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Yield, functional properties and nutritional compositions of leafy vegetables with dehydrated food waste and spent coffee grounds

Young-Ji Jeon[1†], Yun-Gu Kang[2†], Jin-Ah Eun[3,4] and Taek-Keun Oh[2*]

Abstract

This study determined the fertilizer potentials of the dehydrated food waste powder (DFWP) and spent coffee grounds (SCGs) through assessing their effects on yield, antioxidant activities, mineral and proximate compositions of leaf lettuce and Japanese hogfennel their efficiencies to inorganic fertilizers (N-P_2O_5-K_2O, NPK). In this study, both organic amendments were applied at rates that supplied half, double and recommended nitrogen (N) requirements of the leaf lettuce (15 Mg N/ha) and Japanese hogfennel (10 Mg N/ha) established in Daejeon, South Korea. The recommended treatment of DFWP produced the highest lettuce and Japanese hogfennel yields, respectively. Halving the application rates of the organic amendments generally limited the yielding capacities while doubling them invoked negative yield responses in both crops. The highest antioxidant activities, mineral and proximate contents in both crops were obtained with the recommended dosage of amendments. The SCGs outperformed NPK in all the parameters of the Japanese hogfennel assessed in this study even though its impact on the leaf lettuce was adverse. Therefore, both DFWP and SCGs can effectively supply plant nutrients but their application rates should be regulated so as to avoid NaCl toxicity and elevated phytotoxicity in DFWP and SCGs, respectively.

Keywords Antioxidant activity, Dehydrated food waste powder, Fertilizer value, Mineral and proximate composition, Spent coffee grounds

Introduction

Putrescible waste constitutes nearly half of the globally generated detritus each year [1]. Furthermore, this figure is expected to rise due to the increasing global population and escalating urbanization rates, which will inevitably lead to higher demands for agricultural equivalent to one-third of the total food production intended for human consumption worldwide [2, 3]. While food waste makes up a relatively small percentage, around 30%, of the total municipal solid waste generated in South Korea [4], the per capita food waste stands at 130 kg, surpassing the quantities generated in North America and Europe, which were 95 and 115 kg, respectively. In South Korea, approximately 45.1% of the total food waste is recycled through animal feeding, and 44.9% is repurposed through

[†]Young-Ji Jeon and Yun-Gu Kang have contributed equally to this work.

*Correspondence:
Taek-Keun Oh
ok5382@cnu.ac.kr
[1] Donggang Bio Foundation Co. LTD., Wonju, Gangwon 26223, Republic of Korea
[2] Department of Bio-Environmental Chemistry, College of Agriculture and Life Sciences, Chungnam National University, Daejeon 34134, South Korea
[3] Clean Energy Research Center, Korea Institute of Science and Technology, Seoul 02792, Republic of Korea
[4] Department of Chemical and Biological Engineering, Korea University, Seoul 02841, Republic of Korea

composting, while other recycling methods like anaerobic digestion, solid fuel, etc., account for the remaining 10.0% of recycled waste [5].

However, while composting is a widely practiced method for recycling food waste, it comes with a range of issues. These include the emission of greenhouse gases, unpleasant odors, the need for extensive space, and demanding time and management requirements [6, 7]. Anaerobic digestion, similar to composting, also faces several challenges. It not only demands a considerable amount of space but also yields biogas at levels too low for the system to be economically viable [7]. In contrast, dehydration not only reduces waste volumes but also results in an extremely dry final product, making storage and transportation significantly easier. Consequently, this method is far more cost-effective [6, 7].

Likewise, the volume of spent coffee grounds (SCGs) produced worldwide each year is expected to continue rising due to the increasing popularity of coffee consumption. This is partly due to coffee's perceived health benefits in reducing the risks of heart diseases and certain cancers [8]. In 2019, global coffee consumption reached 2.25 billion cups, and since each cup requires approximately 11 g of coffee grounds, it is estimated that around 12 million tonnes of SCGs are generated annually, as reported by [9]. Unfortunately, about half of the total SCGs produced (approximately 6 million tonnes) end up in landfills, where they undergo anaerobic decomposition, leading to the production of greenhouse gases, particularly methane (CH_4) [10]. While various initiatives aimed at repurposing SCGs into valuable products are still in their early stages [10], the simplest and most readily available recycling method would be to utilize the grounds as organic amendments in crop production.

The previous studies reported that SCGs have been indicated to offer other services in the agricultural soil, such as improving water retention capacity at concentrations below 150 g kg^{-1} [11] or reducing pesticide leaching [12]. Unfortunately, SCGs contain high quantities of caffein, chlorogenic acid, and tannins that negatively affected to plant growth [13]. For that reason [13], indicated that the benefits derived from fresh SCGs are scanty and that they must be detoxified through composting for a minimum of 98 days. However, since composting takes a lot of time, research is needed to find a dose that is not toxic when SCGs are processed.

Amid the growing interest in sustainable and eco-friendly agriculture, the use of organic amendments is on the rise. However, the types and quantities of organic amendments generated worldwide vary significantly, making it challenging to apply research findings effectively. In this context, food waste powder and spent coffee grounds offer advantages in terms of accessibility and abundance compared to other organic amendments [14]. Nevertheless, due to their distinct characteristics, it is essential to calculate the optimal application rates while considering their individual properties [15].

We hypothesized that organic amendments can effectively supply the nutrients required for crop growth, enhance the functional components of leafy vegetables, and promote eco-friendly agricultural practices by reducing the chemical fertilization. To investigate this, our study assessed the effects of applying dried food waste powder (DFWP) and spent coffee grounds (SCGs), both of which are abundant waste materials, on various characteristics of leaf lettuce and Japanese hogfennel.

Materials and methods

Organic amendments preparation and experimental setup

Spent coffee sludges and dehydrated food waste were sourced from a local coffee shop and a food waste treatment facility near Chungnam National University (36°22′02.1″ N 127°21′12.1″ E) in Daejeon, South Korea. The collected organic amendments were oven-dried at 80 °C for 24 h, cooled in desiccators, and pulverized into a powder form (SCGs and DFWP).

The organic amendments were added to the experimental soil at rates that satisfied half the recommended (0.5), the recommended (1.0), and double the recommended (2.0) nitrogen (N) requirements of each crop. Application rates of both SCGs and DFWP that satisfied the recommended N requirements of the leaf lettuce and Japanese hogfennel were 15 and 10 Mg N/ha, respectively [16]. Furthermore, only-chemical fertilized (N) and untreated treatments (Control) were included the comparison of the agricultural contributions of SCGs and DFWP. In this study, the urea ($CO(NH_2)_2$), fused magnesium phosphate ($Ca_3(PO_4)_2 + CaSiO_3 + MgSiO_3 + Fe_2O_3$), and potassium chloride (KCl) were utilized as inorganic nutrients source, respectively. $SCGs_{0.5}$, $SCGs_{1.0}$, and $SCGs_{2.0}$ denote SCGs applied at rates that supplied 0.5, 1.0, and 2.0 N requirements of leaf lettuce and Japanese hogfennel, respectively, while $DFWP_{0.5}$, $DFWP_{1.0}$, and $DFWP_{2.0}$ designate the DFWP applied at the same aforementioned rates. All treatments were replicated five times.

The cultivation experiment of both leaf lettuce and Japanese hogfennel was conducted for one month from January 12 to February 12, 2020 in a glasshouse at the Chungnam National University. The leaf lettuce (*Lactuca sativa* L.) was grown in a Wagner pot (1/5000 a), while Japanese hogfennel (*Peucedanum japonicum* Thunb.) was cultivated in an acrylic cylindrical pot of 90 and 32 cm in diameter and height, respectively. The latter arrangement was adopted to induce the appropriate elongation of Japanese hogfennel roots, as they are majorly used in

traditional medicine field. Both the Japanese hogfennel and leaf lettuce seedlings were transplanted to pots at 4 weeks after seeding.

Soil and organic amendments characteristics

The analysis of soil characteristics was carried out following the guidelines provided by the [17]. Soil pH and electrical conductivity (EC) were measured in a slurry of the soil and distilled water (DW) mixed in ratios of 1:5 (v/v) using a Benchtop meter with pH and EC probe (ORION™ Versa Star Pro™, Thermo Scientific Inc., Waltham, Massachusetts, USA). Soil organic matter (OM) content was determined by 0.4 N potassium dichromate ($K_2Cr_2O_7$) solution and Tyurin method. Available phosphorus (Avail. P) content of the soil was colorimetrically determined by UV/Vis-Spectrophotometer (GENESYS 50, Thermo Scientific Inc., Waltham, Massachusetts, USA) on the basis of Lancaster method (720 nm). To measure the exchangeable Na^+ content, the experimental soil was extracted by 1 M ammonium acetate (NH_4OA_C) solution adjusted at pH 7.0, and the supernatant was analyzed using ICP-OES (Inductively Coupled Plasma-Optical Emission Spectrometer, ICAP 7000 series, Thermo Scientific Inc., Waltham, Massachusetts, USA).

The characterization of organic amendments was carried out following the official method proven by the [17–19]. The water content of SCGs and DFWP was determined by measuring the weight before and after drying. The pH and EC of the organic amendments (i.e., SCGs and DFWP) were measured in a slurry of the organic materials and DW in ratios of 1:10 (v/v) using the Benchtop meter with pH and EC probe. The OM content was calculated using the moisture and ash contents of SCGs and DFWP. To measure the total P content of SCGs and DFWP, two grams of SCGs and DFWP were extracted with acid solution (5 mL of nitric acid + 30 mL of sulfuric acid + 4 g of sodium nitrate), filtered to obtained the supernatant, and determined by UV/Vis-Spectrophotometer at 400 nm. Inorganic cations contents were extracted using a ternary mixture, consisting of nitric acid (HNO_3), sulfuric acid (H_2SO_4), and perchloric acid ($HClO_4$) at a ratio of 10:1:4 (v/v), and each cation was measured with ICP-OES equipped the channel electron multiplier detector and calibrated by the varying concentration (i.e., 0, 10, 25, 50, and 100 mg/L) of each cation. The physicochemical properties of organic amendments are given in Table 1.

Growth and nutritional components analysis

The growth components of leaf lettuce and Japanese hogfennel, including fresh shoot weight, fresh root weight, leaf counts, leaf length, leaf width, and root length, were measured using a stainless-steel meter ruler and an electronic scale (Pioneer™ precision, OHAUS Corp., Parsippany-Troy Hills, New Jersey, USA). The chlorophyll content of leafy vegetables was assessed with a chlorophyll meter (SPAD-502 Plus, Konica Minolta. Inc. Japan). Heavy metal content, including As, Cd, Ni, and Pb, in leafy vegetables was determined using ICP-OES. Prior to the analysis of heavy metal content, each plant tissue was extracted by a mixture of nitric acid and perchloric acid.

The nutritional and proximate components of leafy vegetables, including crude ash, crude fat, crude protein, moisture, and mineral elements (i.e., Ca, Mg, K, P, Zn, Fe, Mn, and Na) contents, were assessed as follows. To determine the crude ash content, two grams of the crop sample were placed in a crucible, decomposed at 600 °C for 3 h in an electronic furnace (1100 °C Box Furnace, Thermo Scientific Inc., Waltham, Massachusetts, USA), allowed to cool for 2 h, and weighed. The crude fat content was measured using the chloroform ($CHCl_3$) extraction method, where two grams of the crop sample were sequentially treated with 2 mL of ethyl alcohol (CH_3CH_2OH), 20 mL of hydrochloric acid (HCl), and 25 mL of chloroform. The crude protein content was analyzed using a Kjeldahl protein analyzer (Foss™ Kjeltec™ 2022 auto distillation unit, Foss, Hillerød, Hovedstaden, Denmark). The moisture content was determined by measuring the weight before and after freeze-drying. The mineral elements content of crop tissue was extracted with both 5 mL of nitric acid and 1 mL of perchloric acid and measured using ICP-OES. The analytical methods of nutritional components strictly adhered to those proposed by [20, 21].

Functional components analysis

Functional components, such as total flavonoid content, phenolic compounds content, antioxidant activity,

Table 1 Physicochemical properties of the organic amendments used in the pot experiment

Amendments	pH (1:10, H_2O)	EC (dS/m)	WC (%)	OM	Total N	P_2O_5	K_2O	CaO	MgO	NaCl
SCGs	5.29 ± 0.03	6.66 ± 0.39	9.08 ± 1.05	44.26 ± 3.01	2.21 ± 0.21	10.04 ± 0.01	2.83 ± 0.25	2.38 ± 0.11	2.11 ± 0.19	0.01 ± 0.00
DFWP	5.41 ± 0.01	7.44 ± 0.02	4.60 ± 0.53	51.18 ± 5.24	3.25 ± 0.17	18.54 ± 0.32	1.67 ± 0.11	2.80 ± 0.09	4.96 ± 0.44	1.12 ± 0.17

SCGs Spent coffee grounds *DFWP* Dehydrated food waste powder *WC* Water content *OM* Organic matter *N* nitrogen

2,2′-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid (ABTS) radical scavenging activity, 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical scavenging activity, total sugar content (in leaf lettuce), total anthocyanin content (in leaf lettuce), carotenoids content (in leaf lettuce), and coumarin content (in Japanese hogfennel) were evaluated as following. In particular, among the various types of coumarin content, 3,4-disenecioylkhellactone, hyuganin C, and peucedanol-7-O-D-glucopyranoside contents were analyzed by following the recommendation by the department of Herbal Medicine of the Ministry of Food and Drug Safety (MFDS), South Korea [22]. Before the determination of functional components, the pulverized crop samples were extracted by DW at a ratio of 1:10 (w/v) for 30 min, and the aforementioned process was repeated by three times to prepare the samples for functional components measurement. Total sugar content of leaf lettuce was evaluated with 1 mL of the liquid sample, phenol–sulfuric acid solution (mixed 1 mL of 5% (v/v) phenol and 5 mL of sulfuric acid), and UV/Vis-Spectrophotometer (480 nm). The total anthocyanin content was determined with 1 mL of the filtered sample and UV/Vis-Spectrophotometer (520 nm), which calibrated as cyanidin-3-glucoside (C3G) solution [23], while the total flavonoids content was measured using 1 mL of the sample, 5 mL of 5% (v/v) sodium nitrite ($NaNO_2$), 1 mL of 10% (v/v) aluminum chloride ($AlCl_3$), and UV/Vis-Spectrophotometer (415 nm) [24]. The ABTS radical scavenging activity was measured by combination of 1 mL of liquid sample and ABTS solution, which 7.4 mM ABTS and 2.6 mM potassium persulfate ($K_2S_2O_8$). The DPPH free radical scavenging activity was determined with 1 mL of liquid sample, 1 mL of 0.2 mM DPPH solution, and UV/Vis-Spectrophotometer (520 nm). The ABTS and DPPH free radical scavenging activities were assessed following methods proposed by [25].

To determine the total carotenoid (e.g., lutein, zeaxanthin, and all-trans-β-carotene) content of leaf lettuce, a mixture of ethyl alcohol, 80% (v/v) potassium hydroxide (KOH), and sample were prepared. Then, DW and hexane ($CH_3(CH_2)_4CH_3$) were added in a 1:1 (v/v) ratio to extract the carotenoid content from the sample. The resulting supernatant was treated with a mixture of dichloromethane (CH_2Cl_2) and methanol (CH_3OH) in a 1:1 (v/v) ratio and filtered using a 0.45 μm hydrophilic PTFE syringe filter [26]. The filtered sample was measured using a high-performance liquid chromatography (HPLC, Flexar HPLC, Perkin Elmer Inc., Waltham, Massachusetts, USA) with a YMC column (250×4.6 mml.D., YMC Europe GmbH, Dinslaken, Germany) and a mobile phase consisting of a 25:75 (v/v) mixture of DW and methanol. The flow rate of mobile phase was set at 1.0 mL/min, and the wavelength was set at 450 nm. The coumarin content of Japanese hogfennel was similarly carried out the aforementioned analytical method of total carotenoid content [22, 26]. One gram of Japanese hogfennel sample was mixed with methanol and then filtered using a 0.22 μm hydrophilic PTFE syringe filter. The HPLC analysis was conducted with an Optimapak C18 column (250×4.6 mml.D., RS tech Co., Daejeon, South Korea), and the mobile phase consisted of DW and a mixture of acetonitrile (CH_3CN) and methanol in a 9:1 (v/v) ratio. The flow rate of mobile phase was set at 1.0 mL/min, and the wavelength was set at 322 nm. The carotenoid and coumarin contents were quantified by the varying wavelength and reaction time. Generally, the zeaxanthin was detected at 470 nm and 5 min, while the lycopene content was read at 470 nm and 15 min.

Statistical analysis

The experimental data were subjected to a one-way analysis of variance (ANOVA) using a statistical software (SPSS version 24.0, IBM, Armonk, New York, USA) and and post-testing was performed through the Duncan test. The variability in the data was expressed as the standard deviation with a value of significance level ($p < 0.05$ considered to be statistically significant. The statistical differences amongst the different treatments were denoted by small letters of the English alphabet.

Results

Growth, proximate, and nutritional components of leafy vegetables

Table 2 and presents the growth components of leaf lettuce. The inorganic fertilization (N) treatment resulted in heavier fresh shoot and root weights of leaf lettuce compared to both SCGs and DFWP amendments. For instance, in the N treatment, the fresh shoot weight of leaf lettuce was 77.52 g/plant, which was significantly higher than the 20.77 g/plant in the $SCGs_{1.0}$ and the 52.49 g/plant in the $DFWP_{1.0}$ treatments, representing a 373 and 147% increase, respectively. Moreover, all SCGs amendments led to a decrease in the fresh shoot weight of leaf lettuce as the application rates of SCGs increased, while the $DFWP_{0.5}$ and $DFWP_{1.0}$ treatments showed slight increases. When compared to the control treatment, $SCGs_{0.5}$, $SCGs_{1.0}$, and $SCGs_{2.0}$ amendments reduced the fresh shoot weights of leaf lettuce by 75.57, 60.04, and 83.32%, respectively, while the $DFWP_{0.5}$ and $DFWP_{1.0}$ amendments increased the fresh shoot weights by 19.97 and 0.98%, respectively. Similarly, the fresh root weights in the $SCGs_{0.5}$, $SCGs_{1.0}$, and $SCGs_{2.0}$ treatments were 5.51, 7.59, and 3.08 g/plant, respectively, compared to the control treatment. However, the fresh root weights of the N, $DFWP_{0.5}$, and $DFWP_{1.0}$ treatments were increased by 27.45, 9.63, and 7.69%, respectively. The leaf

Table 2 Yield components of both the leaf lettuce and Japanese hogfennel affected by the varying rates of organic amendments

Crops	Treatments	Fresh weight		Leaf			Root length (cm)
		Shoot (g)	Root	Length (cm)	Width	Counts (ea/plant)	
Leaf lettuce	Control	51.98 ± 2.06^{C}	$15.48 \pm 3.08_{ABC}$	16.78 ± 1.03^{A}	9.70 ± 2.37^{B}	21.40 ± 1.85^{AB}	16.68 ± 1.02^{A}
	N	77.52 ± 2.87^{A}	19.73 ± 3.16^{A}	18.50 ± 1.48^{A}	11.96 ± 2.68^{A}	23.40 ± 1.94^{A}	15.34 ± 2.42^{A}
	$SCGs_{0.5}$	12.70 ± 2.04^{DE}	5.51 ± 2.20^{BCD}	8.02 ± 1.46^{C}	4.24 ± 1.36^{D}	14.80 ± 1.62^{C}	15.08 ± 2.32^{A}
	$SCGs_{1.0}$	20.77 ± 2.83^{E}	7.59 ± 2.34^{CD}	6.40 ± 1.04^{CD}	3.60 ± 1.98^{D}	13.20 ± 2.79^{C}	13.20 ± 2.33^{A}
	$SCGs_{2.0}$	8.67 ± 2.98^{D}	3.08 ± 1.83^{CD}	6.10 ± 2.58^{D}	3.50 ± 2.43^{D}	12.00 ± 2.28^{C}	12.60 ± 1.74^{A}
	$DFWP_{0.5}$	62.36 ± 1.29^{B}	16.97 ± 1.11^{AB}	17.32 ± 2.86^{A}	10.22 ± 1.88^{B}	19.80 ± 1.85^{B}	14.06 ± 1.20^{A}
	$DFWP_{1.0}$	52.49 ± 1.33^{C}	16.67 ± 1.83^{BCD}	17.38 ± 1.48^{A}	10.16 ± 2.39^{B}	19.80 ± 2.96^{B}	14.22 ± 2.67^{A}
	$DFWP_{2.0}$	16.53 ± 1.25^{D}	6.72 ± 1.33^{D}	11.68 ± 1.53^{A}	5.74 ± 2.35^{C}	15.20 ± 2.89^{C}	14.44 ± 2.40^{A}
p-value		**	*	*	**	**	***
Japanese hogfennel	Control	0.40 ± 0.07^{c}	0.71 ± 0.33^{b}	2.35 ± 0.35^{bc}	2.85 ± 0.21^{c}	4.00 ± 0.00^{b}	8.30 ± 0.28^{c}
	N	1.12 ± 0.73^{b}	2.15 ± 1.65^{ab}	2.57 ± 0.81^{bc}	4.23 ± 1.00^{b}	4.00 ± 0.00^{b}	12.60 ± 1.87^{c}
	$SCGs_{0.5}$	0.94 ± 0.57^{bc}	3.71 ± 2.83^{ab}	2.80 ± 0.77^{b}	3.84 ± 0.95^{b}	3.80 ± 0.84^{b}	35.28 ± 2.23^{a}
	$SCGs_{1.0}$	1.18 ± 0.35^{b}	4.47 ± 1.02^{a}	2.96 ± 0.57^{b}	4.52 ± 0.25^{b}	4.00 ± 0.00^{b}	22.38 ± 2.11^{b}
	$SCGs_{2.0}$	0.79 ± 0.21^{bc}	1.16 ± 0.53^{ab}	2.76 ± 0.29^{b}	3.98 ± 0.41^{b}	4.20 ± 0.41^{b}	32.76 ± 2.90^{a}
	$DFWP_{0.5}$	1.42 ± 0.34^{b}	4.71 ± 1.82^{a}	3.26 ± 0.49^{b}	4.52 ± 0.72^{b}	5.20 ± 0.90^{a}	30.20 ± 2.14^{ab}
	$DFWP_{1.0}$	2.41 ± 0.53^{a}	4.77 ± 1.87^{a}	4.30 ± 0.70^{a}	6.30 ± 0.90^{a}	5.80 ± 0.72^{a}	34.08 ± 3.36^{a}
	$DFWP_{2.0}$	0.45 ± 0.17^{c}	0.32 ± 0.20^{b}	1.84 ± 0.30^{c}	2.42 ± 0.30^{c}	3.80 ± 0.27^{b}	10.84 ± 3.49^{c}
p-value		***	*	**	***	*	*

Control, Untreated treatment; N, Treatment with inorganic fertilizers; $SCGs_{x.x}$, Treatment applied at half the recommeded rate (0.5), the recommeded rate (1.0), and double the recommeded rate (2.0) of spent coffee grounds; $DFWP_{x.x}$, Treatment applied at half the recommeded rate (0.5), the recommeded rate (1.0), and double the recommeded rate (2.0) of dehydrated food waste powder. Within each column, values follwed by the same letters are not significant difference at $p < 0.05$

*, **, and *** are used to indicate statistically significant differences at the $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively

length, width, and counts of leaf lettuce were the highest in the N treatment, measuring 18.50 cm, 11.96 cm, and 23.40 ea/plant, respectively. The root length did not show statistically significant differences among all treatments. The heavy metal content in leaf lettuce was not detected, while the Ni content in Japanese hogfennel was range from 0.04 to 0.84 mg/kg (Additional file 1: Table S1).

Similar to the observations made in the leaf lettuce cultivation experiment, DFWP amendments resulted in higher fresh shoot and root weight for Japanese hogfennel compared to SCGs amendments (Table 2). The highest fresh shoot and root weights were recorded in the $DFWP_{1.0}$ treatment at 2.41 and 4.77 g/plant, respectively. Compared to the control treatment, the fresh shoot weight of the $DFWP_{0.5}$, $DFWP_{1.0}$, and $DFWP_{2.0}$ treatments were significantly increased by 502.5, 255, and 12.5%, respectively. Additionally, the N, $SCGs_{1.0}$, and $DFWP_{0.5}$ treatments resulted in heavier fresh roots weights, measuring 1.12, 1.18, and 1.42 g/plant, respectively, with no statistically significant differences. When compared to the fresh root weight in the control treatment, the $DFWP_{0.5}$ amendment increased significantly the fresh root weight by 571.8%, while the $DFWP_{2.0}$ amendment decreased it by 54.9%. The leaf length, width, and counts of Japanese hogfennel were the highest in the $DFWP_{1.0}$ treatment at 4.30 cm, 6.30 cm, and 5.80 ea/plant, respectively, while the root length was not observed the significant differences among the $SCGs_{0.5}$, $SCGs_{2.0}$, $DFWP_{0.5}$, and $DFWP_{1.0}$ treatments. For the leaf length, width, and counts, DFWP application outperformed SCGs amendment, while applying double recommended rates of both SCGs and DFWP resulted in the lowest fresh shoot and root weight of Japanese hogfennel. In this study, SCGs and DFWP amendments positively affected on growth components of Japanese hogfennel at the recommended N requirement (i.e., $SCGs_{1.0}$ and $DFWP_{1.0}$), while SCGs largely elicited negative responses in most of the growth components of leaf lettuce.

Table 3 displays the proximate compositions (i.e., moisture, crude ash, crude fat, and crude protein contents) of both leaf lettuce and Japanese hogfennel affected by the varying rates of SCGs and DFWP. The highest moisture content in leaf lettuce was observed in the N treatment at 85.99%, representing a 110% increase compared to the 78.36% in the control treatment. Additionally, DFWP amendments led to increased moisture retention in leaf lettuce, with the $DFWP_{0.5}$ and $DFWP_{1.0}$ treatments showing moisture contents of 82.34 and 82.97%, respectively.

Table 3 Proximate compositions of both the leaf lettuce and Japanese hogfennel affected by the varying rates of organic amendments

Crops	Treatments	Moisture content (%)	Crude ash	Crude fat	Crude protein
Leaf lettuce	Control	78.36 ± 1.01^{D}	0.09 ± 0.02^{F}	0.20 ± 0.04^{D}	11.99 ± 1.02^{E}
	N	85.99 ± 2.93^{A}	0.11 ± 0.05^{D}	0.30 ± 0.02^{B}	17.47 ± 1.45^{C}
	$SCGs_{0.5}$	68.32 ± 1.16^{E}	0.10 ± 0.01^{E}	0.40 ± 0.07^{A}	6.01 ± 0.98^{G}
	$SCGs_{1.0}$	46.06 ± 1.23^{G}	0.20 ± 0.06^{B}	0.41 ± 0.03^{A}	7.60 ± 1.33^{F}
	$SCGs_{2.0}$	29.64 ± 0.56^{H}	0.10 ± 0.09^{E}	0.40 ± 0.04^{A}	5.89 ± 0.73^{H}
	$DFWP_{0.5}$	82.34 ± 4.66^{C}	0.14 ± 0.02^{C}	0.30 ± 0.01^{B}	21.15 ± 0.92^{B}
	$DFWP_{1.0}$	82.97 ± 3.14^{B}	0.40 ± 0.01^{A}	0.25 ± 0.06^{C}	23.80 ± 1.12^{A}
	$DFWP_{2.0}$	50.88 ± 2.18^{F}	0.11 ± 0.04^{D}	0.30 ± 0.03^{B}	17.36 ± 0.56^{D}
p-value		*	**	***	*
Japanese hogfennel	Control	7.75 ± 1.32^{h}	0.65 ± 0.10^{d}	0.25 ± 0.01^{d}	10.20 ± 1.51^{h}
	N	21.09 ± 1.55^{e}	0.75 ± 0.06^{b}	0.35 ± 0.12^{c}	11.10 ± 2.21^{g}
	$SCGs_{0.5}$	19.58 ± 1.44^{g}	0.75 ± 0.11^{b}	0.37 ± 0.08^{c}	12.00 ± 1.37^{f}
	$SCGs_{1.0}$	20.66 ± 1.67^{f}	0.75 ± 0.16^{b}	0.25 ± 0.03^{d}	14.20 ± 1.21^{e}
	$SCGs_{2.0}$	42.44 ± 1.42^{a}	0.75 ± 0.18^{b}	0.35 ± 0.10^{c}	15.40 ± 2.12^{d}
	$DFWP_{0.5}$	31.93 ± 1.13^{c}	0.70 ± 0.22^{c}	0.75 ± 0.21^{a}	17.30 ± 1.41^{c}
	$DFWP_{1.0}$	36.37 ± 1.43^{b}	0.80 ± 0.24^{a}	0.45 ± 0.13^{b}	31.00 ± 3.11^{a}
	$DFWP_{2.0}$	28.75 ± 1.02^{d}	0.70 ± 0.15^{c}	0.75 ± 0.23^{a}	29.60 ± 1.21^{b}
p-value		**	***	*	**

Control, Untreated treatment; N, Treatment with inorganic fertilizers; $SCGs_{x.x}$, Treatment applied at half the recommeded rate (0.5), the recommeded rate (1.0), and double the recommeded rate (2.0) of spent coffee grounds; $DFWP_{x.x}$, Treatment applied at half the recommeded rate (0.5), the recommeded rate (1.0), and double the recommeded rate (2.0) of dehydrated food waste powder. Within each column, values follwed by the same letters are not significant difference at $p < 0.05$

*, **, and *** are used to indicate statistically significant differences at the $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively

The crude ash and protein contents in leaf lettuce were enhanced by DFWP amendments compared to SCGs amendments. The crude protein content in SCGs amendments was lower than that in the control treatment by 11.99%. The highest crude ash and protein contents were recorded in the $DFWP_{1.0}$ treatment at 0.40 and 23.80%, respectively, representing an increase of 3.64 and 1.36 times compared to 0.11 and 17.47% in the N treatment, respectively. On the other hand, the crude fat content in leaf lettuce was higher with SCGs amendments compared to the control, N, and DFWP treatments. The $SCGs_{1.0}$ treatment had the highest crude fat content at 0.41%, which was 1.37 times higher than in the N treatment. The moisture content of Japanese hogfennel was higher with SCGs and DFWP amendments compared to the 7.75% in the control treatment, while the $SCGs_{0.5}$ and $SCGs_{1.0}$ treatments were lower than the 21.09% in the N treatment. The crude ash content of Japanese hogfennel was the highest in the $DFWP_{1.0}$ treatment at 0.80%, while the $DFWP_{0.5}$ and $DFWP_{2.0}$ treatments were 1.07 times lower than the SCGs amendments. The crude fat content was similar among the N, $SCGs_{0.5}$, and $SCGs_{2.0}$ treatments, while the $DFWP_{0.5}$ and $DFWP_{2.0}$ treatments showed the highest crude fat content at 0.75% compared to other treatments. The $DFWP_{1.0}$ amendment significantly improved the crude protein content, reaching 31.00%, which represented a 304% increase compared to the 10.20% in the control treatment.

Table 4 presents the mineral content of both leaf lettuce and Japanese hogfennel affected by the different organic amendments. The highest mineral contents of leaf lettuce found in DFWP amendments. Specifically, $DFWP_{1.0}$ amendment resulted in the highest concentrations of K and P contents at 607.03 and 77.45 mg/100 g, respectively, while the $DFWP_{0.5}$ treatment led to Fe-rich leaf lettuce with 15.43 mg Fe/100 g. With the increasing rates of SCGs amendments, the Na, Mg, K, P, and Fe contents in leaf lettuce increased, while the Ca, Zn, and Mn content showed the reverse trend. By and large, SCGs amendments led to lower mineral contents of leaf lettuce. Conversely, DFWP amendments induced the mineral-rich Japanese hogfennel, with the highest mineral contents observed in the $DFWP_{1.0}$ treatment (Table 4). Unlike leaf lettuce, where SCGs amendments invoked a negative effect, they had a positive effect on the mineral contents of Japanese hogfennel. The SCGs treatments (i.e., $SCGs_{0.5}$, $SCGs_{1.0}$, and $SCGs_{2.0}$) outperformed the N treatment, with the highest mineral contents achieved in the $SCGs_{1.0}$ treatment. The Ca and P contents of Japanese hogfennel in the $SCGs_{1.0}$ treatment were significantly

Table 4 Mineral content of both the leaf lettuce and Japanese hogfennel affected by the varying rates of organic amendments

Crops	Treatments	Na (mg/100 g)	Mg	K	Ca	P	Fe	Zn	Mn
Leaf lettuce	Control	54.28 ± 2.10^{D}	57.26 ± 2.34^{D}	309.10 ± 7.71^{C}	96.58 ± 4.31^{C}	40.53 ± 2.92^{D}	8.24 ± 1.24^{CD}	0.48 ± 0.02^{C}	0.78 ± 0.03^{E}
	N	59.10 ± 1.67^{D}	72.22 ± 1.74^{C}	340.89 ± 4.65^{B}	105.60 ± 4.65^{B}	62.99 ± 2.90^{C}	7.61 ± 0.57^{D}	0.73 ± 0.11^{A}	1.22 ± 0.19^{C}
	$SCGs_{0.5}$	11.23 ± 0.84^{F}	15.95 ± 1.62^{G}	141.95 ± 3.64^{F}	108.68 ± 8.85^{B}	22.27 ± 0.55^{F}	7.51 ± 0.06^{CD}	0.03 ± 0.00^{F}	0.49 ± 0.01^{G}
	$SCGs_{1.0}$	10.21 ± 1.22^{F}	14.15 ± 1.09^{G}	198.61 ± 3.60^{EF}	59.37 ± 1.17^{D}	18.05 ± 2.75^{E}	9.07 ± 1.55^{CD}	0.03 ± 0.01^{F}	0.30 ± 0.11^{H}
	$SCGs_{2.0}$	20.93 ± 2.60^{E}	32.96 ± 3.87^{F}	291.55 ± 4.79^{C}	52.45 ± 4.93^{D}	42.62 ± 2.86^{D}	8.15 ± 1.15^{CD}	0.26 ± 0.04^{E}	2.31 ± 0.48^{B}
	$DFWP_{0.5}$	82.25 ± 1.02^{C}	40.84 ± 2.90^{E}	255.07 ± 6.67^{D}	147.14 ± 6.95^{A}	59.69 ± 5.39^{C}	15.43 ± 1.71^{A}	0.74 ± 0.09^{A}	6.48 ± 0.10^{A}
	$DFWP_{1.0}$	190.91 ± 2.03^{B}	86.22 ± 3.54^{B}	607.03 ± 9.04^{A}	147.74 ± 4.08^{A}	77.45 ± 2.18^{A}	10.26 ± 1.36^{B}	0.64 ± 0.13^{B}	0.65 ± 0.09^{F}
	$DFWP_{2.0}$	267.71 ± 1.20^{A}	124.20 ± 5.49^{A}	150.93 ± 1.44^{EF}	148.57 ± 2.71^{A}	65.74 ± 3.77^{B}	10.76 ± 1.29^{B}	0.38 ± 0.04^{D}	1.04 ± 0.10^{D}
p-value		***	**	**	**	*	**	***	**
Japanese hogfennel	Control	22.91 ± 1.22^{e}	62.58 ± 2.23^{f}	62.20 ± 3.20^{e}	88.84 ± 3.21^{f}	19.71 ± 1.02^{e}	88.35 ± 2.11^{g}	0.35 ± 0.05^{f}	4.97 ± 0.33^{g}
	N	25.49 ± 1.23^{cd}	86.71 ± 2.22^{e}	82.15 ± 3.19^{d}	90.82 ± 3.15^{f}	19.84 ± 1.02^{e}	161.63 ± 4.12^{f}	0.55 ± 0.05^{e}	7.08 ± 0.93^{f}
	$SCGs_{0.5}$	28.96 ± 0.45^{cd}	98.62 ± 2.68^{d}	83.24 ± 5.18^{d}	98.60 ± 3.42^{e}	24.24 ± 2.67^{d}	219.14 ± 1.62^{d}	0.71 ± 0.08^{c}	9.18 ± 0.68^{d}
	$SCGs_{1.0}$	29.85 ± 0.54^{cd}	108.06 ± 7.07^{c}	84.06 ± 0.50^{d}	134.36 ± 6.59^{d}	27.63 ± 1.91^{c}	254.07 ± 7.00^{c}	0.72 ± 0.00^{c}	9.24 ± 1.71^{d}
	$SCGs_{2.0}$	28.36 ± 0.39^{d}	98.32 ± 6.60^{d}	82.71 ± 5.25^{d}	98.51 ± 3.73^{e}	24.06 ± 1.67^{d}	204.72 ± 3.26^{e}	0.59 ± 0.05^{d}	7.88 ± 0.47^{e}
	$DFWP_{0.5}$	37.22 ± 2.37^{b}	116.77 ± 5.86^{b}	105.60 ± 4.27^{b}	150.10 ± 5.47^{b}	29.44 ± 3.76^{b}	278.87 ± 2.67^{b}	0.78 ± 0.03^{b}	10.30 ± 1.44^{b}
	$DFWP_{1.0}$	44.40 ± 4.05^{a}	132.93 ± 6.10^{a}	114.04 ± 3.24^{a}	165.77 ± 7.17^{a}	32.33 ± 2.01^{a}	351.88 ± 11.01^{a}	1.07 ± 0.19^{a}	11.23 ± 0.81^{a}
	$DFWP_{2.0}$	31.25 ± 2.73^{c}	116.56 ± 5.92^{b}	94.14 ± 1.41^{c}	138.73 ± 5.48^{c}	29.18 ± 1.73^{b}	278.85 ± 7.30^{b}	0.77 ± 0.13^{b}	9.79 ± 0.94^{c}
p-value		*	**	***	**	*	*	**	***

Control, Untreated treatment; N, Treatment with inorganic fertilizers; $SCGs_{x.x}$, Treatment applied at half the recommeded rate (0.5), the recommeded rate (1.0), and double the recommeded rate (2.0) of spent coffee grounds; $DFWP_{x.x}$, Treatment applied at half the recommeded rate (0.5), the recommeded rate (1.0), and double the recommeded rate (2.0) of dehydrated food waste powder. Within each column, values follwed by the same letters are not significant difference at $p < 0.05$

*, **, and *** are used to indicate statistically significant differences at the $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively

higher, at 134.36 and 27.63 mg/100 g, respectively, compared to the $SCGs_{0.5}$ and $SCGs_{2.0}$ treatments. Furthermore, the Fe content of Japanese hogfennel in the $SCGs_{1.0}$ treatment was 254.07 mg/100 g, representing a 288% increase compared to 88.35 mg/100 g of the control treatment.

Functional components of leafy vegetables

The sugar content of leaf lettuce responded positively to SCGs and DFWP amendments, although there were no significant statistical differences among all treatments (Additional file 1: Fig. S1a). The highest total sugar content was induced by $DFWP_{1.0}$ amendment with 261.97 mg/g. The total anthocyanin content by DFWP amendments was augmented its concentration as compared to the control treatment, whereas SCGs amendments were diminished it below of 250 mg C3G/ml DW (Additional file 1: Fig. S1b). In particular, the total anthocyanin content of leaf lettuce was the highest in the $DFWP_{1.0}$ treatment with 714.11 mg C3G/ml DW, while the $SCGs_{0.5}$, $SCGs_{1.0}$, and $SCGs_{2.0}$ treatments resulted into 62, 56, and 44% losses of the total anthocyanin content, respectively.

Figure 1 illustrates the total flavonoid and total phenolic compounds contents of leafy vegetables. In leaf lettuce, the highest total flavonoid content was observed in the $DFWP_{1.0}$ treatment at 740.87 mg CE/mL DW, followed by superior leaf lettuce growth from the $DFWP_{0.5}$, $DFWP_{2.0}$, and N treatments (Fig. 1a). The total flavonoid content in the $DFWP_{1.0}$ treatment was 114% higher than the 650.16 mg CE/mL DW of the control treatment. Similarly, in Japanese hogfennel, the highest total flavonoid content was found in the $DFWP_{1.0}$ treatment at 8.04 mg CE/mL DW, while the control and N treatments had 2.00 and 2.62 mg CE/mL DW, respectively (Fig. 1b). The total flavonoid content from SCGs amendments ranged from 3.39 to 5.81 mg CE/mL DW, which was 1.5 to 2.5 times higher than in the control treatment. In leaf lettuce, the highest total phenolic compounds content was observed in the $DFWP_{1.0}$ treatment at 196.20 mg GAE/mL DW, which was 1.01 times higher than the 194.75 mg GAE/mL DW in the control treatment (Fig. 1c). The total phenolic compounds content in leaf lettuce did not represent statistically significant differences among all treatments. On the other hand, the total phenolic compounds content in the $SCGS_{2.0}$ and $DFWP_{1.0}$ treatments was higher than in other treatments, such as the N, $SCGs_{1.0}$, and $DFWP_{2.0}$ treatments (Fig. 1d). Specifically, the $DFWP_{1.0}$ treatment had the highest total phenolic compounds content in Japanese hogfennel at 36.96 mg GAE/mL DW, which was 226 and 204% higher than in the control and N treatments, respectively.

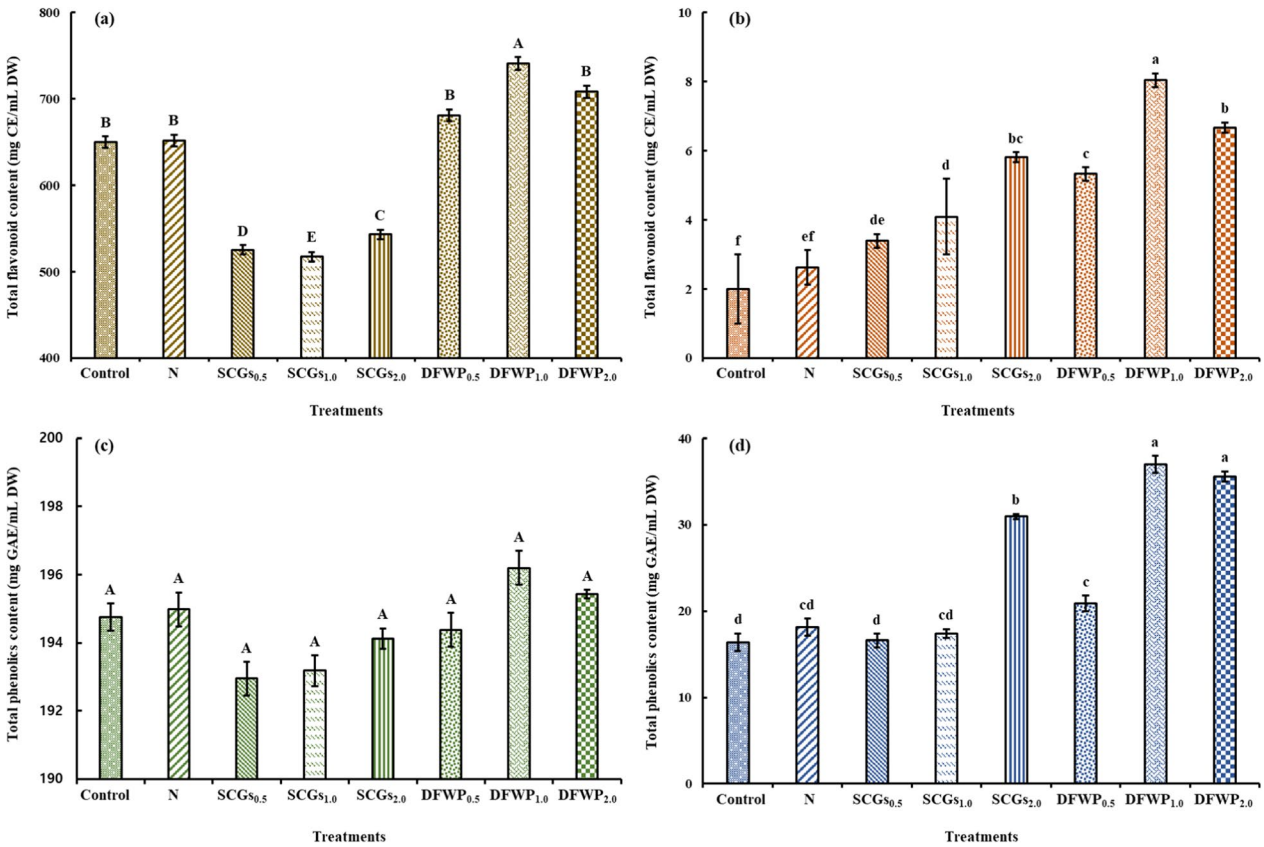

Fig. 1 Total flavonoid contents of **a** leaf lettuce and **b** Japanese hogfennel, and total phenolic contents of **c** leaf lettuce and **d** Japanese hogfennel

Figure 2 depicts the ABTS and DPPH free radical scavenging activities in leafy vegetables. The $DFWP_{1.0}$ amendments produced leaf lettuce with the highest content of the ABTS radical scavenging activity at 99.00%, which was no significant differences from the 98.75% observed in the N treatment (Fig. 2a). Furthermore, the $SCGs_{0.5}$ amendment led to the lowest content of ABTS radical scavenging activity, while the $DFWP_{2.0}$ amendment elicited a negative response in the ABTS radical scavenging activity in leaf lettuce. On the other hand, in Japanese hogfennel, the highest ABTS radical scavenging activity was found in the $DFWP_{1.0}$ treatment at 55.65%, which was statistically superior to other treatments (Fig. 2b). In particular, the control and N treatments were 2.84 and 2.65 times lower than the $DFWP_{1.0}$ treatment, respectively. The DPPH free radical scavenging activity in both leaf lettuce and Japanese hogfennel was the highest in the $DFWP_{1.0}$ treatment with 72.01% and 90.00%, respectively, while the DPPH free radical scavenging activity in Japanese hogfennel was no significant differences between the $DFWP_{1.0}$ and $DFWP_{2.0}$ treatments (Fig. 2c and d). Furthermore, all amendments enhanced the DPPH free radical scavenging activity in both leaf lettuce and Japanese hogfennel, except for the $SCGs_{0.5}$ amendment in leaf lettuce.

Table 5 summarizes the total carotenoid contents in leaf lettuce grown with the varying rates of organic amendments. The highest contents of all-trans-β-carotene, 9Z-β-carotene, 13Z-β-carotene, lutein, violaxanthin, and zeaxanthin were found in the $DFWP_{1.0}$ treatment compared to other treatments. For instance, the $DFWP_{1.0}$ amendment induced the highest lutein content at 12.96 mg/100 g fresh weight (FW), which was 518 and 368% higher than the 2.50 and 3.52 mg/100 g FW in the control and N treatments, respectively. Additionally, the $DFWP_{1.0}$ treatment had the highest violaxanthin content at 1.56 mg/100 g FW while the $DFWP_{0.5}$ and $DFWP_{2.0}$ treatments resulted in leaf lettuce with 12 and 25% lower violaxanthin content, respectively. Furthermore, the total carotenoid contents in leaf lettuce grown with DFWP amendments were higher than in the control and N treatments, while the total carotenoid contents decreased with the application rate of DFWP at double the recommended N requirement (2.0). On the other hand, the total carotenoid contents in leaf lettuce

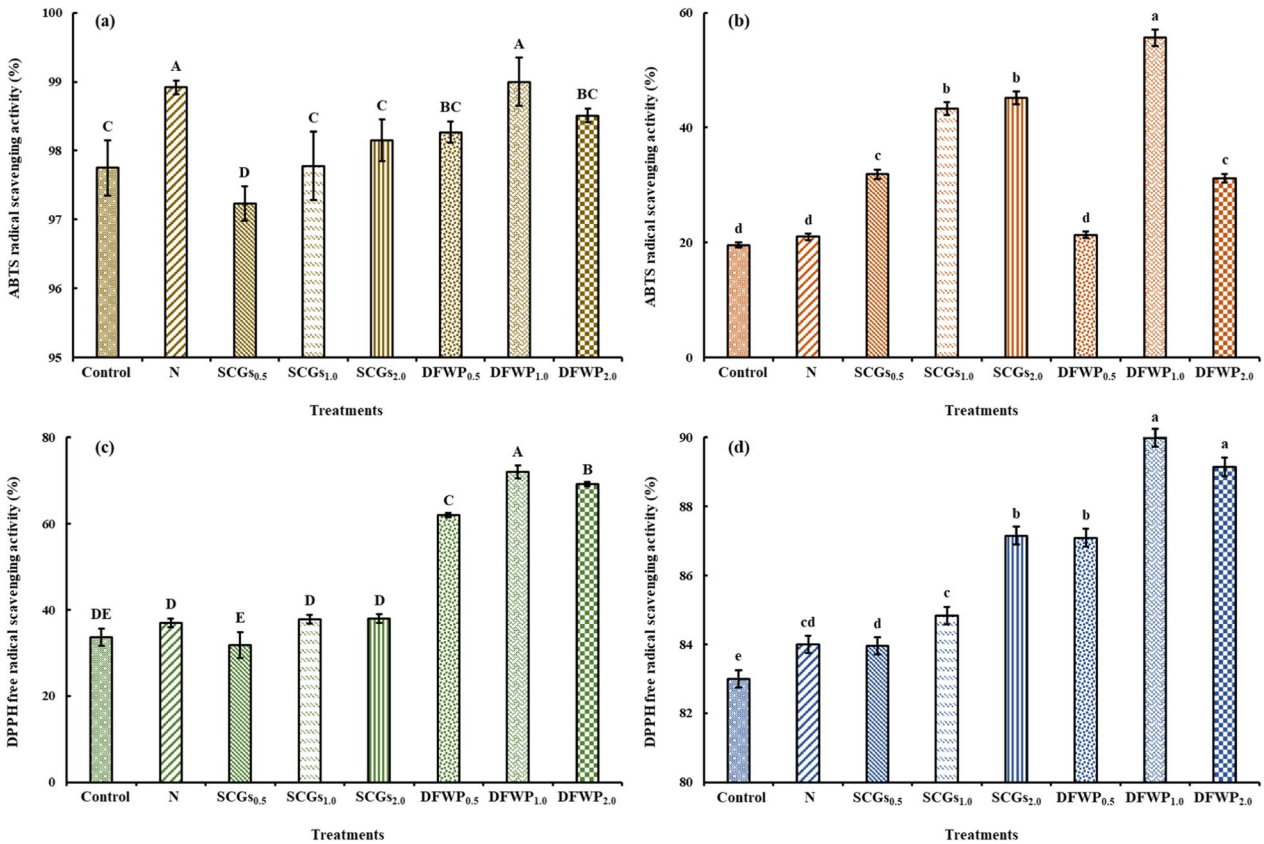

Fig. 2 ABTS radical scavenging activities of **a** leaf lettuce and **b** Japanese hogfennel, and DPPH radical activities of **c** leaf lettuce and **d** Japanese hogfennel

Table 5 Various carotenoids content of the leaf lettuce affected by the varying rates of organic amendments

Treatments	Violaxanthin (mg/100 g FW)	Lutein	All-*trans*-β-carotene	Zeaxanthin	13Z-β-carotene	9Z-β-carotene	Others
Control	0.23 ± 0.02^{h}	2.50 ± 0.72^{g}	2.40 ± 0.66^{h}	0.15 ± 0.09^{e}	0.50 ± 0.19^{e}	0.85 ± 0.16^{h}	2.85 ± 0.88^{h}
N	0.26 ± 0.03^{g}	3.52 ± 0.93^{f}	2.53 ± 0.47^{g}	0.11 ± 0.00^{f}	0.53 ± 0.08^{d}	3.41 ± 0.85^{a}	13.53 ± 2.48^{a}
$SCGs_{0.5}$	0.39 ± 0.02^{f}	4.29 ± 1.23^{e}	4.18 ± 0.59^{f}	0.17 ± 0.08^{d}	0.61 ± 0.16^{c}	1.16 ± 0.69^{f}	5.17 ± 0.58^{fg}
$SCGs_{1.0}$	0.64 ± 0.06^{d}	8.55 ± 0.67^{c}	3.50 ± 0.96^{e}	0.20 ± 0.04^{c}	0.65 ± 0.23^{b}	0.95 ± 0.25^{g}	4.25 ± 0.98^{g}
$SCGs_{2.0}$	0.57 ± 0.05^{e}	7.65 ± 1.29^{d}	5.20 ± 0.90^{d}	0.30 ± 0.08^{a}	0.60 ± 0.18^{c}	1.25 ± 0.50^{e}	6.45 ± 1.77^{e}
$DFWP_{0.5}$	1.37 ± 0.12^{b}	11.34 ± 2.12^{b}	9.90 ± 1.45^{c}	0.24 ± 0.09^{b}	0.96 ± 0.24^{a}	1.74 ± 0.44^{c}	12.18 ± 1.89^{b}
$DFWP_{1.0}$	1.56 ± 0.09^{a}	12.96 ± 1.83^{a}	11.76 ± 0.99^{a}	0.31 ± 0.02^{a}	0.97 ± 0.21^{a}	1.86 ± 0.79^{b}	12.84 ± 1.67^{c}
$DFWP_{2.0}$	1.17 ± 0.20^{c}	12.95 ± 1.78^{a}	10.92 ± 1.91^{b}	0.30 ± 0.06^{a}	0.66 ± 0.13^{b}	1.68 ± 0.38^{d}	11.40 ± 1.68^{d}
p-value	**	*	*	*	**	**	**

Control, Untreated treatment; N, Treatment with inorganic fertilizers; $SCGs_{x.x}$, Treatment applied at half the recommeded rate (0.5), the recommeded rate (1.0), and double the recommeded rate (2.0) of spent coffee grounds; $DFWP_{x.x}$, Treatment applied at half the recommeded rate (0.5), the recommeded rate (1.0), and double the recommeded rate (2.0) of dehydrated food waste powder; FW, Fresh weight. Within each column, values follwed by the same letters are not significant difference at $p < 0.05$

* and ** are used to indicate statistically significant differences at the $p < 0.05$ and $p < 0.01$, respectively

increased with higher rates of SCGs amendments. The detailed HPLC results were documented in [27].

Table 6 presents the coumarin content, including 3,4-disenecioylkhellacton, hyuganin C, and peucedanol-7-O-D-glucopyranoside, in Japanese hogfennel grown with the varying rates of organic amendments. The highest content of 3,4-disenecioylkhellacton, hyuganin C, and peucedanol-7-O-D-glucopyranoside was recorded in the

Table 6 Coumarin contents of Japanese hogfennel affected by the varying rates of organic amendments

Treatments	3,4-disenecioylkhellactone (mg/100 g)	Hyuganin C	Peucedanol-7-o-D-glucopyranoside
Control	0.13 ± 0.01^{h}	2.42 ± 0.72^{h}	11.08 ± 1.01^{g}
N	0.64 ± 0.12^{e}	7.92 ± 1.10^{g}	45.64 ± 4.21^{e}
$SCGs_{0.5}$	4.41 ± 0.25^{d}	9.96 ± 1.20^{f}	42.16 ± 2.12^{f}
$SCGs_{1.0}$	0.41 ± 0.14^{g}	10.08 ± 2.09^{d}	46.44 ± 3.11^{d}
$SCGs_{2.0}$	0.43 ± 0.12^{f}	10.04 ± 1.34^{e}	46.40 ± 2.65^{d}
$DFWP_{0.5}$	5.08 ± 0.87^{c}	13.98 ± 2.11^{c}	53.64 ± 5.97^{c}
$DFWP_{1.0}$	8.81 ± 1.11^{a}	14.94 ± 2.20^{a}	62.62 ± 5.11^{a}
$DFWP_{2.0}$	7.21 ± 1.21^{b}	14.52 ± 1.08^{b}	59.82 ± 6.09^{b}
p-value	**	**	*

Control, Untreated treatment; N, Treatment with inorganic fertilizers; $SCGs_{x.x}$, Treatment applied at half the recommeded rate (0.5), the recommeded rate (1.0), and double the recommeded rate (2.0) of spent coffee grounds; $DFWP_{x.x}$, Treatment applied at half the recommeded rate (0.5), the recommeded rate (1.0), and double the recommeded rate (2.0) of dehydrated food waste powder. Within each column, values follwed by the same letters are not significant difference at $p < 0.05$

* and ** are used to indicate statistically significant differences at the $p < 0.05$ and $p < 0.01$, respectively

$DFWP_{1.0}$ treatment at 8.81, 14.94, and 62.62 mg/100 g FW compared to other treatments. For instance, the 3,4-disenecioylkhellacton content in Japanese hogfennel grown with the $DFWP_{1.0}$ amendment was 8.81 mg/100 g FW, which was 67.77 and 13.77 times higher than in the control and N treatments. Additionally, the total coumarin contents were the highest at 86.37 mg/100 g FW in the $DFWP_{1.0}$ treatment, while the $DFWP_{2.0}$ amendment led to decrease in the total coumarin contents to 81.55 mg/100 g FW. The detailed HPLC results were previously recorded in [28].

Discussions

Effects on growth, proximate, and nutritional components of leafy vegetables

Both DFWP and SCGs amendments have limitations in terms of supporting proper plant growth. DFWP is inherently enriched with sodium chloride (NaCl), which could lead to high salinity conditions in the agricultural soil. [29] have reported reduced crop yields with increasing levels of sodium chloride in the agricultural soil. Additionally, [30] has linked the detrimental effects of sodium chloride on tomato growth to its ability to reduce photosynthesis, chlorophyll content, gas-phase conductance, and dark-adapted quantum yield. As shown in Additional file 1: Fig. S2, the N treatment was produced leaf lettuce with the highest chlorophyll content. However, given the very low level of linear relationship observed between chlorophyll content and marketable leaf lettuce yield ($R^2 = 0.571$), it is highly unlikely that chlorophyll content was the limiting factor for leaf lettuce yield in the current study (Additional file 1: Fig. S2b). DFWP amendments resulted in the production of fewer leaves than the control treatment and showed no statistically significant differences in leaf width and length compared to the control treatment. Therefore, it is plausible to assume that DFWP reduced the photosynthetic surface area of the leaf lettuce, which consequently affected the yield.

On the other hand, the $DFWP_{0.5}$ and $DFWP_{1.0}$ amendments resulted in the highest marketable yield for Japanese hogfennel. This observation suggests that certain crops exhibit varying resilience to elevated levels of sodium (Na^+) and chlorine (Cl^-). Based on [31], the dry weight of safflower increased by 40–50% when adequate Na^+ and potassium (K^+) were supplied, indicating that safflower's yield can be enhanced by providing sufficient Na^+. Additionally, [32] reported that several crops, including lettuce, tomatoes, cabbage, sugar beets, and alfalfa, saw yield increases ranging from 30 to 68% when adequate Cl^- was supplied, suggesting that Cl^- is beneficial for the growth of these plants. Hence, it is essential to determine the appropriate application rate of DWFP, contains both plant nutrients and NaCl contents, for each crop to maximize the benefits obtained from it.

The reduced leaf lettuce yields obtained with SCGs are consistent with findings from [11, 13, 33]. While some studies had suggested that the suppressed plant growth associated with SCGs amendments was owing to N immobilization, [33] refuted these claims by demonstrating that the C/N ratio of the SCGs used could not immobilize N. Moreover, [13] indicated that the lower agronomic performance of parsley plants when grown with SCGs was linked to the higher levels of phytotoxic substances including caffeine, chlorogenic acid, and tannins found in SCGs. [11] suggested that although SCGs could improve soil water-retention capacity, their impact on leaf lettuce growth was negative, attributed to a reduction in the minimum drainable porosity of the agricultural soil. This decrease in minimum drainable porosity directly affected soil aeration by reducing space for oxygen diffusion (Additional file 1: Table S2). The higher yields of Japanese hogfennel obtained with SCGs applied at the standard rate indicate that SCGs can be agronomically beneficial for the growth and production of certain types of crops. Positive results were also noted by [34], who observed that SCGs applied at rates of up to 10% of the soil mixture did not reduce leaf lettuce yields compared to the control.

The variations in moisture content of both leaf lettuce and Japanese hogfennel align with findings from [35], which highlighted that the moisture content of three different vegetables varied depending on the type of fertilizer used. [35] suggested that the higher moisture

content in vegetables grown with organic fertilizers was attributed to the slow-release nature of the fertilizers, which hindered dry matter accumulation in the growing vegetables. However, this argument may not be directly applicable to the current situation, as each amendment had different nutrient compositions for plant growth. The high crude protein content in both the leaf lettuce and Japanese hogfennel grown with the $DFWP_{1.0}$ amendment indicates that DFWP is rich in readily available N and serves as a better N source than the N treatment. The higher crude protein content in Japanese hogfennel grown with SCGs compared to the N treatment implies that Japanese hogfennel is rich in plant nutrients, including N. However, it's important to use appropriate rates of DFWP for crops that are not resistant or resilient to toxins to ensure proper plant growth.

The observation that the $DFWP_{1.0}$ amendment resulted in higher mineral contents in both leaf lettuce and Japanese hogfennel can be attributed to the substantial nutritional value of DFWP, as detailed in Table 1. However, the observed reductions in mineral content in leaf lettuce when grown with SCGs are different with the findings of [36], who reported a decrease in all mineral elements except K^+ with increasing application rates of SCGs. In contrast to the observations made by [36], the mineral elements in the current study consistently varied with the application of SCGs, which increased with higher application rates of the SCGs.

However, similar to the current findings, a study conducted by [37] found that SCGs increased the concentrations of mineral elements in leaf lettuce, with the exception of P and Cu. This previous study attributed the increased uptake of mineral elements to the decreases in soil pH induced by the acidic nature of SCGs. Soil pH can significantly affect the availability of mineral elements, and the mineral availability of plant was generally higher with the lower soil pH [37]. This observation aligns with the findings in Japanese hogfennel, where all mineral elements not only exceeded those obtained from the control but also outperformed the chemical fertilization of the N treatment. Another explanation provided to clarify the increased mineral contents in leaf lettuce grown with SCGs, as suggested by the aforementioned study, was the potential release of chelated elements from the SCGs, such as soluble chelates like melanoidins, polyphenols, or carbohydrate breakdown products [37]. However, it is worth noting that while both mechanisms may have occurred in both lettuce and Japanese hogfennel, only the latter showed positive results. This suggests that there might be a specific reason related to the physiology and composition of Japanese hogfennel that allows it to benefit from SCGs, although further research in this direction is needed to provide a more comprehensive understanding.

Effects on functional components of leafy vegetables

Total sugar and anthocyanin contents are crucial quality attributes of leaf lettuce, with sugar content determining its sweetness and anthocyanin influencing its color [38]. The higher total sugar content obtained from the leaf lettuce grown with DFWP and N amendments contradicts the observation made by [39], which showed that the total sugar content in leaf lettuce decreased with increasing rates of N fertilization. On the other hand, SCGs amendments resulted in the agreement with the findings of previous study, which was recorded that the total sugar content and rates of N fertilization were showed the positive correlation. This is notable since both DFWP and N amendments were N-rich, but produced leaf lettuce with the highest total sugar content (Additional file 1: Fig. S1a). The decrease in total sugar content reported by [39] resulted from reductions in sucrose content, while glucose and fructose concentrations increased with rising N rates, as also observed by [38]. Additionally, since there were no significant differences among all the amendments, it can be concluded that high nutrient supply had relatively lower impact on the total sugar contents of the leaf lettuce. On the other hand, the observations concerning the total anthocyanin contents suggest that it increased with higher nutrient availability for the growing leaf lettuce. In a related study, [40] showed that supplementing soil with N, phosphorus (P_2O_5), and K_2O fertilization, in addition to liming, increased the total anthocyanin contents of lowbush blueberries in a two-year experiment. Furthermore, the effects of these fertilizers on the total anthocyanin contents were particularly evident in the second season with lime application [40]. This observation may explain the higher total anthocyanin contents in leaf lettuce amended with DFWP, as it raised the soil pH and exhibited liming effects (Additional file 1: Fig. S1b and Table S2).

The higher concentrations of total flavonoid and total phenolic compounds observed in both Japanese hogfennel and leaf lettuce grown with the $DFWP_{1.0}$ amendment. The aforementioned results align with the findings of [41], who observed that the N amendment resulted in kacip Fatimah (*Labisia pumila* Benth) with lower contents of both total phenolic compounds and total flavonoids compared to those grown with poultry manure. This observation was later corroborated by [42], who found that organically cultivated guava (*Psidium guajava* L.) contained more phenolic compounds than those grown with chemical fertilization. However, the effect of organic amendments on the total flavonoid

contents in their study was largely neutral, which contradicts the observations made in the present study. In their review, [43] noted that the synthesis of secondary metabolites, including polyphenols, competes with leaf vegetables growth for similar substrates. When environmental conditions are suitable, leaf vegetables growth tends to receive priority over the synthesis of secondary metabolites and storage. Furthermore, [43] put forth the idea that the anticipated C/N balance suggests an inverse relationship between nitrogen availability and the synthesis of carbon-based secondary metabolites, such as phenolic compounds and flavonoids. This implies that high nitrogen supply negatively affects the development of phenolic compounds and flavonoids. However, the observations in the present study, particularly regarding leaf lettuce, do not align with the propositions from the studies mentioned. The N and DFWP amendments, both with high nitrogen content, resulted in higher contents of flavonoids and phenols compared to the control and coffee grounds, which had lower nitrogen levels (Fig. 1). It's worth noting that the C/N balance hypothesis may not be universally applicable. For instance, a study by [44] found that high N rates increased the total phenolic compounds and flavonoid contents of winter wheat grain. Additionally, [45] discovered that the simultaneous application of higher rates of both N and K^+ led to grape berries with the elevated total phenolic compounds content, even though the solitary application of N or combined application with lower K^+ rates reduced them.

The higher DPPH free radical activity and ABTS radical scavenging activity observed with the $DFWP_{1.0}$ amendment are consistent with the findings of [46], who noted that biochar amendments improved both ABTS and DPPH free radical scavenging activity contents in andrographis (*Andrographis paniculate* (Burm. f.) Nees). However, [47] contradicted this observation by stating that vermicompost led to pineapples with higher ABTS and DPPH free radical scavenging activity contents compared to chemical fertilization. [46] proposed that the elevated levels of antioxidant activity might be attributed to the enhancement of the total phenolic compounds and flavonoids content caused by biochar. This explanation may hold in this study since the Pearson's correlation coefficients among the total flavonoids, total phenolic compounds contents, and each of the antioxidant activities contents were very high in both leaf lettuce and Japanese hogfennel (Additional file 1: Tables S3 and S4). The relatively low levels of antioxidant activity observed in the $DFWP_{2.0}$ amendment might have resulted from salinity caused by NaCl in the DFWP. In fact, [48] reported that soil salinity reduced the contents of both ABTS and DPPH free radical scavenging activities in soybean (*Glycine max* L.)

A study by [49] demonstrated that the N application enhanced the total carotenoid content in sweet potatoes (*Ipomoea batatas* L.). This finding was later supported by [50], who reported that the β-carotene content in orange-fleshed sweet potatoes increased with higher application rates of N, P_2O_5, and K_2O fertilization. Based on the studies mentioned above, it can be concluded that the total carotenoid content of leaf lettuce in the present study was positively influenced by the nutrient availability in the soil, as all amendments increased the total carotenoid contents compared to the control. Additionally, a study conducted by [51] reported that the total carotenoid content varied among different cultivars of leaf lettuce and across different cultivation seasons. The former findings indicated that the total carotenoid content of leaf lettuce exhibited variations among cultivars, although these differences were not statistically significant. Furthermore, according to [52], the cultivation season can significantly affect light-related elements such as photosynthesis, and the content of violaxanthin was varied with changes in chlorophyll content [51]. It's noteworthy that in this study, there was a strong positive correlation between violaxanthin and chlorophyll contents with $+0.902^{**}$ as shown in Additional file 1: Table S5, which presents the correlations between different types of carotenoids and their relationship with chlorophyll content.

As noted above, the three types of coumarin content in the Japanese hogfennel highly responded to all the amendments even though the organic amendments produced higher coumarin contents than the N treatment (Table 6). Indeed, [53] found higher contents of coumarin grown on organic amendments than the one grown with the N amendment. However, unlike in their experiment where the chemical fertilizer reduced the coumarin content, the coumarin content was boosted by chemical fertilization in the present study. [53] explained that the accumulation of secondary metabolites like coumarin was correlated with the dry matter accumulation, an observation that might be true given the fact that two of the three coumarin registered strong correlations with the dry weight of the Japanese hogfennel (Additional file 1: Table S6). However, root length seems to be the most important determinant of coumarin due to the strong relationship obtained with all the coumarin types assessed in Additional file 1: Table S6.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13765-024-00863-0.

Additional file 1: Table S1. Heavy metals content of both dried leaf lettuce and Japanese hogfennel affected by the varying application rates of organic amendments. **Table S2.** Changes in physicochemical properties of soil affected by the varying application rates of organic amendments. **Table S3.** Statistical relationships amongst the different antioxidants and functional components of leaf lettuce. **Table S4.** Statistical relationships amongst the different antioxidants of Japanese hogfennel. **Table S5.** Statistical relationships amongst the different carotenoids and chlorophyll content of leaf lettuce. **Table S6.** Statistical relationships amongst the different coumarin and growth components of Japanese hogfennel. **Figure S1.** Total sugar (**a**) and total anthocyanin (**b**) contents of leaf lettuce affected by the varying rates of spent coffee grounds (SCGs) and dehydrated food waste powder (DFWP). Within the figure, values follwed by the same letters are not statistically significant difference at $p < 0.05$. **Figure S2.** Chlorophyll content of leaf lettuce (**a**) affected by the varying rates of spent coffee grounds (SCGs) and dehydrated food waste powder (DFWP), and the linear relationship (**b**) between the chlorophyll content and marketable yield of leaf lettuce. Within the figure, values follwed by the same letters are not statistically significant difference at $p < 0.05$.

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Conceptualization, Y-JJ, Y-GK, and T-KO; data curation, Y-JJ and J-AE; formal analysis, Y-GK and J-AE; investigation, Y-JJ and Y-GK; methodology, Y-JJ; supervision, T-KO; validation Y-GK; roles/writing—original draft, Y-JJ and Y-GK; writing—review and editing, T-KO.

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Availability of data and materials
All data generated or analyzed during this study are included in this published article and its additional information files.

Declarations

Competing interests
The authors declare that they have no competing interests.

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