blends. The etiolating ratio of tomato seedlings was lowest in FWC substrate and 75:25 FWC:PM substrate blend, likely because of reduced heights relative to other treatments (Table 3).

Watermelon seedling height was reduced in substrates with higher concentrations of FWC (Table 4). Watermelon heights were 7.0 cm and 8.9 cm in FWC alone and 75:25 (FWC:PM) substrate blend, respectively. Watermelon heights were similar in substrates comprising ≥50% (v:v) PM and ranged from 10.8 to 12.3 cm. Watermelon stem diameters were 2.71 mm and 3.26 mm in FWC alone and 75:25 (FWC:PM) substrate blend, respectively, which were narrower than those of all other substrates comprising ≥50% (v:v) PM substrate blends (3.89–4.11 cm). Etiolating ratios of watermelon were determined to be significant (*P* = 0.049); however, a multiple comparison adjustment by Tukey's HSD determined that no watermelon etiolating ratios were statistically different (Table 4).

Dry matter production. Both tomato and watermelon seedlings exhibited reduced leaf biomass and total biomass when sown into FWC alone, relative to other substrate blends (Tables 5 and 6). In FWC alone, tomato seedlings produced 0.06 g and 0.09 g of leaf and total biomass, respectively (Table 5). This was a substantial reduction relative to tomatoes in substrates with ≥50% (v:v) PM, which produced 0.19 to 0.21 g and 0.31 to 0.37 g of leaf and total biomass, respectively. Tomatoes in 75:25 (FWC:PM) produced intermediate leaf biomass (0.14 g) and total biomass (0.22 g). In FWC alone, watermelon seedlings produced 0.03 g and 0.08 g of leaf and total biomass, respectively (Table 6). An increase in PM to 75:25 (FWC:PM) substrate caused watermelon seedlings to produce 0.08 g and 0.16 g of leaf and total biomass, respectively. Similar to tomatoes, the greatest biomass was produced by watermelon seedlings grown in substrates with ≥50% (v:v) PM, which produced 0.12 g to 0.15 g and 0.24 g to 0.31 g of leaf biomass and total biomass, respectively.

Leaf indices. Seedlings of tomato and watermelon exhibited reduced leaf number and leaf area in FWC alone, relative to PM alone and other FWC:PM substrate blends (Tables 5 and 6). Reductions in leaf area and leaf number coincided with delayed or reduced emergence (Tables 3 and 4). At 21 d after sowing, tomatoes in FWC alone had the fewest leaves (2.7 leaves) and the smallest leaf area (25.3 cm^2) of all substrates (Table 5). Tomato leaf number (4.0–4.2 leaves) and leaf area (73.8–74.2 cm^2) in the substrate blends of 50:50 and 25:75 FWC:PM exceeded the 3.8 leaves and 54.1 cm^2 leaf area in PM alone; however, leaf number between the 50:50 FWC:PM blend and PM alone were not different (Table 5). The SPAD readings were lowest (28.9) in PM alone and greater in 75:25 FWC:PM (39.5) and 50:50 FWC:PM (37.5) than in PM alone (Table 5). Tomato SLA was highest in FWC

Table 4. Seedling emergence, height, stem diameter, and etiolating ratio of watermelon seedlings (14 d after sowing) in response to prepared blends of food waste compost (FWC) and peatmoss-based potting mix (PM) in 2021 greenhouse trials conducted in Fayetteville, AR, USA. The germination rate was calculated as a percentage of seeds to germinate and emerge with fully expanded cotyledons from each 72-cell plug tray. Seedling height, stem diameter, and etiolating ratio were collected from or calculated based on 16 plants per experimental unit from four replications in each of the two experimental runs.

Substrate FWC:PM[ii] (%, v:v)	Emergence (%)[iii]	Seedling growth parameters[i]		
		Height (cm)[iv]	Stem diam (mm)[v]	Etiolating ratio[vi]
100:0	62 b	7.0 c	2.71 c	24
75:25	81 b	8.9 bc	3.26 b	27
50:50	99 a	10.8 ab	3.89 a	28
25:75	99 a	12.3 a	4.11 a	30
0:100	100 a	11.9 a	4.04 a	30
P value	<0.001	<0.001	<0.001	0.049

[i] Means were separated using Tukey's honestly significant difference at a significance level of $\alpha = 0.05$. Means followed by the same letter are not significantly different. Means lacking letters with $P < 0.05$ indicated that Tukey's multiple comparison adjustment detected no significant differences between means.

[ii] FWC and PM substrates were prepared on a volume:volume basis.

[iii] Emergence was calculated as a percentage of seeds to successfully germinate and emerge within each 72-cell tray and expressed as a percentage of a total of 72 seeds sown per tray. Emergence was assessed using a Kruskal-Wallis test, and means separation was achieved using pairwise comparisons using the Dwass, Steel, Critchlow-Fligner multiple comparisons method. Means followed by the same letter are not significantly different.

[iv] Plant heights were measured from the substrate to the apical meristem.

[vi] Etiolating ratio is the ratio of plant height (cm) to stem diameter (cm).

Table 5. Leaf biomass, total biomass, leaf area, specific leaf area, and leaf area-to-dry matter ratio (LADMR) obtained from the destructive harvest (21 d after sowing) of tomato seedlings in response to prepared substrate blends of food waste compost (FWC) and peatmoss-based potting mix (PM) in 2021 greenhouse trials conducted in Fayetteville, AR, USA. Measurements were collected or calculated from 16 plants per 72-cell plug tray from four replications in each of the two experimental runs.[i]

Substrate FWC:PM[ii] (%, v:v)	Dry matter production (g)		Leaf indices				
	Leaf biomass	Total biomass	SPAD chlorophyll content[iii]	Leaves (n)	Leaf area (cm^2)	Specific leaf area (cm^2·g^{-1})[iv]	LADMR[v]
100:0	0.06 c	0.09 c	34.8 b	2.7 c	25.3 c	454 a	272.1 a
75:25	0.14 b	0.22 b	39.5 a	3.8 b	52.9 b	382 b	237.1 b
50:50	0.19 a	0.31 a	37.5 ab	4.0 ab	73.8 a	392 b	235.8 b
25:75	0.21 a	0.37 a	35.0 b	4.2 a	74.2 a	357 b	203.0 c
0:100	0.19 a	0.35 a	28.9 c	3.8 b	54.1 b	289 c	165.2 d
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

[i] Means were separated using Tukey's honestly significant difference at a significance level of $\alpha = 0.05$. Means followed by the same letter are not significantly different.

[ii] FWC and PM substrates were prepared on a volume:volume basis.

[iii] Soil plant analysis development (SPAD) meter measures the absorbances of a leaf in the red and near-infrared regions to calculate a numerical SPAD value proportional to the amount of chlorophyll present in the leaf (Konica Minolta 2009). It is a unitless measurement.

[iv] Specific leaf area is the ratio of the leaf area (cm) to the dry leaf biomass (g).

[v] LADMR is the ratio of leaf area (cm) to total dry biomass (g).

alone (454 cm·g^{-1}) and lowest in PM alone (289 cm·g^{-1}). Tomato LADMR followed a similar pattern, with tomato seedlings measuring 272 and 165 cm·g^{-1} in FWC alone and PM alone, respectively.

At 14 d after sowing, watermelon in FWC alone had the fewest leaves (1.5) and smallest leaf area (13.4 cm^2) of all substrates (Table 6). Watermelon leaf number was consistent in all treatments other than FWC alone, and leaf area was greatest in substrates containing 50:50 (45.0 cm^2) and 25:75 (50.3 cm^2) FWC:PM. A large amount of overlap was observed in leaf chlorophyll content from substrate blends, but SPAD readings were greater in FWC alone (45.4) compared with that in PM alone (37.2). Watermelon SLA was greater in substrate blends with ≥50% (v:v) FWC (342–415 cm·g^{-1}) compared with that in PM alone (270 cm·g^{-1}). It is worth noting that the exceedingly small tomato and watermelon leaf biomass and leaf area from the FWC alone substrates (Tables 5 and 6) may have limited the utility of comparisons of SLA and LADMR.

Plant nutrient concentrations. Substrate had an effect on tomato seedling tissue concentrations of N, P, K, Ca, Mg, S, Na, and Mn, but no significant effect of substrate on Fe, Zn, and B tissue concentrations was observed (Table 7). According to Tukey's HSD, substrate blends containing fractions of both PM and FWC fell into overlapping statistical categories for all nutrients that were affected by substrate, with the exception of P. The overlapping statistical categories of the substrate blends indicate that FWC alone and PM alone were distinct from each other regarding nutrient concentrations. The tomato plant N concentration was 2.4% in PM alone, which was lower than that in FWC alone and 75:25 (FWC:PM), which each contained 4.0% N (Table 7). The tomato plant K concentration only differed between FWC alone and PM alone, which contained 8.5% and 4.5% K, respectively. In general, the plant nutrient concentrations aligned with the nutrient content of the corresponding substrate blend, with substrates containing higher concentrations of a particular nutrient producing seedlings with increased concentrations of that nutrient

Table 6. Leaf biomass, total biomass, leaf area, specific leaf area, leaf area-to-dry matter ratio (LADMR) obtained from the destructive harvest (14 d after sowing) of watermelon seedlings in response to prepared substrate blends of food waste compost (FWC) and peatmoss-based potting mix (PM) in 2021 greenhouse trials conducted in Fayetteville, AR, USA. Measurements were collected from or calculated based on 16 plants per 72-cell plug tray from four replications in each of the two experimental runs.[i]

Substrate FWC:PM[ii] (%, v:v)	Dry matter production (g)		Leaf indices				
	Leaf biomass	Total biomass	SPAD chlorophyll content[iii]	Leaves (n)	Leaf area (cm^2)	Specific leaf area (cm^2·g^{-1})[iv]	LADMR[v]
100:0	0.03 c	0.08 d	45.4 a	1.5 b	13.4 c	415 a	149.9 bc
75:25	0.08 b	0.16 c	43.0 ab	2.5 a	28.9 b	357 ab	182.1 ab
50:50	0.12 a	0.24 b	42.0 ab	2.9 a	45.0 a	372 ab	189.6 a
25:75	0.15 a	0.29 a	40.1 ab	2.9 a	50.3 a	342 b	173.2 ab
0:100	0.13 a	0.31 a	37.2 b	2.5 a	36.1 b	270 c	115.1 c
P value	<0.001	<0.001	0.004	<0.001	<0.001	<0.001	<0.001

[i] Means were separated using Tukey's honestly significant difference at a significance level of $\alpha = 0.05$. Means followed by the same letter are not significantly different.

[ii] FWC and PM substrates were prepared on a volume:volume basis.

[iii] Soil plant analysis development (SPAD) meter measures the absorbances of a leaf in the red and near-infrared regions to calculate a numerical SPAD value proportional to the amount of chlorophyll present in the leaf (Konica Minolta 2009). It is a unitless measurement.

[iv] Specific leaf area is the ratio of leaf area (cm) to dry leaf biomass (g).

[v] LADMR is the ratio of leaf area (cm) to total dry biomass (g).

Table 7. Plant tissue concentrations of tomato seedlings (21 d after sowing) in response to prepared blends of food waste compost (FWC) and peatmoss-based potting mix (PM) in 2021 greenhouse trials conducted in Fayetteville, AR, USA. Tissue samples were collected as bulk samples of 16 seedlings of each treatment replication, ground to 1.0 mm, and submitted to the Fayetteville Agricultural Diagnostic Laboratory for analysis.[i]

Substrate FWC:PM[iv] (%, v:v)	Plant tissue nutrient concn (%)[ii]						Plant tissue nutrient concn (mg·kg^{-1})[iii]				
	N	P	K	Ca	Mg	S	Na	Fe	Mn	Zn	B
100:0	4.0 a	0.45 abc	8.5 a	0.8 b	0.37 b	0.28 b	7297 a	146	17 b	65	29
75:25	4.0 a	0.52 a	6.9 ab	1.5 a	0.75 a	0.29 b	4237 ab	138	46 b	75	28
50:50	3.6 ab	0.51 ab	6.3 ab	1.5 a	0.78 a	0.30 b	3298 bc	175	52 b	74	29
25:75	3.2 ab	0.41 bc	6.5 ab	1.2 ab	0.64 ab	0.30 b	2398 bc	112	54 b	66	29
0:100	2.4 b	0.38 c	4.5 b	1.6 a	0.94 a	0.36 a	682 c	220	106 a	61	28
P value	0.004	<0.001	0.003	<0.001	<0.001	0.002	<0.001	0.103	<0.001	0.168	0.972

[i] Means were separated using Tukey's honestly significant difference at a significance level of $\alpha = 0.05$. Means followed by the same letter are not significantly different.

[ii] Nutrients are reported as a percent of the total mass of the ground plant tissue sample.

[iii] Nutrients are reported as mg of the nutrient per kg of the dry plant tissue.

[iv] FWC and PM substrates were prepared on a volume:volume basis.

B = boron; Ca = calcium; Fe = iron; K = potassium; Mg = magnesium; Mn = manganese; N = nitrogen; Na = sodium; P = phosphorus; S = sulfur; Zn = zinc.

(Tables 2 and 7). Accumulation of Na was observed in tomato seedlings in substrates with high concentrations of FWC. Tomatoes grown in FWC alone and 75:25 (FWC:PM) contained Na at 7297 mg·kg^{-1} and 4237 mg·kg^{-1}, respectively, representing as much as a 10-fold increase relative to the Na concentration of 682 mg·kg^{-1} in PM alone (Table 7).

Substrate had an effect on watermelon seedling tissue concentrations of N, P, K, Ca, Mg, Na, and B, but no significant effect of substrate on S, Fe, Mn, and Zn concentrations was observed (Table 8). Watermelon plant N concentrations were 2.0% and 2.4% in PM alone and 25:75 (FWC:PM), respectively, and were lower than that of the substrate blends containing ≥50% (v:v) FWC, which produced watermelon with tissue N concentrations of 3.6% to 3.8% (Table 8). Watermelon plant K concentrations were 4.4% and 5.2% in PM alone and 25:75 (FWC:PM), respectively. Tissue K concentrations were higher in substrates containing ≥50% (v:v) FWC than those in the PM alone, with plant tissue K concentrations ranging from 7.0% to 7.6%. The concentration of Na in watermelon tissue was 6798 mg·kg^{-1} when grown in FWC alone. The FWC alone substrate had a tissue Na concentration that differed from those in 25:75 (FWC:PM) substrate and PM alone, which were 2295 mg·kg^{-1} and 2014 mg·kg^{-1}, respectively. Similar to tomato seedlings, watermelon nutrient concentrations aligned with the nutrient content of the corresponding substrate blend, meaning that substrates with higher concentrations of a nutrient produced seedlings with increased concentrations of that same nutrient (Tables 1 and 8). The lone exception to this trend was observed in the B concentration. Watermelon seedlings grown in FWC alone contained 28 mg·kg^{-1} of B, whereas those grown in a 25:75 (FWC:PM) substrate had 35 mg·kg^{-1}. Although this difference was statistically significant, it is likely negligible in practical terms. Substrate saturation extract values ranged from 0.50 to 0.11 mg·mL^{-1}, and B concentrations in watermelon and tomato were narrowly distributed, ranging from 28 to 35 mg·kg^{-1} and 28 to 29 mg·kg^{-1}, respectively.

If we assume that this variation in B levels has practical significance, then it is likely attributed to differences in pH. Soil pH plays a key role in the distribution of B between the soil solution and its organic and mineral fractions (Hrmova et al. 2020; Vera-Maldonado et al. 2024). However, B availability is further influenced by a variety of soil physicochemical properties, including texture, moisture, clay

Table 8. Plant tissue concentrations of watermelon seedlings (14 d after sowing) in response to prepared blends of food waste compost (FWC) and peatmoss-based potting mix (PM) in 2021 greenhouse trials conducted in Fayetteville, AR, USA. Tissue samples were collected as bulk samples of 16 seedlings of each treatment replication, ground to 1.0 mm, and submitted to the Fayetteville Agricultural Diagnostic Laboratory for analysis.[i]

Substrate FWC:PM[ii] (%, v:v)[iv]	Plant tissue nutrient concn (%)[ii]						Plant tissue nutrient concn (mg·kg^{-1})[iii]				
	N	P	K	Ca	Mg	S	Na	Fe	Mn	Zn	B
100:0	3.8 a	0.52 abc	7.6 a	0.7 c	0.43 c	0.39	6798 a	226	71	68	28 b
75:25	3.6 a	0.59 a	7.3 a	1.1 bc	0.57 bc	0.42	4030 ab	164	50	76	29 ab
50:50	3.7 a	0.59 ab	7.0 ab	1.3 b	0.65 bc	0.41	3957 ab	193	63	74	30 ab
25:75	2.4 b	0.46 bc	5.2 bc	1.5 ab	0.85 ab	0.40	2295 b	226	89	74	35 a
0:100	2.0 b	0.40 c	4.4 c	1.9 a	0.98 a	0.41	2014 b	161	86	67	33 ab
P value	<0.001	<0.001	<0.001	<0.001	<0.001	0.741	0.006	0.242	0.209	0.116	0.007

[i] Means were separated using Tukey's honestly significant difference at a significance level of $\alpha = 0.05$. Means followed by the same letter are not significantly different.

[ii] Nutrients are reported as a percent of the total mass of the ground plant tissue sample.

[iii] Nutrients are reported as mg of the nutrient per kg of the dry plant tissue.

[iv] FWC and PM substrates were prepared on a volume:volume basis.

B = boron; Ca = calcium; Fe = iron; K = potassium; Mg = magnesium; Mn = manganese; N = nitrogen; Na = sodium; P = phosphorus; S = sulfur; Zn = zinc.

content, mineral type, hydroxy-oxides of aluminum and iron, calcium carbonate content, and organic matter composition (Arora and Chahal 2010, 2020; Vera-Maldonado et al. 2024).

Discussion

The various v:v ratios of FWC and PM led to different substrate nutrient concentrations (Table 1). With the exceptions of Mg, Mn, and Ca, nutrient concentrations, pH, and EC of FWC and PM substrate blends exhibited trends similar to previous works with compost as a substrate amendment, including composts derived from yard waste, vegetable waste, solid urban waste (sourced from a commercial facility with undefined mixtures of compostable materials), and grape vine pomace (Dekalb et al. 2014; Díaz-Pérez and Camacho-Ferre 2010). The FWC in this study also had lower concentrations of Mg, Mn, and Ca than those in other compost substrates reported, which is likely attributable to the differing feedstock of each compost (Costello et al. 2019; Long et al. 2017). Substrate blends used in previous studies also varied based on what was considered a standard PM, which included blonde peat, black peat, vermiculite, coconut fiber, and others, depending on the experiment (Dekalb et al. 2014; Díaz-Pérez and Camacho-Ferre 2010).

The EC of compost and elevated Na concentrations often exceeded acceptable levels for vegetable substrates (Ozores-Hampton 2017), which can result in reduced germination rates or plant growth. In a 330-mM NaCl solution, tomato germination was reduced to ≤30% of the 0 mM NaCl control (Cuartero and Fernández-Muñoz 1998). While sensitivity varied between *Lycopersicon* accessions, increasing the NaCl concentration consistently reduced germination (Cuartero and Fernández-Muñoz 1998), which aligned with the observations of the present study (Tables 1 and 3). Salinity stress can be an issue throughout a cropping cycle, particularly in containerized production. A greenhouse study by Moya et al. (2017) found that the total and commercial tomato yields decreased by 5% to 19% and 3% to 22%, respectively, when EC was increased from 2.2 $dS{\cdot}m^{-1}$ to 3.5 $dS{\cdot}m^{-1}$ and 4.5 $dS{\cdot}m^{-1}$. Additionally, high EC levels negatively impacted fruit size distribution, with significant decreases in extra-large and large fruits (Moya et al. 2017).

Elevated EC is a recurring concern for compost substrates and PMs, and numerous studies have reported high EC levels in composts used as organic amendments (Clark and Cavigelli 2005; Rippy et al. 2004; Rogers 2017; Russo 2005; Zhang et al. 2013). When comparing commercial mixes and custom blends, tomato germination was highest in commercial PMs with the lowest initial EC in the root zone (Peet et al. 2008), in agreement with present findings. In a separate study, differences in tomato seedling emergence across various media were partially attributed to EC (Maynard et al. 2024). A regression analysis showed that the EC of the growing media accounted for 79% of the variation in maximum emergence (Maynard et al. 2024). Similarly, reduced emergence of tomatoes has been observed when solid urban waste compost was used as a substrate amendment, whereas no such reduction occurred with vegetable waste compost as a substrate blend (Díaz-Pérez and Camacho-Ferre 2010).

Chemical properties of substrates indicate that FWC is excessive in EC, K, and Na (Table 1), and may not be an ideal substrate for seedling propagation. An increased concentration of N in FWC did not increase seedling emergence or growth for either species, most likely because seedlings had not yet become nutrient-deprived by the end of each trial (14 d for watermelon and 21 d for tomato), even in PM, which had the lowest concentration of N (Table 1). Watermelon and tomato tissues had higher N and K in substrate blends with higher proportions of FWC, which may be beneficial for emerged seedlings to reduce the fertility needs (Tables 7 and 8). Furthermore, watermelon and tomato plants grown in substrate with FWC had higher SPAD readings, indicating greener leaves and more chlorophyll content (Tables 5 and 6).

This work demonstrates the utility of FWC as a component of substrates for tomato and watermelon seedling propagation, reinforcing previous work using compost with tomatoes (Castillo et al. 2004; Díaz-Pérez and Camacho-Ferre 2010; Herrera et al. 2008). The present findings suggest FWC can be incorporated up to 50% v:v with PM to make an acceptable substrate for tomato seedlings, which is a higher proportion than that of a previous study, which reported that substrates with up to 30% municipal solid waste compost (blended with peat) were suitable for tomato seedlings (Herrera et al. 2008). The disparity of emergence and plant growth responses of substrate blends with higher proportions of FWC in the present study may be attributable to the source material of municipal solid waste (incorporating a wider range of decomposable materials) compared with strictly food waste with a bulking agent. This highlights the importance of more precise characterization of compost-derived substrate amendments. Furthermore, watermelon, a larger-seeded crop, exhibited consistent germination in substrate blends as high as 75% (by volume) FWC.

Reduced emergence of tomato seedlings in FWC alone and 75:25 (FWC:PM) substrate blends (Table 3) and reduced emergence of watermelon seedlings in FWC alone (Table 4) underscore the limitations of using FWC as the sole substrate or in high proportions for seedling propagation. These findings highlight the importance of incorporating FWC only as a component of a balanced substrate blend rather than relying on FWC alone for commercial seedling production. Although 50:50 and 25:75 (FWC:PM) blends performed comparably to PM alone for tomato and watermelon emergence and seedling production, the high EC, elevated pH, and increased Na levels associated with FWC are likely major factors affecting seedling emergence and growth. Therefore, when substituting PM with FWC, careful evaluation of substrate chemical parameters, such as EC, pH, and Na levels, is essential to ensuring suitability for seedling propagation. Despite these challenges, FWC can be a sustainable alternative substrate amendment for tomato and watermelon seedling production in blends with PM, particularly when PM or other commercial substrates are limited or prohibitively expensive.

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