agronomy

Article

Grocery Waste Compost as an Alternative Hydroponic Growing Medium

Christina Emmanouela Moschou, Dimitrios M. Papadimitriou, Fenia Galliou, Nikolaos Markakis, Nikolaos Papastefanakis, Georgios Daskalakis, Michael Sabathianakis, Eugenia Stathopoulou, Chryssa Bouki, Ioannis N. Daliakopoulos and Thrassyvoulos Manios *

Laboratory of Natural Resources Management & Agricultural Engineering, Department of Agriculture, Hellenic Mediterranean University, Estavromenos, 71410 Heraklion, Greece; xitina30@gmail.com (C.E.M.); dimpap@hmu.gr (D.M.P.); fgalliou@hmu.gr (F.G.); nmarkakis@hmu.gr (N.M.); npapastefanakis@hmu.gr (N.P.); gdaskalakis@hmu.gr (G.D.); sabathianakism@hmu.gr (M.S.); steugenia@hotmail.com (E.S.); cbouki@hmu.gr (C.B.); idaliak@hmu.gr (I.N.D.)

* Correspondence: tmanios@hmu.gr

Citation: Moschou, C.E.; Papadimitriou, D.M.; Galliou, F.; Markakis, N.; Papastefanakis, N.; Daskalakis, G.; Sabathianakis, M.; Stathopoulou, E.; Bouki, C.; Daliakopoulos, I.N.; et al. Grocery Waste Compost as an Alternative Hydroponic Growing Medium. *Agronomy* **2022**, *12*, 789. https://doi.org/10.3390/agronomy12040789

Academic Editors: Elżbieta Jamroz, Gabriela Barancikova and Jakub Bekier

Received: 10 March 2022
Accepted: 23 March 2022
Published: 25 March 2022

Abstract: Modern hydroponic substrates have contributed significantly to the popularity and progress of hydroponic cultivations worldwide, nevertheless, their development, transportation, and disposal often come at a significant environmental cost. Here we investigate the feasibility of partial to total replacement of conventional organic growing media constituents, such as cocodust (C), in a 20% perlite (P) and 80% cocodust substrate (hereafter control 8C), with compost from locally sourced grocery waste (W). For this purpose, four treatment mixtures were developed (6C:2W, 4C:4W, 2C:6W, 8W), with the grocery waste-compost fraction ranging from 20 to 80%, respectively (perlite constant at 20%). The new substrates were tested on hydroponic lettuce (*Lactuca sativa* var. Tanius) cultivation. During the 35-day experiment, lettuce physiology was evaluated using chlorophyll concentration [SPAD], chlorophyll fluorescence [Fv/Fm], number of leaves, and plant growth index. At harvest, the plant yield was evaluated using leaf area [cm^2], leaf fresh and dry weight [g], as well as leaf firmness [g]. Results show that substrates with compost led to superior physiology and yield characteristics, with 8W inducing a significant increase in leaf area, chlorophyll concentration, dry weight, and firmness, by 11.6%, 5.4%, 19.8% and 12.8%, respectively, compared to the control treatment 8C. Results indicate that grocery waste-based compost is an excellent sustainable alternative for the soilless cultivation of lettuce. After its use in hydroponic cultivation, substrate material is safe to dispose of or be used as a soil amendment, thus contributing to a circular agro-food economy model.

Keywords: grocery waste compost; growing media; hydroponic; lettuce; yield; firmness

1. Introduction

Today, 3.5% of agricultural production takes place under controlled systems of cultivation, and greenhouses are progressively moving to hydroponic solutions in an effort to increase sustainability and optimize the use of natural resources [1,2], and also to minimize their environmental footprint [3]. It is indicative that in the Netherlands, greenhouse crops are the main production system [4], while in the USA, 95% of greenhouse tomato production is soilless [5]. The advantages of soilless cultivation include efficient irrigation [6], optimal nutrient and plant protection management [7], yield increase compared to soil-bound systems due to higher plant densities and faster plant growth [8,9], and great post-harvest conservation of the product [10]. Nevertheless, despite the great progress, there is still ample space for improvement in this crop production system [3].

Part of this progress is due to modern hydroponic substrates (e.g., rockwool, perlite, cocodust, peat), the physical, chemical, biological, and hydraulic properties of which provide a growth environment with ideal moisture and aeration conditions, free of pathogens and weeds, at an affordable cost. For commercial soilless production of vegetables and cut flowers, several organic and inorganic materials, such as rockwool, perlite, peat, and cocodust are used [11–14]. However, most of these substrates are considered unstable in terms of mineral concentration, pH content, and hydraulic characteristics (unsaturated hydraulic conductivity). In an effort to mitigate this physicochemical heterogeneity, organic substrates are usually amended with different mixtures of inorganic growing media (e.g., rockwool, perlite, zeolite, vermiculite) [15,16], which nevertheless can pose important health and environmental challenges [17]. At the same time, organic substrate production is limited and is carried out in specific countries where raw materials are easily accessible, while peat is a non-renewable natural resource, the high demand of which has adverse effects on the environment [18]. Finally, the transport of substrates, often due to their inelastic volume, increases their environmental footprint [19].

Moreover, when compared against open field cultivations, hydroponic crops face several quality issues. For instance, several authors state that even though soilless systems of cultivation significantly reduce lettuce (*Lactuca sativa* L.) plant growth period and increase yield characteristics and nutrient availability [10,20], hydroponic lettuce has lower dry matter and chlorophyll concentration, and increased leaf nitrate content compared to soil-grown plants [21,22]. Furthermore, while leaf texture hardness (firmness) of leafy vegetables typically depends on the cultivation period, plant variety, and nutrient status of the plants [12–14], experiments have shown that it is also affected by the cultivation system and is frequently reduced in hydroponic systems compared to conventional and organic cultivation systems [23,24]. The cause of this effect on leaf texture firmness and, ultimately, post-harvest quality, has been sought in the physicochemical properties of the growing media [25–27].

Compost deriving from a mixture of horticultural and fruit residues could be a promising alternative composting technique. Mazuela et al. [28] report that a mixture of pepper, cucumber, runner bean, and almond shell residues (2:1:1:1), after physico-chemical property adjustment for melon soilless cultivation, was found to be a viable and ecologically friendly alternative to the conventional rock wool and coconut coir growing substrate. Additionally, Pant et al. [29] demonstrate that in an experiment conducted on pak choi (*Brassica rapa* var. Bonsai), the peat–perlite medium and food waste compost positively impacted plant growth and plant tissue nutrient content. Another study showed that agro-industrial compost could be considered a promising alternative for use as an organic substrate in a sustainable soilless cultivation system for baby leaf red lettuce (*Lactuca sativa* L., cv. 'Ligier'), able to improve the yield and quality of the product [30]. Likewise, De Falco et al. [31] highlight that compost derived from the recovery cultivation residues of green leafy vegetables, used as a partial growing substrate, provides a good opportunity to obtain baby leaf species with well-developed root systems. However, to our best knowledge, literature investigating the production of growing media from grocery waste compost is not available.

Grocery waste presents a great environmental challenge since, only in 2010, the USDA reported that food losses in the US retail sector amounted to almost 2.7 Mt of fruit and 3.2 Mt of vegetables [32]. In the same year, food waste in the EU grocery retail sector was estimated at almost 4.4 Mt, which accounts for 5% of the overall food waste in the European food supply chain [33]. In Mediterranean countries, due to consumer behaviour and dietary particularities, the amount of fruit and vegetable waste is even higher. Although reported values have great variability, it is indicative that in 2015, an Italian supermarket reported food waste that amounted to 49 t, of which fruit and vegetables accounted for 60–70% of the total weight and about 20% of the total value of discarded products [34]. While easily discarded, this resource presents a great opportunity, as compost can be produced close to the source of waste and utilized in neighbouring agricultural systems, thus minimizing transportation which comprises one of the main financial and environmental hurdles [35].

During the last decade, megacities such as Paris and London, have been actively seeking alternative food production systems and strategies that simultaneously satisfy the increasing food demand of the developing urban population, contribute to a reduced carbon footprint, promote food self-sufficiency, and have a high potential of social and cultural integration [36,37]. As such a system, urban farming has to establish cultivation practices that allow the recovery of waste coming directly from their source of production, and render circular economy more efficient [38]. On this aspect, several scientific reports contemplate alternative methods of urban organic waste valorization to produce a "green-based" compost aimed at replacing common commercial growing media. For instance, Parada et al. [38] evaluated the performance of compost from urban vegetable waste in three consecutive crop cycles of lettuce (*Lactuca sativa* L. var. crispa), demonstrating its feasibility in urban agriculture, as they attained significantly increased yield compared to a conventional substrate. Similarly, Dorr et al. [39] evaluated the environmental and economic impacts of rooftop gardening practices, focusing on crop rotations of tomato and lettuce grown showing that compost substrate performed better environmentally and economically than the potting soil, having 17–47% less greenhouse gas emissions per kg of product.

In this context, the present study focuses on the feasibility of the partial replacement of soilless cultivation non-sustainable growing media by compost derived from grocery (i.e., vegetable and fruit) waste. Here we move beyond the standard or fully controlled compost mixes and develop a compost from actual grocery waste. The resulting compost was tested on lettuce and the evaluation of yield and physiological characteristic during the cultivation period.

2. Materials and Methods

2.1. Grocery Residues Composting

For the production of compost, disposed fruits and vegetable were sourced from the grocery store of a supermarket in Heraklion, Crete, Greece. Special temporary biowaste storage bins with dimensions $1.3 \times 0.8 \times 0.8$ m and a working volume of 0.7 m^3, were placed outside of the supermarket where the raw materials were stored. The bins were supplied with grocery waste on a daily basis and, at the same time, a bulking agent (chipped olive tree prunings) was added at a volume ratio of 1:1 to 1:2 (grocery waste: chipped olive tree prunings), depending on the moisture of the raw materials. The storage of the compostable material in the bins lasted usually 5 to 6 weeks. Subsequently, bins were transferred to the Hellenic Mediterranean University, to continue the process of composting in open trapezoid windrows (1.2 m $\times$ 0.6 m). During the open composting process, chipped olive tree prunings were added as a bulking agent at a volume ratio of 1:1 (fruits and vegetables: olive tree prunings). Temperature at the core of the windrows was measured daily and compost was sampled randomly to monitor moisture levels and other chemical characteristics (see next section). Based on these measurements, windrows were turned using a BACKHUS 16.30 compost turner (Eggersmann Recycling Technology, Bad Oeynhausen, Germany) at 1–2-week intervals and irrigated manually to maintain moisture between 50% and 60% (w/w). The composting process lasted for 40 days with 14 turnings in total.

2.2. Physicochemical Analysis of Compost Samples

Moisture content was estimated by determining the loss of weight of the sample after drying at 105 °C [40]. pH and electrical conductivity (EC) were measured in 1/1.5 solid/liquid aqueous extract (extraction time equal to 24 h). Total volatile (VS) solids were measured gravimetrically, and total nitrogen (TKN) was measured using the Semi—Micro—Kjeldahl Method after [40]. Total organic carbon (TOC) of the materials was analysed using a TC/TN analyser with a solid sample module (TOC-V, SSM-5000A, Shimadzu, Japan). Chemical characteristics of the final product are summarized in Table 1.

2.3. Substrate Mixtures

Five experimental treatments (different mixtures of growing media) were assessed against a control substrate with 80% cocodust and 20% perlite (hereafter 8C). In the treatments, the perlite ratio remained constant (20%) and the fraction of cocodust was gradually replaced by compost. Table 2 shows the control and treatment names and ingredients for all substrates.

Table 1. Chemical characteristics of grocery waste-based compost.

Parameter	Value
pH	4.20
EC [mS /cm]	1.95
TKN [%]	1.17
Ca [%]	3.50
TOC [%]	62.03
VS [g/kg]	962.82

Table 2. Mixtures of investigated growing media. P: Perlite, C: Cocodust, W: Green waste compost. In all treatments, the perlite ratio is 20% and is thus omitted in treatment naming.

Treatment	Mixing Ratios	Bulk Density [g cm^{-3}]
8C (Control)	20% P, 80% C	0.08
6C:2W	20% P, 60% C, 20% W	0.12
4C:4W	20% P, 40% C, 40% W	0.16
2C:6W	20% P, 20% C, 60% W	0.18
8W	20% P, 80% W	0.19

2.4. Experimental Setup

Lettuce (*Lactuca sativa* var. Tanius) seedlings at the stage of four true leaves (25 November 2021) were transplanted in plastic pots (10 L), in an open hydroponic system within an unheated saddle roof double-span greenhouse covered with polyethylene film in an area of 120 m^2 (10 × 12 m). Plastic pots were arranged in three double rows spaced 3.0 m × 0.45 m apart, in a fully randomized design with six treatments of substrate ratios and five replications per treatment (6 × 5 = 30 experimental units). Additional control units were included but not discussed in this work (Figure 1).

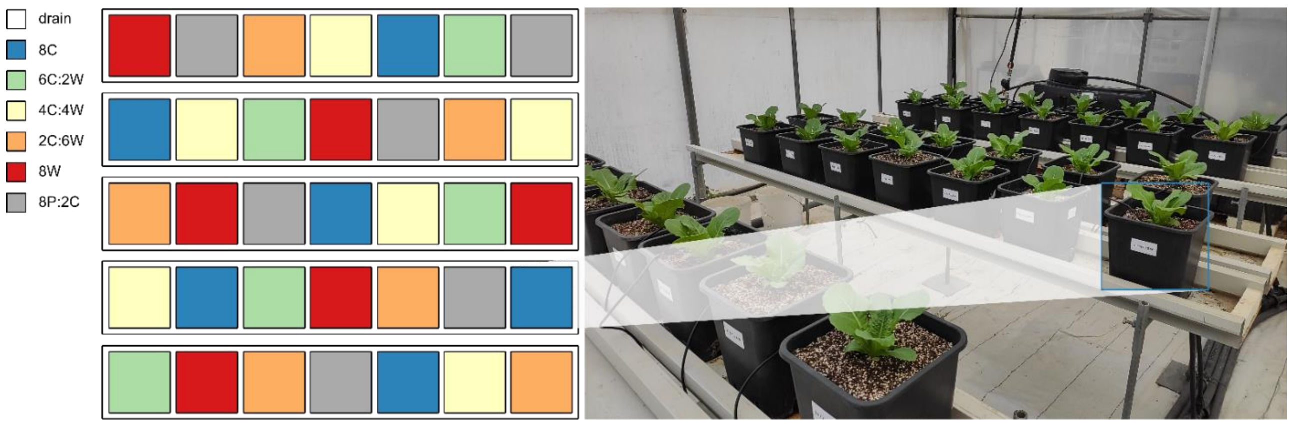

Figure 1. Experimental design (left) including all treatments (as shown in Table 2) and an additional control treatment (Perlite: Coir 8:2). On the right, a photograph of the experimental greenhouse during the experiment, with pot placement corresponding to the experimental design.

A nutrient solution (NS) was calculated according to Savvas and Adamidis [41] using the software NUTRISENSE [42] and prepared using the ALAGRO IQ60 (Athens, Greece) automatic nutrient mixing system. Macro- and micro-nutrient concentrations in the nutrient solution are shown in Table 3. The solution was delivered to the plants via drip irrigation, and each plant was supplied from an individual emitter at a flow rate of 4 L h^{-1}. The fraction of the drainage solution released after each irrigation event was maintained within the range 0.30–0.40 by adjusting the frequency and duration in accordance with the climatic conditions. This resulted in three to four irrigation applications per day in each experimental unit. The experimental crop lasted until 30 December, 2021, i.e., for 35 days after transplanting (DAT). Throughout the experiment, plants were grown without the application of pesticides, and pest control was limited to the removal of weeds from the pot to avoid competition. Air temperature T [°C] and relative humidity RH [%] were monitored at 30-min intervals throughout the cultivation period (Figure 2).

Table 3. Nutrient concentration in the nutrient solution (NS).

Nutrients		Concentration [mmol lt^{-1}]
Marco-nutrients	NH_4^--N	1.82
	K^+	9.13
	Ca^{2+}	5.64
	Mg^{2+}	1.29
	NO_3^--N	18.33
	SO_4^{2-}-S	1.00
	Cl^-	2.80
	$H_2PO_4^-$-P	1.66
Trace elements	Fe	0.3370
	Mn	0.0445
	Zn	0.0545
	Cu	0.0010
	B	0.0362
	Mo	0.0005

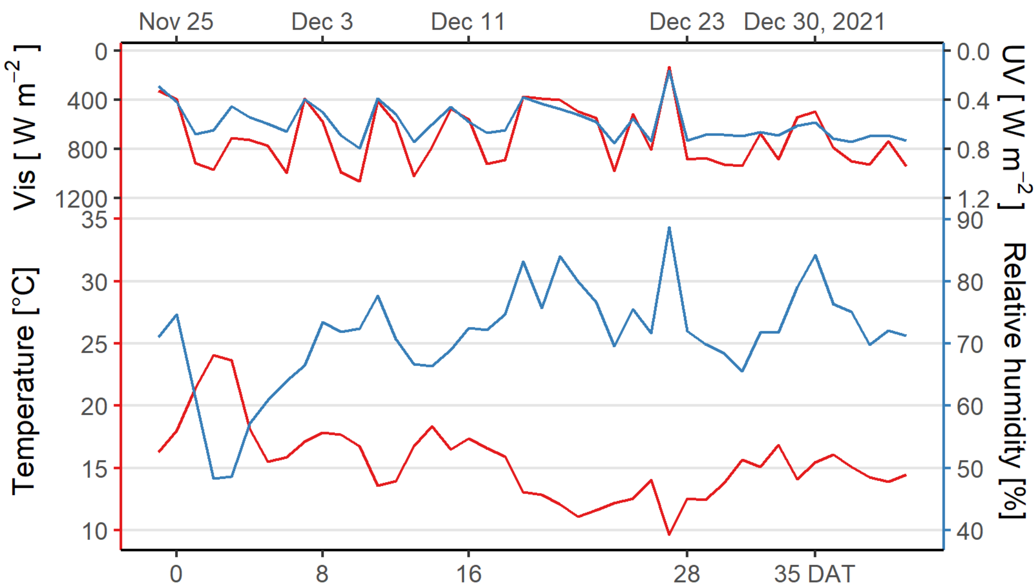

Figure 2. Mean daily air temperature T [°C], mean daily relative humidity RH [%], and mean daytime irradiance in the visible (Vis) and ultraviolet (UV) spectrum [W m^{-2}] during the cultivation.

2.5. Plant Physiology and Biomass Measurements

On 8, 16, 28, and 35 DAT (between 07:00–09:00 a.m.), the four most recent fully expanded leaves of each experimental unit were chosen to measure relative chlorophyll fluorescence (Fv/Fm) and relative optical chlorophyll concentration (SPAD). Chlorophyll fluorescence (dark-adapted Fv/Fm) has been considered a useful tool for the relative estimation of the maximum quantum yield of photosystem II photochemistry in a wide range of plant species [26]. Optical chlorophyll concentration was measured with a SPAD-502 (Minolta, Osaka, Japan) and chlorophyll fluorescence was measured using an OS-30p fluorometer (Opti-Sciences, Hudson, NH, USA) after Baker and Rosenqvist [43] and Jiang et al. [44]. Additionally, the number of leaves (>10 cm) and plant growth measurements were performed by determining the growth rate (growth index) at 5, 12, 16, 20, 26, 30, and 35 DAT.

On the same days after transplant, the growth index was calculated from the average of the three dimensions of each plant [45]:

$$G.I. = \frac{H + L + W}{3}$$

where H is the plant height [cm], L is the crown's larger dimension [cm] and W is the dimension of the crown which is perpendicular to B. At 35 DAT, lettuce plants at the stage of commercial maturity were harvested. Leaf area [cm^2] was measured for each plant through digital image analysis. All leaves were detached from plants (five plants per treatment) and after capturing flat on a white plastic surface of known dimensions (1 m^2), leaf area was measured after Valle et al. [46] using ImageJ 1.52v (National Institutes Health, Bethesda, MD, USA). Figure 3 shows an example of the process. Leaf fresh weight (WF_L) [g] was measured directly and leaf tissues were dried in a forced air oven at 65 °C for 72 h for dry leaf WD_L determination. Leaf firmness [g] was measured with the Lutron FG-5000 digital force tester (Lutron Electronic Enterprise Co., Ltd., Taipei, Taiwan) at both sides of the mid-rib of the external leaf (three leaves per plant and five plants per substrate treatment) using a pressure tester (8 mm diameter pressure tester needle).

Figure 3. Processing of a leaf samples with ImageJ. Leaf areas are enveloped in black solid lines and area values are denoted in cm^2. Treatment name in the photograph includes 2P to denote perlite fraction.

2.6. Statistical Analysis and Visualization

The data were analysed using R statistical software (R Development Core Team, 2017). One-way analysis of variance (ANOVA) was performed to assess the effect of compost substrates on yield and physiological characteristics and Student's t-test (α = 0.05) was employed to determine differences among treatments means. To reject the null hypothesis, we selected a p-value threshold of 0.05. While measurements were made on various intervals (i.e., 5, 8, 16, 28 and 35 DAT), for simplicity, only the first and last measurements (i.e., 5 or 8 DAT and 35 DAT) are shown in the Results section. In subsequent figures, vertical bars denote standard errors of means.

3. Results

Compost phytotoxicity assays are commonly evaluated by using seed germination techniques as described by Wang et al. [47] and Tiquia [48], however, in the present study, seedlings at the stage of four true leaves were chosen to be transplanted in the final growing positions. Therefore, phytotoxicity was evaluated by daily inspection of the leaves, aiming to locate any symptoms that could be attributed to phytotoxic effects, likely associated with the grocery-based compost used as the growing medium [49,50]. The experiment ended on 30 December, 2021, without any plant losses or any visible symptoms on the leaves, suggesting a complete lack of phytotoxicity of the compost-based substrates. Figure 4 shows samples from all treatments.

Figure 4. Treatment samples on DAT35. From left to right 8W, 2C:6W, 8C, 4C:4W, 6C:2W. Treatment names in the photograph include 2P to denote perlite fraction.

Moreover, as shown in Figure 5, treatments 8W, 2C:6W, 4C:4W, 6C:2W did not induce any significant effect on the number of leaves from 5 until 35 DAT (20.66 ± 0.89, 20.50 ± 0.67, 20.66 ± 0.48 and 20.33 ± 0.42, respectively), compared to that of treatment 8C (20.33 ± 0.42). Correspondingly, no significant effect of coir and compost was detected on plant growth index from seedlings transplant until 35 DAT (Figure 6).

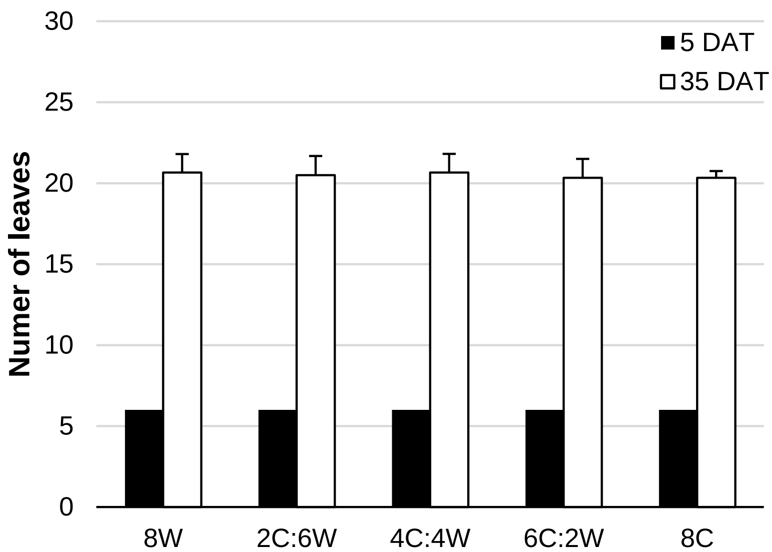

Figure 5. Number of leaves 5 and 35 DAT. Vertical bars denote standard errors of means.

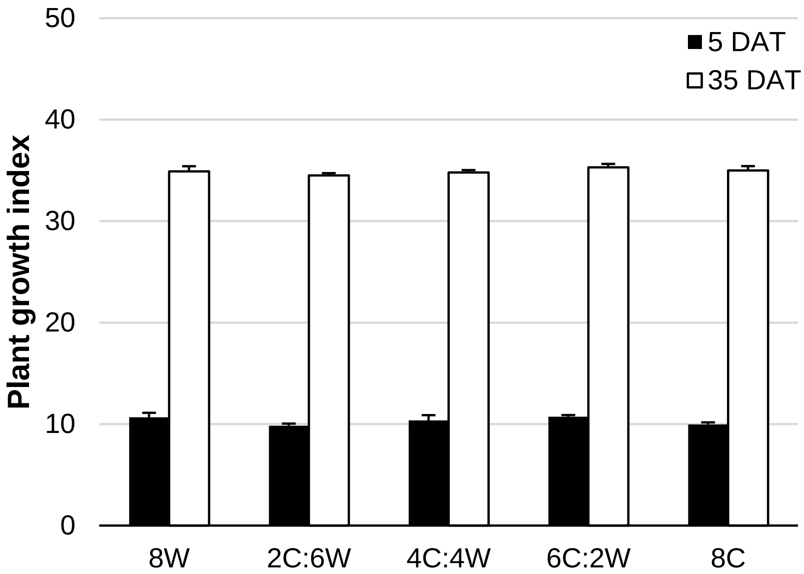

Figure 6. Plant growth index 5 and 35 DAT. Vertical bars denote standard errors of means.

The measurement of relative chlorophyll fluorescence [Fv/Fm] did not indicate any significant differences associated with the substrate treatments from 5 until 35 DAT (Figure 7). On the contrary, the relative optical chlorophyll content [SPAD] significantly increased in the substrate treatment of 8W, 8 DAT (36.13 ± 1.02) until 35 DAT (38.88 ± 0.3) compared to the substrate of 8C (33.75 ± 0.76 and 36.78 ± 0.40, respectively) (Figure 8).

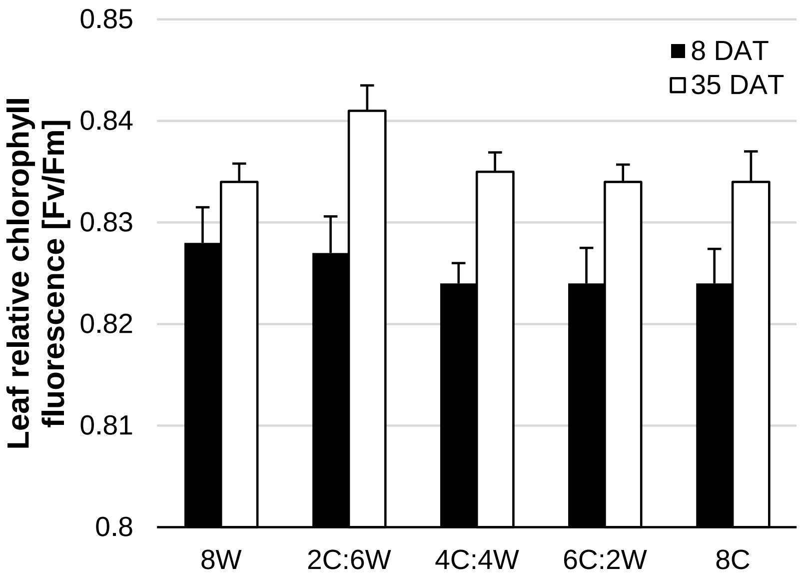

Figure 7. Leaf relative chlorophyll fluorescence (Fv/Fm), 8, 16, 28 and 35 DAT. Vertical bars denote standard errors of means.

WF_L remained unaffected by substrate ratios of 8W (283.85 ± 17.27 g), 2C:6W (283.97 ± 10.11 g), 4C:4W (287.1 ± 9.13 g), 6C:2W (303.52 ± 11.25 g) and 8C (286.11 ± 6.50 g), 35 DAT (Figure 9). Additionally, WD_L was significantly reduced only in the substrate treatment of 8C (11.63 ± 0.55 g) compared to the treatments of 8W (14.5 ± 0.50 g), 2C:6W (13.1 ± 0.64 g), 4C:4W (13.08 ± 0.54 g) and 6C:2W (13.63 ± 0.65 g), 35 DAT (Figure 10).

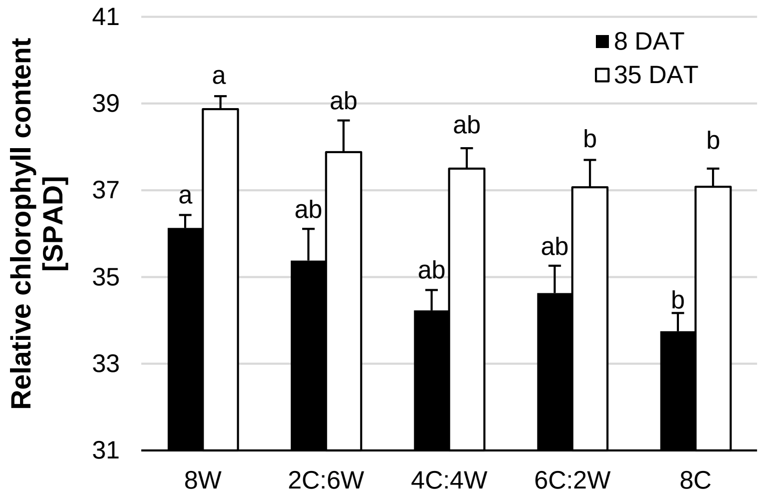

Figure 8. Leaf relative chlorophyll content [SPAD], 8 and 35 DAT. Vertical bars denote standard errors of means. Different letters denote significant differences among treatments according to the Student's *t*-test at $p \leq 0.05$.

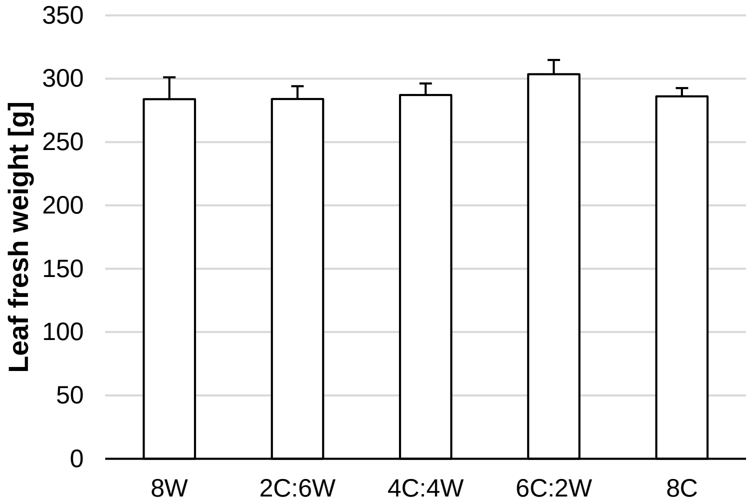

Figure 9. Effect of growing media ratio on WFL [g], 35 DAT. Vertical bars denote standard error.

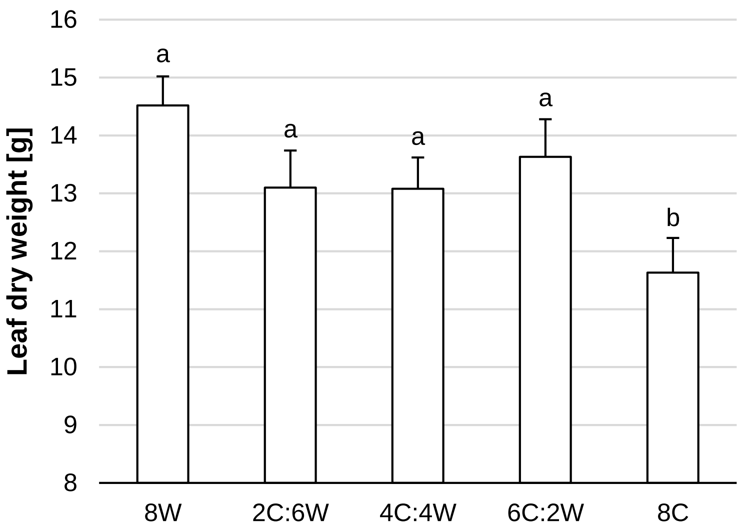

Figure 10. Effect of growing media ratio on leaf dry weight [g], 35 DAT. Vertical bars denote standard error. Different letters denote significant difference according to the Student's *t*-test at $p \leq 0.05$.

Leaf area was significantly increased in the 8W substrate ratio (299.21 ± 13.63 cm^2) compared to 8C, 4C:4W, 2C:6W and 6C:2W (268.15 ± 6.90, 267.94 ± 10.10, 263.69 ± 7.65 and 262.55 ± 5.10 cm^2, respectively) substrate treatments, 35 DAT (Figure 11). Accordingly, the results of leaf texture hardness (leaf firmness) indicate a range of leaf puncture values of 1150 to 1350 g force, with substrate 8W causing a significant increase in leaf hardness by 12.8% compared to the 8C substrate, 35 DAT. In more detail, leaf texture hardness demonstrated a significantly reduction in the substrate ratio of 8C (1188 ± 93.38 g) compared to the substrate treatments of 8W (1339.83 ± 74.99 g), without any statistical difference being observed between 2C:6W, 4C:4W and 6C:2W (1315.33 ± 92.58, 1228.66 ± 86.41 and 1280.83 ± 103.24 g, respectively), 35 DAT (Figure 12).

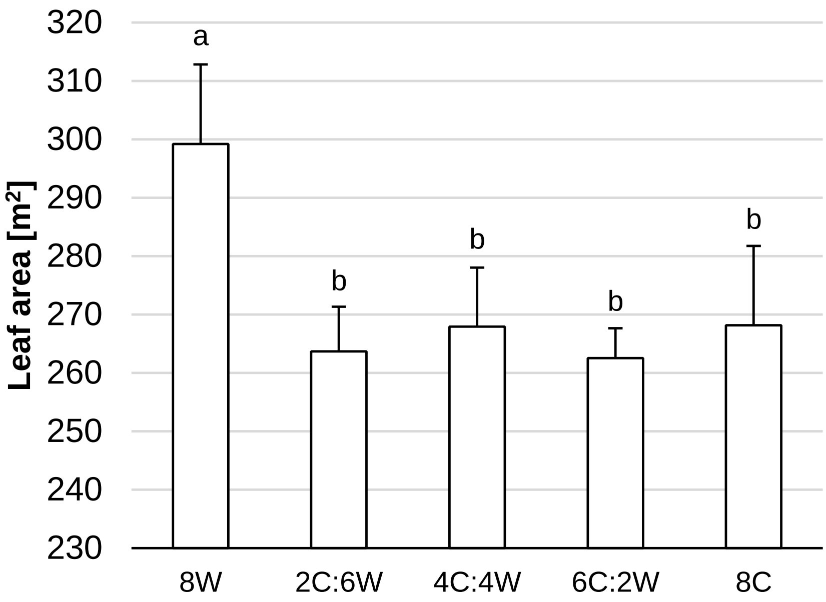

Figure 11. Effect of growing media ratio on leaf area (cm^2), 35 days after transplant. Vertical bars denote standard error. Different letters denote significant difference according to the Student's *t*-test ($p \leq 0.05$).

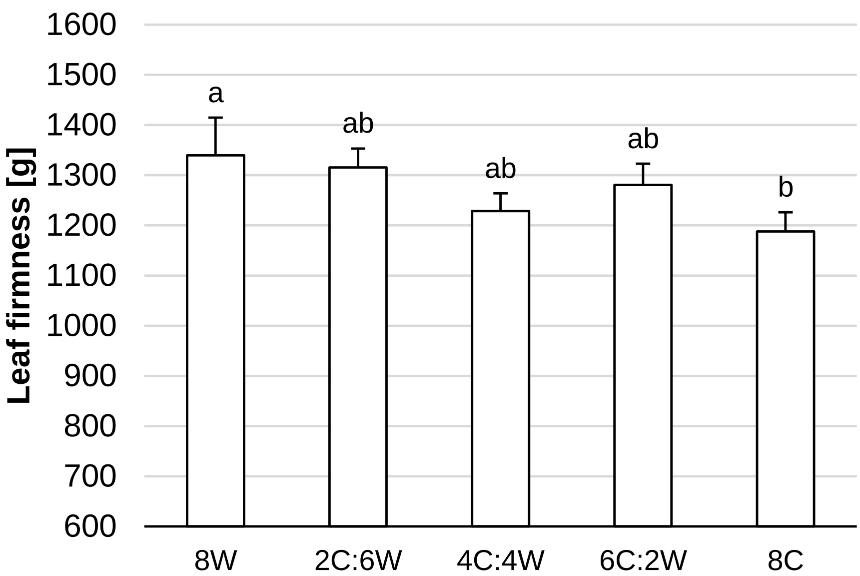

Figure 12. Effect of growing media ratio on leaf firmness (g), 35 days after transplant. Vertical bars denote standard error. Different letters denote significant difference according to the Student's *t*-test at $p \leq 0.05$.

4. Discussion

4.1. Biomass Production

One major challenge for the countries of the Mediterranean basin is to implement nature-friendly (or even nature-based) solutions on crop production systems that promote sustainability and optimize the use of natural resources, leading to a more self-sufficient economy. The results of the present study indicate that yield and physiological characteristics of hydroponic lettuce grown in a grocery waste-based compost substrate were comparable to commercial organic substrates such as cocodust, and superior to the inorganic substrate of perlite which was examined in a separate treatment (not shown here). However, WF_L did not appear to be significantly affected by the nature of the organic substrate, since no significant differences were observed between compost and cocodust treatments in any of the examined ratios. Contrarily, the substrate ratio of 8W significantly increased WD_L (19.8%) of the plants compared to the 8C treatment, which could be related to the increased relative chlorophyll content (SPAD) observed in the 8W treatment. Another interesting finding is that leaf area [cm^2] was significantly increased in the 8W treatment compared to 2C:6W, 4C:4W, 6C:2W and 8C by 13.5%, 11.7%, 13.9% and 11.6%, respectively. Giménez et al. [51] demonstrate that during summer cultivation cycle, agro-industrial compost increased the root length (cm) of baby leaf red lettuce (*Lactuca sativa* L., cv. 'Ligier'), and that during the autumn cultivation period, the quality (antioxidant capacity and vitamin C content of leaves) increased by reducing nitrate accumulation compared to peat substrate. In another experiment conducted to evaluate tomato and leek by-product compost on the growth and quality of red baby leaf lettuce (*Lactuca sativa* L.), yield increased by about 23% with respect to peat (control treatment) substrate [47]. Moreover, the results of the study conducted by De Falco et al. [31] designate a significant effect of 25% and 50% of green compost obtained from green leafy vegetable residues, on leaf number (102.5% and 98%, respectively), shoot (110% and 94%, respectively) and root dry weight (163.4% and 138.4%, respectively) of lettuce (*Lactuca sativa* var. Batavia verde Falstaff) compared to peat substrate, however, these effects of green compost on plant growth must be considered to be species-specific due to drawbacks associated with the content of salt in the growing media [31].

4.2. Physiological Parameters

The physiological effects of growing media on vegetable crops are frequently reported. Our results designate that even though a grocery-based substrate did not induce any significant effect on leaf relative chlorophyll fluorescence (Fv/Fm), a substrate treatment of 8W significantly increased the relative optical chlorophyll content (SPAD) compared to the substrate of 8C from 8 until 35 DAT (6.5% and 5.4%, respectively). Nerlich and Dannehl [47] investigated the effect of three organic materials (wood chips, sphagnum moss, and hemp fibres) in relation to an inorganic growing media, rockwool substrate, on plant growth and quality of lettuce. According to the results of the study, the plants grown in hemp substrate presented the lowest relative optical chlorophyll content (SPAD). In contrast, the highest SPAD values of lettuce leaves were obtained on the rockwool substrate, 55 DAT. Accordingly, Alu'datt et al. [48] reports that green waste-derived compost significantly increased leaf relative chlorophyll content (SPAD) in lettuce plants compared to vermicompost substrate, 49 DAT. According to the literature, the numerical SPAD value measures the absorbance of a leaf in the red and near-infrared regions, and is proportional to the concentration of chlorophyll present in the leaf, which indicates variations in nitrogen uptake from the plants [49].

4.3. Leaf Firmness

Firmness is frequently estimated in lettuce plants as a harvest maturity and shelf-life index, because firm leaves are more suitable for long distance transportation with minimum postharvest losses and constitute a quality characteristic associated with freshness and crispy texture [35,50]. According to the literature, the values of lettuce leaves hardness-firmness, vary significantly and are strongly related to the cultivation system (conventional, organic, or hydroponic cultivation systems), the growing season, the variety of the plant and the nature of the growing medium [23,52,53]. Zhang and Yang [54], conducted an experiment to evaluate the effect of organic compatible sanitisers on organic and conventional fresh-cut lettuce (*Lactuca sativa* L. var. crispa) and the results of the study reveal that leaf firmness ranged between 1499 and 1917 g for conventional cultivation and 1346 and 1437 g for organic cultivation. Furthermore, Lei and Engeseth [55] compared the growth characteristics and texture of hydroponically grown and soil-grown lettuce and concluded that leaf firmness was 2187 g in soil-grown lettuce, while in hydroponic lettuce the force to break middle leaves was 952 g, a value which was significantly reduced compared to the soil-grown lettuce. Leaf firmness was also studied by Pernice et al. [56] who performed texture analysis on three commercial lettuce cultivars ("Montego", "Great Lakes 118", and "Salad Bowl") cultivated in xerofluvent soil in December. The highest firmness values were observed in "Montego" (3110 g) and "Great Lakes 118" (3161 g), while the firmness level of the "Salad Bowl" cultivar appeared significantly lower (1162 g). On the other hand, Tong et al. [57] found that post-harvest quality characteristics (fruit firmness) of bell pepper (*Capsicum annuum* cv. King Arthur) was significantly reduced when cultivated in organic "bokashi" growing medium (compost consisting of oil cake, wheat bran, molasses, and chicken manure) compared to conventional hydroponic substrates such as vermicompost and perlite in soilless cultivation systems. In the present study, the range of leaf puncture values recorded in 8W substrate corresponded to the values obtained in the organic system of cultivation according to Zhang and Yang [54] and were respective to "Salad Bowl" but substantially lower than the "Montego" and "Great Lakes 118" lettuce varieties examined by Pernice et al. [56]. Moreover, our results indicate that grocery-based compost significantly increased the post-harvest quality of lettuce compared to the commercial growing medium of 8C, results that contradict the findings of Tong et al. [57] and suggest that further research must be carried out, to evaluate the impact of "green-based" composts on the post-harvest life of lettuce.

5. Conclusions

During this study, grocery waste was transformed to compost, which was then used as a quality hydroponic substrate constituent for lettuce cultivation. The transformation of grocery waste to compost and its use in the indicated ratios (up to 80% of the substrate) was successful, as during the experiment there were no losses due to phytotoxicity. Furthermore, all treatments including compost showed equal or superior physiology and yield characteristics compared to the control. According to the results of the study, entire replacement of cocodust by grocery waste-based compost led to a significant increase in leaf area, leaf relative chlorophyll content, leaf dry weight and leaf firmness at the time of harvest. Moreover, at the end of its life, the new substrates were safe to dispose of or use as soil amendment.

These results indicate that grocery waste-based compost is a viable and sustainable alternative for soilless cultivation of lettuce by replacing commercial organic substrates such as cocodust without deteriorating yield characteristics and whilst increasing post-harvest shelf-life of the product. Further research must be carried out to examine the effect of the seasonality of grocery waste on the produced substrates, as well as the exact mechanism that leads to the improved physiology and yield characteristics, such as additional nutrients and hydraulic characteristics. Our findings confirm the valorization potential of fruit and vegetable waste-based compost as a hydroponic media and support the mainstreaming of the circular utilization grocery waste, which is especially interesting in the context of urban farming.

Author Contributions: Conceptualization, G.D., T.M. and F.G.; methodology, I.N.D. and D.M.P.; validation, F.G. and I.N.D.; formal analysis, I.N.D. and D.M.P.; investigation, M.S., C.B. and C.E.M.; resources, C.B. and N.M.; data curation, I.N.D.; writing—original draft preparation, N.P., C.E.M. and D.M.P.; writing—review and editing, E.S. and I.N.D.; supervision, T.M. and I.N.D.; project administration, T.M.; funding acquisition, T.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research is funded by the Operational Program Crete 2014–2020 and co-funded by the European Regional Development Fund in the framework of "Strengthening the competitiveness, innovation and entrepreneurship of Crete", Action 1.b.1: Demonstration—experimental development projects. The above promotes research and innovation in areas of RIS3Crete (Regional Innovation System of Crete). Project BEATLE (MIS 5029193): Innovative Low Cost Processes for the Production of animal feed or Soil Improvement by whey and Hypermarket Vegetable Residues.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are available by the authors at request.

Acknowledgments: The authors would like to thank Ioannis Sabathianakis and Ioannis Louloudakis for their assistance experimental setup.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Gruda, N.; Bisbis, M.; Tanny, J. Influence of Climate Change on Protected Cultivation: Impacts and Sustainable Adaptation Strategies—A Review. *J. Clean. Prod.* **2019**, *225*, 481–495. [CrossRef]
2. Bisbis, M.B.; Gruda, N.; Blanke, M. Potential Impacts of Climate Change on Vegetable Production and Product Quality—A Review. *J. Clean. Prod.* **2018**, *170*, 1602–1620. [CrossRef]
3. Sambo, P.; Nicoletto, C.; Giro, A.; Pii, Y.; Valentinuzzi, F.; Mimmo, T.; Lugli, P.; Orzes, G.; Mazzetto, F.; Astolfi, S.; et al. Hydroponic Solutions for Soilless Production Systems: Issues and Opportunities in a Smart Agriculture Perspective. *Front. Plant Sci.* **2019**, *10*, 923. [CrossRef] [PubMed]
4. Torrellas, M.; Antón, A.; Ruijs, M.; García Victoria, N.; Stanghellini, C.; Montero, J.I. Environmental and Economic Assessment of Protected Crops in Four European Scenarios. *J. Clean. Prod.* **2012**, *28*, 45–55. [CrossRef]
5. Gruda, N. Do Soilless Culture Systems Have an Influence on Product Quality of Vegetables? *J. Appl. Bot. Food Qual.* **2009**, *82*, 141–147. [CrossRef]
6. Katsoulas, N.; Savvas, D.; Kitta, E.; Bartzanas, T.; Kittas, C. Extension and Evaluation of a Model for Automatic Drainage Solution Management in Tomato Crops Grown in Semi-Closed Hydroponic Systems. *Comput. Electron. Agric.* **2015**, *113*, 61–71. [CrossRef]
7. Savvas, D.; Olympios, C.; Passam, H.C. Management of Nutrition and Irrigation in Soil-Grown and Soilless Cultivations in Mild-Winter Climates: Problems, Constraints and Trends in the Mediterranean Region. *Acta Hortic.* **2009**, *807*, 415–426. [CrossRef]
8. De Haan, J.J.; Spruijt, J.; Vermeulen, T. Farm Management and Economic Drivers for Implementation of Soilless Cultivation of Field Vegetables in The Netherlands. *Acta Hortic.* **2014**, *1034*, 177–184. [CrossRef]
9. Fontana, E.; Nicola, S. Traditional and Soilless Culture Systems to Produce Corn Salad (*Valerianella olitoria* L.) and Rocket (*Eruca sativa* Mill.) with Low Nitrate Content. *J. Food Agric. Environ.* **2009**, *7*, 405–410.
10. Selma, M.V.; Luna, M.C.; Martínez-Sánchez, A.; Tudela, J.A.; Beltrán, D.; Baixauli, C.; Gil, M.I. Sensory Quality, Bioactive Constituents and Microbiological Quality of Green and Red Fresh-Cut Lettuces (*Lactuca sativa* L.) Are Influenced by Soil and Soilless Agricultural Production Systems. *Postharvest Biol. Technol.* **2012**, *63*, 16–24. [CrossRef]
11. Barrett, G.E.; Alexander, P.D.; Robinson, J.S.; Bragg, N.C. Achieving Environmentally Sustainable Growing Media for Soilless Plant Cultivation Systems—A Review. *Sci. Hortic.* **2016**, *212*, 220–234. [CrossRef]
12. Atzori, G.; Pane, C.; Zaccardelli, M.; Cacini, S.; Massa, D. The Role of Peat-Free Organic Substrates in the Sustainable Management of Soilless Cultivations. *Agronomy* **2021**, *11*, 1236. [CrossRef]
13. Bonanomi, G.; Antignani, V.; Capodilupo, M.; Scala, F. Identifying the Characteristics of Organic Soil Amendments That Suppress Soilborne Plant Diseases. *Soil Biol. Biochem.* **2010**, *42*, 136–144. [CrossRef]
14. Eksi, M.; Rowe, D.B.; Fernández-Cañero, R.; Cregg, B.M. Effect of Substrate Compost Percentage on Green Roof Vegetable Production. *Urban For. Urban Green.* **2015**, *14*, 315–322. [CrossRef]
15. Al Naddaf, O.; Livieratos, I.; Stamatakis, A.; Tsirogiannis, I.; Gizas, G.; Savvas, D. Hydraulic Characteristics of Composted Pig Manure, Perlite, and Mixtures of Them, and Their Impact on Cucumber Grown on Bags. *Sci. Hortic.* **2011**, *129*, 135–141. [CrossRef]
16. Yildiz, S.N.; Dasgan, H.Y.; Dere, S. Comparison of Substrate, Hydroponic and Aeroponic Cultivation Systems for the Production of Carrot Root. *Acta Hortic.* **2020**, *1273*, 107–114. [CrossRef]

17. Quantis. *Comparative Life Cycle Assessment of Horticultural Growing Media Based on Peat and Other Growing Media Constituents*; European Peat and Growing Media Association (EPAGMA): Lausanne, Belgium, 2012; p. 156.
18. Gruda, N.S. Increasing Sustainability of Growing Media Constituents and Stand-Alone Substrates in Soilless Culture Systems. *Agronomy* **2019**, *9*, 298. [CrossRef]
19. Olympios, C.M. Soilless media under protected cultivation rockwool, peat, perlite and other substrates. *Acta Hortic.* **1993**, *323*, 215–234. [CrossRef]
20. Majid, M.; Khan, J.N.; Ahmad Shah, Q.M.; Masoodi, K.Z.; Afroza, B.; Parvaze, S. Evaluation of Hydroponic Systems for the Cultivation of Lettuce (*Lactuca Sativa* L., Var. Longifolia) and Comparison with Protected Soil-Based Cultivation. *Agric. Water Manag.* **2021**, *245*, 106572. [CrossRef]
21. Nicola, S.; Fontana, E.; Hoeberechts, J.; Saglietti, D. Raphanus Sativus Production in Soilless or Traditional Culture Systems and Postharvest Packaging. *Acta Hortic.* **2005**, *682*, 1303–1310. [CrossRef]
22. Siomos, A.S.; Beis, G.; Papadopoulou, P.P.; Barbayiannis, N. Quality and composition of lettuce (cv. 'Plenty') grown in soil and soilless culture. *Acta Hortic.* **2001**, 445–450. [CrossRef]
23. Conversa, G.; Santamaria, P.; Gonnella, M. Growth, Yield, and Mineral Content of Butterhead Lettuce (*Lactuca sativa* Var. *Capitata*) Grown in NFT. *Acta Hortic.* **2004**, *659*, 621–628. [CrossRef]
24. Lei, C.; Engeseth, N.J. Comparison of Growth Characteristics, Functional Qualities, and Texture of Hydroponically Grown and Soil-Grown Lettuce. *Lwt* **2021**, *150*, 111931. [CrossRef]
25. Kaur, H.; Bedi, S.; Sethi, V.P.; Dhatt, A.S. Effects of Substrate Hydroponic Systems and Different N and K Ratios on Yield and Quality of Tomato Fruit. *J. Plant Nutr.* **2018**, *41*, 1547–1554. [CrossRef]
26. Nicola, S.; Hoeberechts, J.; Fontana, E. Comparison between Traditional and Soilless Culture Systems to Produce Rocket (Eruca Sativa) with Low Nitrate Content. *Acta Hortic.* **2005**, *697*, 549–555. [CrossRef]
27. Nicola, S.; Fontana, E. Cultivation Management on the Farm Influences Postharvest Quality and Safety. *Acta Hortic.* **2007**, *746*, 273–280. [CrossRef]
28. Mazuela, P.; Salas, M.D.C.; Urrestarazu, M. Vegetable Waste Compost as Substrate for Melon. *Commun. Soil Sci. Plant Anal.* **2005**, *36*, 1557–1572. [CrossRef]
29. Pant, A.P.; Radovich, T.J.K.; Hue, N.V.; Paull, R.E. Biochemical Properties of Compost Tea Associated with Compost Quality and Effects on Pak Choi Growth. *Sci. Hortic.* **2012**, *148*, 138–146. [CrossRef]
30. Giménez, A.; Fernández, J.A.; Pascual, J.A.; Ros, M.; López-Serrano, M.; Egea-Gilabert, C. An Agroindustrial Compost as Alternative to Peat for Production of Baby Leaf Red Lettuce in a Floating System. *Sci. Hortic.* **2019**, *246*, 907–915. [CrossRef]
31. De Falco, E.; Vitti, A.; Celano, G.; Ronga, D. Suitability of On-Farm Green Compost for the Production of Baby Leaf Species. *Horticulturae* **2021**, *7*, 512. [CrossRef]
32. Buzby, J.C.; Hyman, J.; Stewart, H.; Wells, H.F. The Value of Retail- and Consumer-Level Fruit and Vegetable Losses in the United States. *J. Consum. Aff.* **2011**, *45*, 492–515. [CrossRef]
33. Filimonau, V.; Gherbin, A. An Exploratory Study of Food Waste Management Practices in the UK Grocery Retail Sector. *J. Clean. Prod.* **2017**, *167*, 1184–1194. [CrossRef]
34. Cicatiello, C.; Franco, S.; Pancino, B.; Blasi, E.; Falasconi, L. The Dark Side of Retail Food Waste: Evidences from in-Store Data. *Resour. Conserv. Recycl.* **2017**, *125*, 273–281. [CrossRef]
35. Manios, T. The Composting Potential of Different Organic Solid Wastes: Experience from the Island of Crete. *Environ. Int.* **2004**, *29*, 1079–1089. [CrossRef]
36. Menyuka, N.N.; Sibanda, M.; Bob, U. Perceptions of the Challenges and Opportunities of Utilising Organic Waste through Urban Agriculture in the Durban South Basin. *Int. J. Environ. Res. Public Health* **2020**, *17*, 1158. [CrossRef]
37. Pons, O.; Nadal, A.; Sanyé-Mengual, E.; Llorach-Massana, P.; Cuerva, E.; Sanjuan-Delmàs, D.; Muñoz, P.; Oliver-Solà, J.; Planas, C.; Rovira, M.R. Roofs of the Future: Rooftop Greenhouses to Improve Buildings Metabolism. *Procedia Eng.* **2015**, *123*, 441–448. [CrossRef]
38. Parada, F.; Ercilla-Montserrat, M.; Arcas-Pilz, V.; Lopez-Capel, E.; Carazo, N.; Montero, J.I.; Gabarrell, X.; Villalba, G.; Rieradevall, J.; Muñoz, P. Comparison of Organic Substrates in Urban Rooftop Agriculture, towards Improving Crop Production Resilience to Temporary Drought in Mediterranean Cities. *J. Sci. Food Agric.* **2021**, *101*, 5888–5897. [CrossRef]
39. Dorr, E.; Sanyé-Mengual, E.; Gabrielle, B.; Grard, B.J.P.; Aubry, C. Proper Selection of Substrates and Crops Enhances the Sustainability of Paris Rooftop Garden. *Agron. Sustain. Dev.* **2017**, *37*, 51. [CrossRef]
40. Xu, Z. Dissolved Oxygen Dynamics and Modeling—A Case Study in A Subtropical Shallow Lake. Master's Thesis, Louisiana State University and Agricultural and Mechanical College, Baton Rouge, LA, USA, 2014.
41. Savvas, D.; Adamidis, K. Automated Management of Nutrient Solutions Based on Target Electrical Conductivity, PH, and Nutrient Concentration Ratios. *J. Plant Nutr.* **1999**, *22*, 1415–1432. [CrossRef]
42. Savvas, D.; Drakatos, S.; Panagiotakis, I.; Ntatsi, G. NUTRISENSE: A New Online Portal to Calculate Nutrient Solutions and Optimize Fertilization of Greenhouse Crops Grown Hydroponically. *Acta Hortic.* **2021**, *1320*, 149–156. [CrossRef]
43. Baker, N.R.; Rosenqvist, E. Applications of Chlorophyll Fluorescence Can Improve Crop Production Strategies: An Examination of Future Possibilities. *J. Exp. Bot.* **2004**, *55*, 1607–1621. [CrossRef] [PubMed]
44. Jiang, C.; Johkan, M.; Hohjo, M.; Tsukagoshi, S.; Maturo, T. A Correlation Analysis on Chlorophyll Content and SPAD Value in Tomato Leaves. *HortResearch* **2017**, *71*, 37–42.

45. Kotsiris, G.; Nektarios, P.A.; Paraskevopoulou, A.T. Lavandula Angustifolia Growth and Physiology Is Affected by Substrate Type and Depth When Grown under Mediterranean Semi-Intensive Green Roof Conditions. *HortScience* **2012**, *47*, 311–317. [CrossRef]
46. Valle, B.; Simonneau, T.; Boulord, R.; Sourd, F.; Frisson, T.; Ryckewaert, M.; Hamard, P.; Brichet, N.; Dauzat, M.; Christophe, A. PYM: A New, Affordable, Image-Based Method Using a Raspberry Pi to Phenotype Plant Leaf Area in a Wide Diversity of Environments. *Plant Methods* **2017**, *13*, 1–17. [CrossRef] [PubMed]
47. Nerlich, A.; Dannehl, D. Soilless Cultivation: Dynamically Changing Chemical Properties and Physical Conditions of Organic Substrates Influence the Plant Phenotype of Lettuce. *Front. Plant Sci.* **2021**, *11*, 2235. [CrossRef] [PubMed]
48. Alu'datt, M.H.; Rababah, T.; Alhamad, M.N.; Al-Tawaha, A.; Al-Tawaha, A.R.; Gammoh, S.; Ereifej, K.I.; Al-Karaki, G.; Hamasha, H.R.; Tranchant, C.C.; et al. Herbal Yield, Nutritive Composition, Phenolic Contents and Antioxidant Activity of Purslane (*Portulaca oleracea* L.) Grown in Different Soilless Media in a Closed System. *Ind. Crops Prod.* **2019**, *141*, 111746. [CrossRef]
49. Shah, S.H.; Houborg, R.; McCabe, M.F. Response of Chlorophyll, Carotenoid and SPAD-502 Measurement to Salinity and Nutrient Stress in Wheat (*Triticum aestivum* L.). *Agronomy* **2017**, *7*, 61. [CrossRef]
50. Alvarado-Camarillo, D.; Valdez-Aguilar, L.A.; González-Fuentes, J.A.; Rascón-Alvarado, E.; Peña-Ramos, F.M. Response of Hydroponic Lettuce to Aeration, Nitrate and Potassium in the Nutrient Solution. *Acta Agric. Scand. Sect. B—Soil Plant Sci.* **2020**, *70*, 341–348. [CrossRef]
51. Giménez, A.; Fernández, J.A.; Pascual, J.A.; Ros, M.; Saez-Tovar, J.; Martinez-Sabater, E.; Gruda, N.S.; Egea-Gilabert, C. Promising Composts as Growing Media for the Production of Baby Leaf Lettuce in a Floating System. *Agronomy* **2020**, *10*, 1540. [CrossRef]
52. Bonasia, A.; Lazzizera, C.; Elia, A.; Conversa, G. Nutritional, Biophysical and Physiological Characteristics of Wild Rocket Genotypes as Affected by Soilless Cultivation System, Salinity Level of Nutrient Solution and Growing Period. *Front. Plant Sci.* **2017**, *8*, 300. [CrossRef]
53. Johannessen, G.S.; Frøseth, R.B.; Solemdal, L.; Jarp, J.; Wasteson, Y.; Rørvik, L.M. Influence of Bovine Manure as Fertilizer on the Bacteriological Quality of Organic Iceberg Lettuce. *J. Appl. Microbiol.* **2004**, *96*, 787–794. [CrossRef] [PubMed]
54. Zhang, J.; Yang, H. Effects of Potential Organic Compatible Sanitisers on Organic and Conventional Fresh-Cut Lettuce (*Lactuca sativa* Var. *Crispa* L). *Food Control* **2017**, *72*, 20–26. [CrossRef]
55. Pedrosa, A.W.; Martinez, H.E.P.; Matiello, E.M.; Fontes, P.C.R.; Pereira, P.R.G. Influence of the N/K Ratio on the Production and Quality of Cucumber in Hydroponic System. *Rev. Ceres* **2011**, *58*, 619–624. [CrossRef]
56. Pernice, R.; Scuderi, D.; Napolitano, A.; Fogliano, V.; Leonardi, C. Polyphenol Composition and Qualitative Characteristics of Fresh-Cut Lettuce in Relation to Cultivar, Mulching, and Storage. *J. Hortic. Sci. Biotechnol.* **2007**, *82*, 420–427. [CrossRef]
57. Tong, R.C.; Whitehead, C.S.; Fawole, O.A. Effects of Conventional and Bokashi Hydroponics on Vegetative Growth, Yield and Quality Attributes of Bell Peppers. *Plants* **2021**, *10*, 1281. [CrossRef]