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Spent Coffee Ground Derived Amendments for Horticultural Substrates: Maturity Assessment and Plant Growth Responses

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Abstract

Spent coffee grounds (SCGs) are a widely available organic by-product with potential value as horticultural substrate amendments, but their biological instability, salinity, and possible phytotoxicity can limit direct use. This study evaluated whether accelerated household composting can produce stable SCG-derived amendments suitable for container substrates. SCGs were processed for 1, 5, or 10 days using two electric composting systems, Lomi® and Vego®. The resulting materials were assessed for Solvita® CO_2 burst response, pH, electrical conductivity (EC), bulk density, particle size distribution, and macronutrient composition. Lettuce (*Lactuca sativa*) and *Petunia* (*Petunia* × hybrida) were grown in pine bark-based substrates amended with 5% or 10% (v/v) processed SCGs. One-day treatments remained biologically active, whereas 5- and 10-day treatments reached Solvita® values consistent with practical stability. Processing increased bulk density, reduced particle size, and produced acidic, nutrient-rich materials with C/N ratios below 25:1. SCG amendments improved biomass and SPAD values in both species compared with the pine bark control, with the strongest responses at 5% - 10% incorporation. However, increasing EC indicates that higher rates may be limited by salinity. Overall, 5 - 10 days of accelerated processing produced SCG-derived amendments suitable for low-rate use in pine bark-based substrates.

Keywords

Spent Coffee Grounds, Organic Amendment, Compost Maturity, Pine Bark Substrate, Electrical Conductivity, Container Substrates, Lettuce, *Petunia*

1. Introduction

Spent coffee grounds (SCGs) are a widely available organic by-product of coffee preparation. They contain organic matter, nutrients, polysaccharides, lipids, and phenolic compounds, which makes them promising for reuse as horticultural substrate amendments [1] [2]. However, untreated SCGs can inhibit plant growth because of phytotoxic compounds, high biological activity, salinity, and possible nitrogen immobilization [3] [4]. Recent studies show that plant responses depend strongly on SCG processing method and application rate, with lower rates usually considered to be safer than higher rates [5]. Therefore, biological stabilization use is important to reduce phytotoxicity, prevent plant burns, prevent environmental degradation, break down organic compounds, eradicate plant pathogens, reduce pollutants, and improve reliability of SCG derived amendments in horticultural substrates.

Composting can reduce phytotoxicity, lower microbial instability, and improve the agronomic value of organic amendments [6] [7]. In SCG-based materials, stabilization is especially important because plant response depends on both the processing method and the incorporation rate [2] [8]. Several studies show that composted or co-composted SCGs can support plant growth when used at low to moderate rates, but excessive additions may increase EC and restrict growth [4] [9]. Therefore, SCG derived amendments should be evaluated not only for nutrient content, but also for maturity, salinity, and crop response.

Compost maturity is a key criterion for using organic residues in horticultural substrates. Immature materials may continue to respire, release unstable compounds, or cause phytotoxic effects after incorporation into the growing medium [6] [7]. For this reason, maturity should be assessed with more than one indicator. Common criteria include C/N ratio, pH, EC, respiration activity, and plant-based responses [6] [10]. The Solvita® CO_2 burst test is useful in this context because it provides a rapid estimate of biological activity and has shown good agreement with established CO_2 respiration methods [11] [12]. These indicators are especially relevant for rapidly processed SCG amendments, where short processing time may not always guarantee biological stability.

Accelerated household composters may offer a practical way to process SCGs at a small scale. These systems use heat, aeration, and mixing to reduce moisture and promote rapid organic matter transformation. Similar in-vessel and rotary systems have shortened organic waste processing times under controlled conditions [13] [14]. However, rapid processing does not always mean that the final material is mature or suitable for plant production. This is especially important for SCGs because their phytotoxicity and salinity can limit plant growth when they are used without adequate stabilization [2] [4]. Therefore, the horticultural value of SCG derived amendments from household composters should be tested through both maturity indicators and greenhouse plant responses.

Although the relative concentrations of individual compounds may differ between *Coffea arabica* and *Coffea canephora* var. *robusta*, SCGs generally share

similar major chemical classes, including polysaccharides, lignin, proteins, lipids, minerals, and phenolic compounds [2]. This composition supports their potential use as organic amendments but also explains why untreated SCGs may require stabilization before incorporation into horticultural substrates. Despite increasing interest in SCG valorization, limited information is available on the horticultural suitability of SCG derived amendments produced in accelerated household composters. Most previous studies have focused on conventional composting systems, co-composting strategies, or direct soil application of SCGs [2] [3]. Information remains scarce regarding whether short-duration processing can produce biologically stable materials suitable for container substrates and greenhouse crop production. The second study's objective was to evaluate the effects of accelerated household composting duration on the maturity, physicochemical properties, and horticultural performance of SCG derived amendments. Plant responses of lettuce (*Lactuca sativa*) and *Petunia* (*Petunia* × *hybrida*) grown in PB-based substrates amended with processed SCGs were also assessed. These two species of plants were selected for their intense leaf and flower production. We hypothesized that increasing processing duration would improve biological stability and enhance plant growth performance at low incorporation rates.

2. Materials and Methods

2.1. Source of Spent Coffee Grounds

Spent coffee grounds (SCGs) were collected from a national beverage chain immediately after coffee preparation. The material consisted only of homogenized blends of coffee roasts and grinds and did not include filters, food scraps, or other organic waste. After collection, SCGs were stored at room temperature (22˚C) and processed within 24 hours (h) to limit uncontrolled microbial activity before the start of the experiment.

2.2. Accelerated Composting Systems and Experimental Design

Two commercially available electric household composters were used: Lomi® (Pela, Kelowna, BC, Canada) and Vego® Kitchen Composter (Vego® Innovations Inc., Tomball, TX, USA). Both units are closed countertop in-vessel systems designed to process household organic residues through automated drying/heating, mixing or grinding, aeration, ventilation, and cooling phases [15] [16]. A simplified representation of the main operational phases is shown in **Figure 1**. The main manufacturer-reported operating characteristics of both devices are summarized in the Supplementary Materials section of this chapter's discussion.

The Lomi® unit has a chamber capacity of approximately 2.5 liters (L) and operates at 500 watts (W), whereas the Vego® unit has a chamber capacity of 4.0 L and operates at 400 W. The manufacturer-reported waste volume reduction is approximately 80% for Lomi® and 85% - 95% for Vego®.

Only SCGs were processed in this experiment. Three processing durations were evaluated for each composter: 1, 5, and 10 days. This resulted in six SCG derived

amendment treatments: Lomi® 1 day, Lomi® 5 days, Lomi® 10 days, Vego® 1 day, Vego® 5 days, and Vego® 10 days. SCGs, PB, and peat moss were characterized as reference materials. Each treatment was replicated four times.

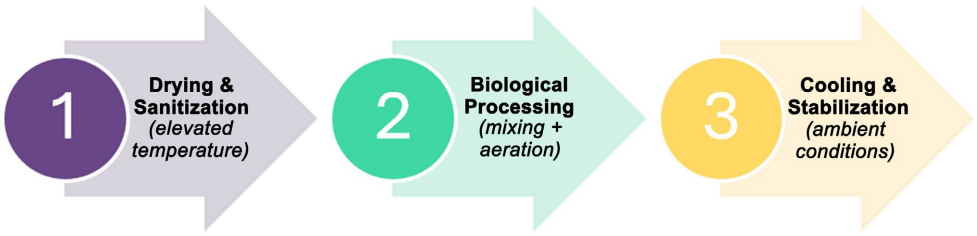


Figure 1. Operational phases of spent coffee ground (SCG) processing in the electric household composters. SCGs were processed using manufacturer-recommended garden amendment modes involving drying/heating, biological processing with mixing and aeration, and cooling/stabilization phases.

At the start of each batch, the chamber was filled to a maximum of 75% of its capacity, following the manufacturers' recommendations. A manufacturer-supplied activator additive and 80 milliliters (mL) of water were added to each batch. The Lomi® additive is described by the manufacturer as LomiPods™, a proprietary probiotic blend intended to improve degradation rate, reduce odor, and improve the final garden amendment. The Vego® additive is described by the manufacturer as VegoTabs™, which are intended to accelerate the breakdown of organic matter and improve compost quality. The exact microbial composition and formulation of these additives were not disclosed in the manufacturers' manuals. Each branded additive aids in biological stabilizing and is crucial to experimental reproducibility. No additional feed stocks, bulking agents, or other amendments were included.

Processing was conducted using the standard manufacturer-recommended garden-amendment modes [15] [16]. For Lomi®, Grow Mode was used; according to the manufacturer, this operational mode is intended for food waste, operates at low heat to preserve microorganisms and bacteria beneficial to soil, and has a cycle duration of 16 to 20 h. The Lomi® cycle includes drying, mixing, and cooling phases. For Vego®, "Vego Mode" was used; according to the manufacturer, this operational mode is intended to produce a biologically active garden amendment, has a cycle duration of 9 to 24 h, and maintains internal temperature, humidity, and ventilation while processing the material every 2 h. Exact chamber temperature ranges, airflow rates, and mixing frequencies were not reported in the manufacturer manuals. Therefore, temperature, mixing, ventilation, and cooling were controlled automatically by each unit according to the selected manufacturer program, and no manual adjustments were made to the operating conditions.

For the 5 and 10 day treatments, SCGs remained in the corresponding unit for the full assigned duration and were subjected to repeated automatic processing cycles. At the end of each assigned duration, the processed material was removed, homogenized, and air-dried before analysis. Four replicate analytical samples per

treatment were prepared for compost maturity, physicochemical, nutrient, and physical property analyses.

2.3. Compost Maturity and Physicochemical Analysis

Compost maturity and biological activity of the processed SCG materials were assessed using the Solvita® CO_2-Burst colorimetric respiration method. The Solvita® compost maturity test and gas emission measurement methods were preferred due to acceptance by compost science and as a cheaper alternative to infrared gas analyzers. Air-dried samples were homogenized, and a 30 cm^3 subsample was rewetted to approximately 50% water-filled pore space. Samples were placed in standard 475 mL Solvita® airtight incubation jars with a Solvita® low-level CO_2 detector paddle and incubated for 24 h at room temperature (20˚C) in the dark. After incubation, the detector paddle was evaluated using a Solvita® digital color reader according to the manufacturer's calibration. The Solvita® documentation describes the digital color reader as a pre-calibrated colorimetric system that converts gel color response to CO_2 concentration. The optical calibration relationship reported by the manufacturer is $y = 1.00 \ln(x) + 4.20$, where y is the Solvita® probe color response and x is CO_2 concentration in the jar headspace. Final CO_2 conversion is based on the ideal gas law at 20˚C and 1 standard atmosphere (atm). Solvita® testing was conducted using four replications for each composting treatment.

Additional physicochemical properties were measured for each material, including pH, EC, organic matter content, total carbon, total nitrogen, C/N ratio, Mehlich-3-extractable macronutrient concentrations (P, K, Ca, Mg, S), bulk density, and particle size distribution with each measurement assessing four replications per treatment. Chemical analyses were conducted by the Louisiana State University (LSU) Agricultural Center Soil Testing and Plant Analysis Laboratory. Substrate pH was determined in a 1:1 sample-to-water suspension, and EC was determined in a 1:2 sample-to-water extract. Organic matter content was determined by loss on ignition. Total carbon and total nitrogen were determined using a LECO CN628 carbon/nitrogen analyzer, and C/N ratio was calculated from total C and total N. Extractable P, K, Ca, Mg, and S were determined using Mehlich-3 extraction. All chemical analysis results were reported on a dry-weight basis. Analytical procedures followed *Soil Test Methods from the Southeastern United States*, Southern Cooperative Series Bulletin No. 419. The laboratory participates in the North American Proficiency Testing (NAPT) and Agricultural Laboratory Proficiency (ALP) programs. Bulk density and particle size distribution were determined separately from the Soil Test Plant Analysis Laboratory (STPAL) chemical analyses. Particle size distribution was determined by dry sieve analysis using a stack of sieves: 3/8-inch, #6, #14, #25, and #40, with the remaining material collected in the pan. The mass retained on each sieve was recorded and expressed as a percentage of the total sample mass. Bulk density was determined as dry bulk density and expressed as $g \cdot cm^{-3}$. Four replicate analytical samples per treatment

were analyzed.

2.4. Substrate Formulation and Greenhouse Experiment

SCG derived amendments were produced using two electric composters, Lomi® and Vego®, after 1, 5, or 10 days of processing. For the greenhouse experiment, each processed SCG derived amendment was incorporated into a PB-based substrate at 5% or 10% (v/v). The substrate treatments included a non-amended PB control (100% PB), peat moss reference treatments consisting of 95% PB + 5% peat moss and 90% PB + 10% peat moss (v/v), and SCG-amended treatments consisting of 95% PB + 5% SCG derived amendment or 90% PB + 10% SCG derived amendment (v/v). The SCG-amended treatments included amendments produced using Lomi® or Vego® after each processing duration (1, 5, or 10 days). All substrate treatments received a controlled-release fertilizer (4-month release, 15-9-12) at a rate of 1 lb. N yd^{-3}, together with 8 lbs. yd^{-3} dolomitic lime and 0.5 lb. yd^{-3} Micromax®.

The greenhouse experiment was conducted at the Louisiana State University Agricultural Center, Baton Rouge, LA, USA. Greenhouse air temperature ranged from 22˚C to 28˚C during the growing period, and plants were grown under natural light and natural photoperiod. Relative humidity and light intensity were not continuously recorded. Two species were evaluated: lettuce (*Lactuca sativa* "Red Sails") and *petunia* (*Petunia* × *hybrida* "Madness Plum"). Five inch (12.7 centimeters (cm)) diameter pots were filled with the corresponding substrate treatments. Lettuce and *petunia* transplants grown in 128 cell trays were transplanted into the substrates and grown for 8 weeks. Plants were irrigated as needed to maintain adequate substrate moisture and avoid visible water stress; substrate moisture content was not quantitatively monitored. No additional fertilizer was applied after transplanting. Leaves were randomly selected based on developmental age, greenness, and plants were photographed at 14 day intervals. At harvest, SPAD readings, which measure relative chlorophyll content and serve as a proxy for N status, were recorded using a SPAD-502Plus meter (Konica Minolta, Tokyo, Japan). Aboveground shoot biomass was collected, dried in a forced-air dryer at 60˚C, and weighed. Lettuce and *petunia* data were analyzed separately.

2.5. Experimental Design and Statistical Analysis

The greenhouse experiment was arranged as a randomized complete block design (RCBD) utilizing eight replications per plant. Each experimental unit consisted of one pot containing one plant. Lettuce and *petunia* were analyzed separately, as were shoot biomass and SPAD values.

The data was analyzed by analysis of variance (ANOVA) using SAS software (SAS Institute Inc., Cary, NC, USA; Version 9.4). Treatment was considered a fixed effect, and block was included as a blocking factor. When the overall F-test was significant, treatment means were separated using Duncan's multiple range test (DMRT) at $\alpha = 0.05$. DMRT was retained to maintain consistency with the

original mean-separation procedure used for the available compost physicochemical and plant growth datasets. Lettuce and *petunia* were analyzed separately, as were shoot biomass and SPAD values. Only available observations were used for each response variable.

3. Results

Particle size distribution differed substantially among initial materials and SCG derived amendments (Table 1). PB and peat were dominated by coarse fractions (3/8-inch and #6), whereas raw SCGs consisted primarily of medium and fine particles, with the highest proportion retained in the #25 fraction (55.3%). Accelerated composting decreased particle size, increasing the #25 fraction in both systems. In VC, this fraction increased from 37.3% after 1 day to 59.3% after 10 days; in the Lomi® Composter (LC), it remained consistently high throughout processing, reaching 65.7% at 10 days. Coarser fractions (3/8-inch and #6) were reduced to negligible levels in all composted treatments from day 1. The #40 mesh screen fraction decreased modestly with increased composting duration, and the pan fraction showed no significant differences among treatments. Significant treatment effects were detected for the 3/8-inch, #6, #14, and #25 mesh screen fractions ($p < 0.05$; Table 1).

Bulk density increased significantly with processing duration in both systems ($p < 0.001$; Table 1), however, also resulted in significant differences between both composters. PB and peat had the lowest values (0.215 and 0.211 g·cm^{-3}, respectively). SCGs had a higher bulk density (0.338 g·cm^{-3}), which increased further during composting. In VC, bulk density rose progressively from 0.359 g·cm^{-3} at 1 day to 0.463 g·cm^{-3} at 10 days, the highest value recorded. In LC, bulk density increased from 0.443 g·cm^{-3} at 1 day to 0.451 g·cm^{-3} at 5 days, followed by a slight decline to 0.426 g·cm^{-3} at 10 days.

Table 1. Particle size distribution of composts produced.

Compost Treatment	Days Composted	Bulk Density [g·cm^{-3}]	Particle size distribution [%]					
			3/8 inch	#6	#14	#25	#40	Pan
PB (3/8-inch)	0	0.215 f^{z}	1.00 a^{z}	36.8 a	33.9 a	14.1 c	11.0	3.2
Peat	0	0.211 g	0.33 b	32.3 b	25.3 b	17.1 c	9.0	16.0
Spent Coffee Grounds	0	0.338 e	0.00 b	0.0 c	0.0 d	57.2 a	20.7	22.1
Vego® Composter	1	0.359 d	0.00 b	0.0 c	16.0 bc	37.3 b	20.0	26.7
	5	0.456 ab	0.00 b	0.0 c	3.9 d	55.2 a	20.6	20.3
	10	0.463 a	0.00 b	0.0 c	6.4 cd	59.8 a	11.4	22.4
Lomi® Composter	1	0.443 bc	0.00 b	2.0 c	1.7 d	57.6 a	22.5	16.2
	5	0.451 ab	0.00 b	0.7 c	1.6 d	57.2 a	21.9	18.6
	10	0.426 c	0.00 b	0.0 c	0.0 d	65.2 a	10.3	24.5
Significance (<0.05 level)	-------	***	**	***	***	***	n.s.	n.s.

^{z}Means within each column having similar letters are not significantly different at the $\alpha = 0.05$ level.

Both electric composters substantially reduced the mass and volume of SCGs during processing (Figure 2). In LC, mass declined rapidly during the first three days, decreasing from 100% of the initial value on day 0 to approximately 37% on day 2 and approximately 33% by day 3, after which it remained nearly unchanged through day 10. Volumes in LC followed a similar pattern, decreasing to approximately 55% of the initial value by day 2 and approximately 40% by day 3, with only minor additional reduction thereafter. In VC, mass decreased more gradually, from 100% on day 0 to approximately 53% on day 4, 45% on day 5, and approximately 36% by day 6, after which it stabilized through day 10. Volume reduction in VC was also progressive, declining from 100% on day 0 to approximately 50% on day 4 and approximately 39% on day 6, with final values near 35% by day 10. These results indicate that LC achieved rapid mass and volume reduction within the first three days of processing, whereas VC exhibited a more gradual reduction pattern, reaching similar final remaining values after approximately six to ten days.

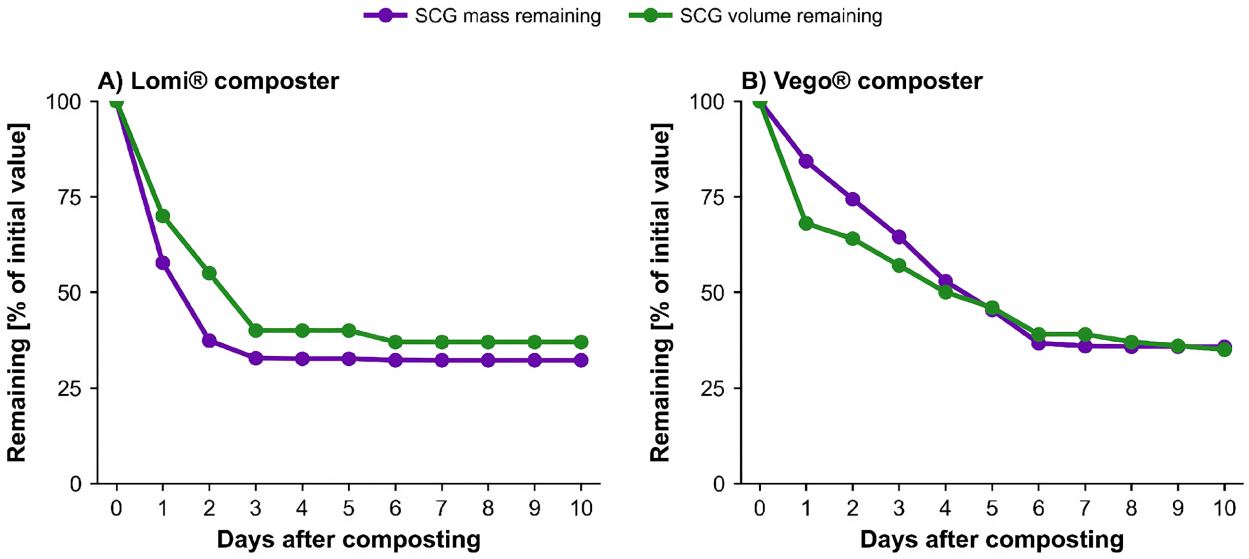


Figure 2. Remaining mass and volume of spent coffee grounds (SCGs) during composting. Relative remaining mass and volume of spent coffee grounds (SCGs) during accelerated composting in two electric household composters over a 10 day processing period. Values are expressed as percentages of the respective initial mass or volume. n = 4. (A) Lomi® composter. (B) Vego® composter.

The quality of compost health was dependent upon processing times and on the type of accelerated electric composter (Figure 3). The vertical axis shows the compost health index (Solvita®), and the horizontal axis displays the experimental variants. This indicator test was utilized for its inexpensiveness and universal acceptance. Results are presented as mean values ± standard deviation. Horizontal lines represent interpretive Solvita® test ranges: compost of practical quality (6.0 - 6.9) and mature compost (≥7.0). The lowest Solvita® values were recorded after 1 day of composting in both systems, indicating that the material was still immature. Extending the processing time to 5 and 10 days resulted in a clear improve-

ment in compost quality, with samples Lomi® Composter 5 days (LC5), Lomi® Composter 10 days (LC10), Vego® Composter 5 days (VC5), and Vego® Composter 10 days (VC10) reaching the thresholds of practical or mature compost. These results highlight the essential role of processing time in achieving stable and mature compost in electric kitchen composters.

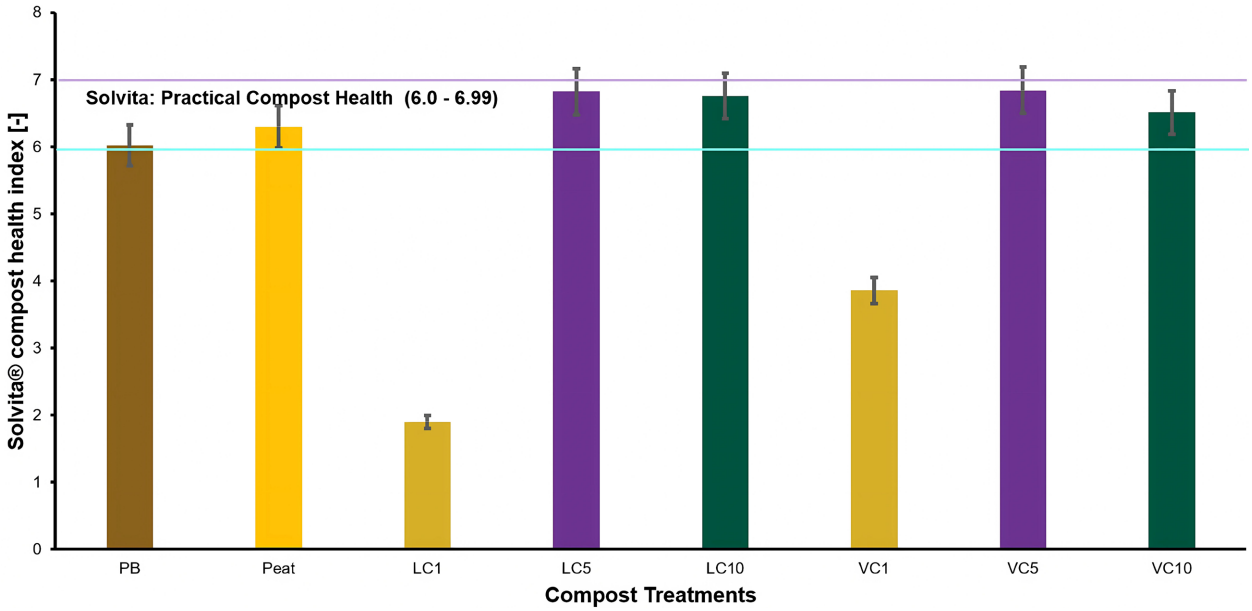


Figure 3. Solvita® compost health index of processed derived amendments. Solvita® compost health index [-] of pine bark (PB), peat, and spent coffee ground (SCG)-derived amendments processed in Lomi® and Vego® electric household composters. LC1, LC5, and LC10 indicate SCGs processed in the Lomi® composter for 1, 5, and 10 d, respectively; VC1, VC5, and VC10 indicate SCGs processed in the Vego® composter for 1, 5, and 10 d, respectively. Bars represent mean values ± standard deviation. Horizontal lines indicate Solvita® interpretive values for practical compost health (6.0 - 6.99) and mature compost (≥7.0).

Changes in pH during SCG processing in the two electric composters are shown in Figure 4. The results are presented as mean values, and different letters above the bars indicate statistically significant differences among treatments ($p < 0.05$). Throughout the study period, pH remained within a narrow, slightly acidic range of approximately 4.8 to 5.7, with only small differences among composters and processing durations. This narrow pH range suggests relatively stable chemical conditions during processing. However, pH alone should not be interpreted as evidence of biological maturity, which was assessed separately using the Solvita® CO_2-Burst response.

Changes in EC during SCG processing in the two electric composters are shown in Figure 5. The results are presented as mean values, and different letters above the bars indicate statistically significant differences among treatments ($p < 0.05$). In both systems, EC increased with processing duration, with the lowest values recorded after 1 day and the highest values after 10 days. No significant difference between composters was observed at the end of processing. These results indicate that EC increased during accelerated processing, likely reflecting moisture removal, concentration of soluble ions, and organic matter transformation. How-

ever, elevated EC may constrain higher incorporation rates of SCG derived amendments in horticultural substrates, particularly for salt-sensitive crops.

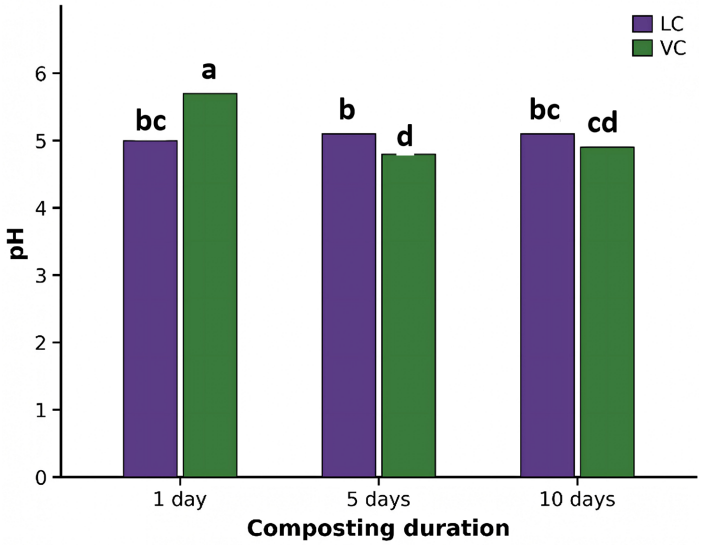


Figure 4. Composting duration effects on pH. Composting duration effects on pH compared to accelerated composters (LC = Lomi® Composter; VC = Vego® Composter).

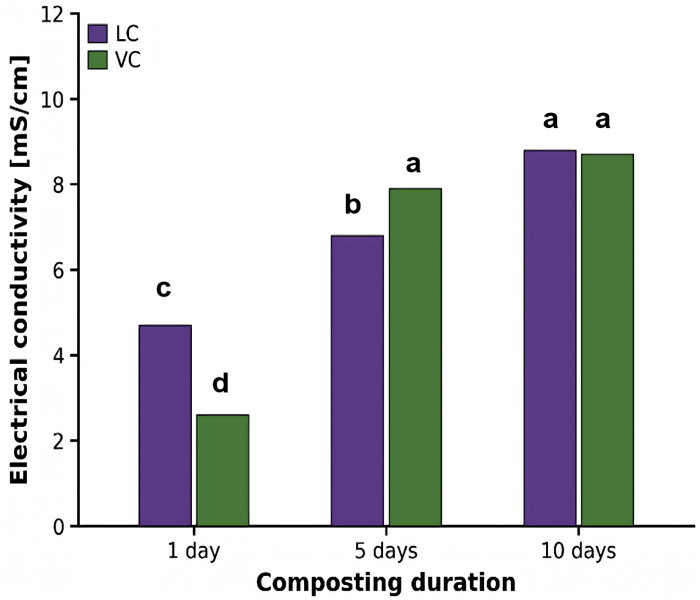


Figure 5. Composting duration increases substrate EC. Composting duration increases substrate EC (LC = Lomi® Composter; VC = Vego® Composter).

The chemical composition of composts obtained from SCG using LC and VC over a processing period of up to 10 days is presented in Table 2.

Concentrations of P, K, Ca, Mg, and S generally increased with processing duration in both systems, consistent with progressive mass loss and concentration of mineral components. Potassium was the dominant mineral nutrient across all composted treatments, ranging from 1134 parts per million (ppm) (VC1) to 2015

ppm (LC10), compared with 46 ppm in PB and 3089 ppm in raw SCGs. Phosphorus reached the highest concentrations at 10 d: 457 ppm in LC and 434 ppm in VC. Calcium concentrations were variable and did not follow a consistent directional trend with processing duration. Total carbon remained stable across all composted treatments (48.6% to 50.3%), as did total nitrogen (2.1% to 2.3%). The C/N ratio of all composted SCG materials ranged narrowly from 22:1 to 24:1, substantially below that of PB (103:1) and peat (30:1), and below the 25:1 threshold commonly associated with compost maturity. Significant treatment effects were detected for all chemical parameters ($p < 0.001$; Table 2).

Table 2. Chemical composition of horticultural standards and coffee ground treatment groups.

Compost Treatment	Days Composted	P [ppm]	K [ppm]	Ca [ppm]	Mg [ppm]	S [ppm]	C [%]	N [%]	C/N [Ratio]
PB (3/8-inch)	0	5 f	46 f	17 e	5 f	0.1 d	34.9 f	0.34 e	103:1 a
Peat	0	2 f	8 f	59 d	46 e	111 a	41.2 e	1.4 d	30:1 b
Spent Coffee Grounds	0	522 a	3089 a	169 a	483 a	60 c	49.1 cd	2.2 b	23:1 c
Vego® Composter	1	248 d	1134 e	52 d	142 d	50 cd	48.6 cd	2.1 c	23:1 c
Vego® Composter	5	268 c	1857 c	61 c	256 c	80 b	49.9 ab	2.3 a	22:1 c
Vego® Composter	10	434 b	1905 c	135 b	371 b	85 b	50.1 ab	2.1 c	24:1 c
Lomi® Composter	1	131 e	1171 e	48 d	122 d	44 d	49.6 bc	2.2 b	23:1 c
Lomi® Composter	5	296 c	1589 d	95 c	256 c	62 c	50.3 a	2.2 b	23:1 c
Lomi® Composter	10	457 b	2015 b	46 d	388 b	82 b	50.0 ab	2.1 c	24:1 c
Significance (0.05 Level)	-------	***	***	***	***	***	***	***	***

Table 3. Lettuce plant growth characteristics and biomass.

Compost Treatment	Days Composted	Percent compost (v/v)	SPAD Reading	Biomass (g)
Pine bark (3/8") (PB)	0	0	26.1 c[z]	29.6 c[z]
Lomi composter (LC)	1	5	31.8 b	42.6 a
Lomi composter (LC)	1	10	35.4 a	32.0 b
Vego composter (VC)	1	5	28.6 b	44.5 a
Vego composter (VC)	1	10	34.2 a	43.0 a
Vego composter (VC)	5	5	31.8 b	44.0 a
Vego composter (VC)	5	10	35.4 a	40.3 a
Vego composter (VC)	10	5	31.9 b	43.5 a
Vego composter (VC)	10	10	35.4 a	44.5 a
Significance (<0.05 level)	-------	-------	***	***

[z]Means having similar letters are not significantly different at the 0.05 level. ** = Significant at the 0.01 level; ***Significant at the 0.001 level.

SPAD readings and biomass (g) of lettuce (*Lactuca sativa*) and *petunia*s (*Petu-*

nia × *hybrida*) grown in substrates enriched with compost produced using LC and VC electric composters are shown in Table 3 and Table 4 respectively.

Table 4. *Petunia* plant growth characteristics and biomass.

Compost Treatment	Days Composted	Percent compost (v/v)	SPAD Reading	Biomass (g)
Pine bark (3/8") (PB)	0	0	31.1 b[z]	4.3 c[z]
Lomi composter (LC)	1	5	29.6 b	5.4 b
Lomi composter (LC)	1	10	37.0 a	6.4 a
Vego composter (VC)	1	5	31.2 b	5.4 b
Vego composter (VC)	1	10	31.7 b	5.3 b
Vego composter (VC)	5	5	37.0 a	5.6 b
Vego composter (VC)	5	10	36.9 a	6.4 a
Vego composter (VC)	10	5	29.9 b	5.0 b
Vego composter (VC)	10	10	33.0 b	5.4 b
Significance (<0.05 level)	-------	-------	***	***

[z]Means having similar letters are not significantly different at the 0.05 level. ** = Significant at the 0.01 level; ***Significant at the 0.001 level.

Compost additions of 0% (control-PB), 5%, and 10% (v/v) were used. The vertical axis shows plant biomass (g), while the horizontal axis shows the percentage of compost in the substrate (% v/v). The results are presented as mean values, and different letters above the bars indicate statistically significant differences between variants ($p < 0.05$). Compost addition significantly increased the biomass of both species compared to the control (Table 3 and Table 4). In the case of *petunia*s, the highest biomass was obtained with 10% LC compost addition, while VC compost showed a comparable effect at 5% addition. In lettuce, maximum biomass was observed at 5% compost addition in both systems, while 10% LC compost addition led to a decrease in biomass compared to the 5% variant. The results indicate that a moderate addition of 5% to 10% (v/v) compost can significantly improve plant growth, with the optimal level depending on both the plant species and the type of composter used. Direct application of SCGs to soil in concentrations above 20% (v/v) has caused phytotoxic effects due to the presence of caffeine, tannins, and polyphenols [5] [17]. Composting with other organic matter can mitigate negative effects and enhance the agronomic value of SCGs. Previous research established that applying 10% (v/v) SCGs to lettuce cultivation improved chlorophyll content by up to 37%, with only a minor decrease in organic nitrogen (4.4%) [2]. Pre-treated SCGs significantly improved soil pH, C:N ratio, and microbial activity compared to raw SCGs, which tended to reduce seedling growth and nutrient uptake in early stages of growth [5]. The blend of SCGs with other organic sources could unlock the potential of soils while reducing plant phytotoxicity by itself [18]. This statement lends itself to further research, especially horticulture,

where most substrates are organically based. SPAD readings with different letters behind their values indicate significant differences among treatments at $p < 0.05$. In both species, SPAD values increased with compost addition relative to the PB control, indicating improved leaf greenness. In *Petunia*, the highest SPAD reading was observed at 10% LC compost, whereas VC compost produced comparable values at 5% and 10%. In lettuce, both LC and VC compost significantly increased SPAD readings at 5% and 10%, with the highest values observed at 10% compost addition. Overall, the results indicate that moderate incorporation of composted SCGs improved leaf chlorophyll status in both species.

4. Discussion

Accelerated processing altered the physical structure of SCGs in both electric household composters. Bulk density increased from 0.338 $g \cdot cm^{-3}$ in raw SCGs to 0.463 $g \cdot cm^{-3}$ in Vego® after 10 days and reached 0.451 $g \cdot cm^{-3}$ in Lomi® after 5 days, followed by a slight decline to 0.426 $g \cdot cm^{-3}$ after 10 days, while particle size shifted toward finer fractions, particularly the #25 sieve fraction (**Table 1**). These changes are consistent with moisture removal, grinding, and progressive organic matter transformation reported for other in-vessel composting systems [13] [14]. Lomi® produced rapid particle size reduction from the first day, whereas Vego® showed a more gradual shift over time. This physical homogenization is relevant for substrate use because fine SCG derived amendments can be more uniformly incorporated into coarser PB substrates.

Both composters substantially reduced SCG mass and volume during processing (**Figure 2**). In the Lomi® system, the most reduction occurred within the first three days, whereas Vego® showed a more gradual reduction pattern over the 10 day period. These results indicate that both systems can reduce SCG waste volume and produce more concentrated material for horticultural use, although the temporal pattern of reduction differed between devices.

Biological stability was strongly influenced by processing duration. Materials processed for 1 day remained below the Solvita® practical compost health threshold, indicating continued biological activity, whereas 5 and 10 day treatments reached values consistent with practical stability or mature compost (**Figure 3**). This pattern agrees with the established relationship between composting duration and respiration-based maturity indicators [6] [10] [11]. Importantly, rapid dehydration and particle size reduction alone were insufficient to indicate maturity. SCGs contain readily available carbohydrates, caffeine, and phenolic compounds that may sustain microbial activity after physical processing [1] [2]. Therefore, visual dryness or volume reduction should not be interpreted as evidence of biological stability. Under the conditions of this study, at least 5 days of processing was required for SCG derived amendments to approach practical stability.

Chemical indicators further supported the maturity assessment. The C/N ratio of processed SCG amendments remained narrow, ranging from 22:1 to 24:1, and

was below the commonly used 25:1 threshold associated with compost maturity [6]. Total C and N contents remained relatively stable across processing durations, suggesting proportional mass loss without substantial N depletion. In contrast, EC increased with processing duration, reaching the highest values after 10 days (**Figure 5**). This increase was likely caused by moisture loss and concentration of soluble ions, as well as mineralization of organic matter, consistent with previous SCG-based amendment studies [3] [4]. The pH of processed SCGs remained slightly acidic, which is relevant for PB-based substrates but may require adjustment for crops with higher pH requirements.

The nutrient profile of SCG derived amendments also differed markedly from the PB and peat reference materials. Processed SCGs contained higher macronutrient concentrations, particularly K, P, and N (**Table 2**). Potassium was the dominant mineral nutrient, and P and K generally increased with processing duration as material mass decreased. These results support the potential of processed SCGs as supplemental nutrient sources in container substrate systems. However, the simultaneous increase in EC indicates that nutrient value must be balanced against salinity risk, particularly when using higher incorporation rates or salt-sensitive crops.

Because all greenhouse substrate treatments received the same baseline controlled-release fertilizer, lime, and micronutrient amendment, plant growth responses should be interpreted as the effect of SCG derived amendments under a common fertility regime rather than as a response to fertilizer addition alone. No additional fertilizer was applied after transplanting. Therefore, the improved biomass and SPAD responses observed in amended substrates likely reflect combined effects of SCG derived nutrients, nutrient retention and release within the PB matrix, and changes in substrate physicochemical properties.

Both lettuce and *petunia* responded positively to selected SCG derived amendments incorporated at 5% to 10% (v/v), with biomass and SPAD values generally exceeding those of the unamended PB control. Lettuce biomass increased most strongly to a 5% amendment, whereas *Petunia* continued to respond positively at 10% LC incorporation. These species-specific responses likely reflect differences in salinity tolerance. Lettuce (*Lactuca sativa*) is moderately salt-sensitive, and elevated EC at higher incorporation rates may have partially offset the nutrient benefit. *Petunia* (*Petunia* × *hybrida*) appears comparatively more tolerant of variable substrate conditions [19]. Therefore, SCG amendment rates should be adjusted to crop-specific salinity thresholds rather than applied uniformly.

SPAD values increased with amendment addition in both species, indicating improved leaf greenness and nutritional status. However, because all treatments received the same baseline fertilizer, the SPAD response cannot be attributed solely to N supplied by SCG derived amendments. Instead, it likely reflects the combined effects of supplemental nutrients from processed SCGs, nutrient retention in the PB matrix, and changes in substrate conditions.

Overall, both Lomi® and Vego® produced SCG derived amendments with Sol-

vita® values consistent with practical stability after 5 to 10 days of processing. Lomi® achieved more rapid initial mass and volume reduction, whereas Vego® showed a more gradual reduction pattern. The greenhouse trial demonstrated that selected processed SCG amendments can improve plant growth when incorporated at low rates into PB-based substrates. A primary limitation of the processed materials was an elevated EC, particularly after 10 days of processing, which may reduce incorporation rates and limit use with salt-sensitive crops.

These results support accelerated household processing as a small-scale strategy for converting SCGs into organic amendments for horticultural substrates. Processing for at least 5 days and incorporation at rates not exceeding 10% (v/v) appear appropriate under the conditions evaluated here. Future research should evaluate additional crop species with contrasting salt sensitivity, nutrient release and leaching behavior under irrigation, longer production cycles, and the performance of mixed household feedstocks in electric composters. Additionally, incorporating coffee into container compost heaps to finish the composting process should be explored in other scientific studies.

5. Conclusions

Accelerated processing altered the physical, chemical, and biological properties of spent coffee grounds (SCGs). Both Lomi® and Vego® reduced material mass and volume and produced finer, denser, and more uniform SCG derived amendments. Materials processed for 1 day remained biologically active, whereas 5 and 10 day treatments reached Solvita® CO_2 values consistent with practical stability.

The processed SCG amendments were acidic and nutrient-rich, with C/N ratios below 25:1. However, EC increased with processing duration and remained an important limitation for horticultural use. Therefore, SCG derived amendments should be used at low incorporation rates, particularly for salt-sensitive crops.

Lettuce and *Petunia* responded positively to SCG derived amendments incorporated at 5% to 10% (v/v). Biomass and SPAD values increased compared with the PB control, indicating that processed SCGs can improve plant performance when used conservatively. Based on the combined maturity, physicochemical, and plant growth responses, incorporation rates not exceeding 10% (v/v) are recommended for PB-based substrates.

Overall, accelerated household processing can convert SCGs into practically stable, nutrient-rich organic amendments suitable for small-scale horticultural substrate use. Further research should evaluate additional crop species, longer production cycles, nutrient release and leaching behavior, and the performance of mixed household feedstocks in electric composters.

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Author Contributions

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Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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