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Valorization of Waste Grape Pomace: Effects on Growth, Flowering, and Leaf Nutrient Content of *Dahlia variabilis* sp. "Figaro" Violet

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ABSTRACT

Composting is a sustainable method widely used in the evaluation of organic wastes, and stabilized soil amendments and growing media can be obtained by this method. In this study, the effects of compost obtained from grape pomace on the growth and development of *Dahlia variabilis* "Figaro Violet" were investigated by adding 20% and 40% to the growing medium. Additionally, the interactions of different fertilization levels (EC 0.75, 1.10, and 1.85 dS m^{-1}) and compost use were evaluated. According to the research findings, 40% compost + EC 1.85 dS m^{-1} application provided the highest values in number of flowers (5.2 pcs $plant^{-1}$), number of leaves (64.7 pcs $plant^{-1}$), plant fresh weight (81.0 g), plant dry weight (41.5 g), and branch thickness (7.56 mm); also, it gave the best results in phosphorus (357 mg kg^{-1}), magnesium (184 mg kg^{-1}), iron (0.90 mg kg^{-1}), and copper (0.26 mg kg^{-1}) contents. 40% compost + EC 0.75 dS m^{-1} application gave the highest results in terms of flower diameter (84.1 mm) and SPAD value (37.5), while it also stood out in calcium (68.2 mg kg^{-1}), molybdenum (0.38 mg kg^{-1}), and boron (1.49 mg kg^{-1}) contents. 40% compost + EC 1.10 dS m^{-1} application showed the highest values in nitrogen (8.41%), potassium (709 mg kg^{-1}), and manganese (2.30 mg kg^{-1}) contents. The 20% compost + EC 1.10 dS m^{-1} application yielded the best results in plant height (38.3 cm) and root length (24.8 cm). It also resulted in earlier flowering, occurring within 39–40 days. The 20% compost + EC 0.75 dS m^{-1} application was superior in root fresh weight (21.5 g) and root dry weight (13.9 g). In the control treatments, only the 0% compost + EC 1.10 dS m^{-1} combination was distinguished by a root dry weight (15.4 g). Overall, the 40% compost and high EC (1.85 dS m^{-1}) combination was found to be the most superior treatment in terms of plant growth performance, flowering characteristics, and leaf nutrient content. These results demonstrate that grape pomace can be an economical and viable alternative in ornamental plant cultivation, considering environmental sustainability and resource efficiency.

1 | Introduction

Dahlia variabilis is one of the perennial, tuberous flower species belonging to the *Asteraceae* family, and its height varies between 30 and 180 cm depending on the variety [1]. Flower forms vary as simple, lotus, anemone, pompom, ball, semi-cactus, cactus, decorative, orchid, and peony [2]. *Dahlia* is a species utilized as cut flowers and outdoor and potted plants in many countries [3, 4]. The demand for Dahlia cut flowers is increasing yearly and has the highest transaction value growth rate among the 30 main flower items in the flower market. Dahlias are grown commercially in Mexico, Japan, France, South Africa, Italy, Germany, and the United States, and a significant area (400 ha) of tubers is produced in the Netherlands [5].

The production of cover crops involves a large number of cultural inputs. Perhaps, the most important of these inputs is the type of

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growing medium (substrate) used. For this reason, substrates used in soilless culture systems exhibit great advantages over soils and are preferred. The reason for this is thought to be better water-holding capacity, aeration, and favorable physico-chemical environment [6]. Organic substrates commonly used in soilless culture include peat, vermicompost, coconut fiber, press mud, compost, farmyard manure, wood-based materials, and biochar [7]. Among these substrates, peat offers good physical and chemical properties and is reported to be safe for plant health, but it is a nonrenewable resource. Furthermore, exploitation of peat deposits increases CO_2 emissions and negatively affects the environment [8, 9]. Considering the natural importance of peatlands, the European Union has introduced radical restrictions on the exploitation of peat production areas and the production of horticultural substrates [10]. Recently, a renewable substrate that can replace peat in plant cultivation has been sought due to environmental concerns and a dwindling supply of peat for plant-growing media [11]. Rapidly increasing urbanization with global population growth leads to the generation of significant amounts of organic waste [12, 13]. These organic wastes generally include food wastes from residential, commercial, and manufacturing sectors and wastes from food processing factories [14]. Traditional organic waste management methods such as landfilling, landfilling, or incineration are used to dispose of these wastes, but these methods are not sustainable [15]. Instead, it is known that these organic wastes can be biodegraded under aerobic conditions and transformed through a process called composting [13]. Compost obtained from the composting process is a rich source of nutrients with a high organic matter content. It improves soil properties (e.g., bulk density, porosity, water conductivity, water-holding capacity, cation exchange capacity (CEC), organic carbon and nitrogen contents, biological function, and mineralization) and can ultimately improve plant growth and quality [16]. Compost is an environmentally friendly product that contributes to plant health and is increasingly preferred as a substrate in soilless agriculture applications [17].

The valorization of agri-food byproducts is a critical pathway toward building sustainable food systems, reducing waste, and advancing the circular economy [18, 19]. The main residue in winemaking is grape pomace (GP), also called grape bagasse or grape marc. It consists of the stems, skins, pulp, and seeds that remain after the grapes have been pressed. GP has a high concentration of bioactive chemicals, primarily phenolics [20]. Grape marc is an interesting soil fertilizer due to its richness in potassium and high organic matter content [21]. Using GP residues as soil amendment holds promise for sustainable viticulture [22]. Composting can be a suitable way to improve winery waste characteristics and to reintroduce them into the soil according to the principles of a circular economy [21]. Studies examining the effects of GP residues, such as GP compost and vermicompost, on C and N stocks and their fractions in soils remain insufficient [22].

GP, the solid residue remaining after winemaking and juice production, is one of the most abundant agro-industrial byproducts in viticulture regions. It contains lignocellulosic material, organic carbon, polyphenols, potassium, calcium, magnesium, and other nutrients, making it a potential soil amendment [23, 24]. Traditionally, GP has been used in animal feed, bioenergy production, or simply discarded, but its direct use in agriculture is limited due to high moisture and phytotoxic compounds. Composting is considered an effective way to stabilize GP, reduce phytotoxicity, and improve its agronomic value [25]. Studies have shown that composted GP can enhance soil fertility, improve plant nutrient uptake, and contribute to waste valorization within the circular bioeconomy framework [23].

In ornamental horticulture, replacing peat with renewable organic substrates is increasingly emphasized. Previous studies with municipal compost, vermicompost, and agro-industrial residues have demonstrated improvements in growth, flowering, and nutrient content of ornamentals such as geranium, petunia, and marigold [26]. However, little is known about the use of GP compost in ornamental plants [23]. Therefore, investigating its potential in *Dahlia variabilis*, a species of high ornamental and economic value, may contribute to sustainable substrate management and the diversification of waste-based growing media.

This study aimed to determine the possible effects of composting GP, which is one of the agricultural wastes, adding the compost obtained at the end of the composting process to the growing media at different rates and fertilizing these media at different EC levels on the growth, flowering and nutrient content in the leaves of *Dahlia variabilis* sp. “Figaro” Violet.

2 | Materials and Methods

2.1 | Compost and Composting Process

In this study, compost was obtained from the wastes of grape fruit, which is widely consumed in the world. GP, one of the main materials of composting, was obtained from a company producing fruit juice commercially. 6 tonnes of GP, 500 kg of cattle manure, and 4 straw bales of 12 and 20 kg of lime were separated for composting. The pile used for decomposition is 300 cm long × 150 cm wide × 180 cm high. For the nitrogen and energy needs of the microorganisms in the heap, 4 kg urea was added. The pile was mixed with a mechanical mixer every day for aeration, and the composting process ended on the 135th day.

The materials (barnyard manure, straw, lime, and urea) for compost to be used as a medium for dahlia cultivation were mixed and produced under aerobic conditions according to the sequential heap composting method (Windrow Method) [8]. The compost matured after 135 days, and 1 kg samples taken after maturation were analyzed by Ankara Soil, Fertilizer and Water Resources Central Research Institute, and the physical, chemical, and biological properties of the samples are given in Table 1.

2.2 | Preparation and Application of Commercial Fertilizers With Different EC Levels

Four different nutrient solutions [28–30] prepared according to Hoagland and Arnon [31] were examined, and the nutrient solutions and amounts were adapted according to these nutrient solutions, which are shown in Table 2.

Two 1000 L capacity nutrient tanks were used for nutrient solution. The EC level of the first nutrient tank was set to 1.1 dS m^{-1}, and the EC level of the second nutrient tank was set to 1.85 dS m^{-1}. The control in the fertilization application was given directly to the plants from tap water by drip irrigation system,

TABLE 1 | Methods and results of analysis of grape compost.

Analysis	Analysis method	Result
Moisture (%)	A.O.A.C., 1995	48.77
Organic matter (%)	AOAC 967.03-04-05	68.82
pH	1/10 Potentiometric	8.52
EC (dS m^{-1})	1/10 Potentiometric	2.51
Total nitrogen (%)	TL 7.02-02 (Rev:4)	2.71
Total phosphorus (%)	Kacar and Kütük [27]	0.58
Total potassium (%)	Kacar and Kütük [27]	3.26
Total calcium (%)	GPGDY Ek-3 9.1/10.1	3.54
Total magnesium (%)	GPGDY Ek-3 9.1/10.1	0.72
Total iron (%)	GPGDY Ek-3 9.1/10.1	0.71
Total copper (mg kg^{-1})	GPGDY Ek-3 9.1/10.1	31.66
Total manganese (mg kg^{-1})	GPGDY Ek-3 9.1/10.1	204.45
Total zinc (mg kg^{-1})	GPGDY Ek-3 9.1/10.1	76.65
Total bacteria count (cfu g^{-1})	TS EN ISO 4833-2	4.75×10^6

TABLE 2 | Nutrient solution formulations used in the study.

Nutrient elements	(mg L^1)
Nitrogen (N)	160
Phosphorus (P)	30
Potassium (K)	200
Magnesium (Mg)	40
Calcium (Ca)	120
Sulfur (S)	40
Iron (Fe)	2.5
Manganese (Mn)	0.5
Boron (B)	0.5
Copper (Cu)	0.5
Zinc (Zn)	0.5
Molybdenum (Mo)	0.1

and the nutrient solutions were transferred to the plants by drip pipes. At the end of each week, the nutrient tanks were checked and the EC levels and pH values (5.6) of the nutrient solutions were kept at the desired levels [5, 32].

2.3 | Study Plan

This study was carried out in soilless agriculture in crates. Seedlings of *Dahlia variabilis* sp. "Figaro" Violet F1 variety were used in the greenhouse study. Three different rates of compost addition (0%–20%–40%) and 3 different EC levels (EC 0.75, EC 1.10, and EC 1.85 dS m^{-1}) were applied. Compost was mixed into the growing substrate at three ratios prior to planting: 0%, 20%, and 40% (w/w). During the growing period, plants were watered three times per week with nutrient solutions adjusted to three electrical conductivity (EC) levels (0.75, 1.10, and 1.85 dS m^{-1}). Approximately 100 mL of nutrient solution was applied per plant during each watering, and a consistent source of nutrients and moisture was provided throughout the experiment. Application frequencies were also adjusted according to greenhouse and outdoor conditions. The control treatments were defined as the substrate without GP (0%) under each EC level (0.75, 1.10, 1.85 dS m^{-1}). These controls allow separating the main effect of compost from that of fertilization EC. The crates in which the study was carried out were 20 cm high × 40 cm wide and 60 cm long. Coccopite was preferred as the growing medium. Samples for EC and pH analyses of the growing medium were taken at the end of the study. Young leaves were selected for leaf analysis.

2.4 | Plant Parameters

At the end of the experiment, various plant growth and physiological parameters were measured. Stem diameter was measured 5 cm above the soil surface using a digital caliper, and flower diameter was recorded across the widest point of the fully opened inflorescence. The total number of flowers and leaves per plant was counted manually. Plant height was measured from the soil surface to the apex of the main stem with a ruler. The first flowering date was determined by recording the number of days from transplanting to the appearance of the first open flower. Chlorophyll content was estimated using a SPAD-502 Plus chlorophyll meter (Minolta, Japan) on three fully expanded leaves per plant, and the average value was calculated. Plant fresh weight was measured immediately after harvesting, while plant dry weight was obtained after oven-drying the shoots at 80 ± 2°C until constant weight. Root fresh weight was recorded after gently washing the roots to remove substrate residues, and root dry weight was determined after oven-drying at 80 ± 2°C. Root length was measured from the stem base to the tip of the longest root using a ruler. All measurements were conducted on three randomly selected plants per replicate to ensure accuracy and reproducibility.

2.5 | Leaf Analyses

2.5.1 | Macro- and Microelement Analyses

Leaf samples were collected at the full vegetative stage, when plants had reached approximately 50% of their maximum canopy development. Sampling was performed 60 days after transplanting by collecting the most recently fully expanded leaves from the middle portion of each plant. Five leaves per plant were

sampled from each replicate, avoiding mechanical damage or diseased tissues. The collected leaves were first rinsed with distilled water to remove surface contaminants and then oven-dried at 80 ± 2°C until constant weight. Dried samples were ground using a stainless-steel mill and stored in airtight polyethylene containers prior to analysis. According to the method reported by Miller [33], the readings of macro- and micronutrients such as phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu) dissolved in hydrochloric acid were determined by ICP-AES. Nitrogen (N) was analyzed by standard Kjeldahl fresh digestion method. According to the methods reported by Bowman et al. [34] and Jones [35], ammonium (NH_4) formed from the decomposition of nitrogen in the plant sample by fresh combustion using sulfuric acid and Kjeldal flasks with catalysts was measured by distillation method.

2.5.2 | Greenhouse and Environment Conditions

Dahlia study was carried out in a 450 m^2 (35 m length, 12.5 m width, 3 m height under the gutter and 4.5 m roof height) glass greenhouse with overhead (roof) ventilation, without heating and cooling. The prepared crates were placed in the greenhouse according to the factorial coincidence block design. The study was carried out between April 28, 2022 and June 30, 2022. Temperature and humidity values were given based on the time elapsed during the study. The average temperature values were 26.90°C ± 2°C, the highest temperature value ranged between 39.93 ± 2°C and the lowest temperature value ranged between 16.67 ± 1°C, and the relative humidity in the greenhouse was measured as 56.73 ± 2% (Hobo, Datalogger U12-O12). In the greenhouse, 55% shading net was used in the area where the study was carried out and the light intensity was kept constant between 18.000 and 20.000 lux by throwing shadow dust on the greenhouse roof. Plants were irrigated with a drip irrigation pipe (2 L h^{-1} flow rate). The irrigation amount was determined as 80 mL of water per plant and was given at regular intervals every 2 days. After the formation of 2 rows of male organs in dahlia flowers, the plants were harvested and measurements were started.

2.6 | Statistical Analyses

The study followed a two-factor factorial arrangement (3 compost rates × 3 fertilization EC levels) in a completely randomized design (CRD). Compost rates were 0%, 20%, and 40% (v/v) GP compost incorporated into the base substrate; fertilization EC levels were 0.75, 1.10, and 1.85 dS m^{-1}. This yielded 9 treatments in total. The planned number of factors (salinity level and compost treatments) and their interactions were statistically examined within the scope of the study. • Factor 1: Salinity levels (3 levels, including control), •Factor 2: Compost treatments (3 levels, including control), • Number of replicates: 3, • Each replicate: 24 plants, Total: 3 (salinity) × 3 (compost) × 3 (replicates) × 24 (plants) = 648 plants were used. Randomization, treatments were assigned to crate positions using computer-generated random numbers (CRD) to minimize microenvironment effects. In statistical analyses, the main effect of each factor and the two-way (Stress × Compost) interaction effects were evaluated using analysis of variance (ANOVA), and between-group differences were analyzed using the Duncan test. Statistical Package for Social Sciences (SPSS) (Statistical Package for Social Sciences, Version 26.0) was used in the calculations and evaluated according to analysis of variance.

3 | Results

3.1 | The Effect of Different Compost Ratios and Fertilization Applications at Different EC Levels on Some Quality Criteria in Dahlia (*Dahlia* sp.)

The effects of GP compost and different EC levels on the growth parameters of Dahlia variabilis "Figaro Violet" were examined, and significant differences were observed in all measurements. The highest flower diameter value was determined to be 84.1 mm in the 40% compost + EC 0.75 dS m^{-1} application. The number of flowers reached the highest level at 5.2 flowers/plant with the application of 40% compost + EC 1.85 dS m^{-1}. Plant height showed the highest value at 38.3 cm with the application of 20% compost + EC 1.10 dS m^{-1}. In terms of leaf number, the 40% compost + EC 1.85 dS m^{-1} application stood out and yielded the highest result with a value of 64.7 leaves/plant. A similar trend was observed in branch diameter, with the highest value of 7.56 mm obtained in the 40% compost + EC 1.85 dS m^{-1} application. When examining the first flowering time, the earliest flowering was recorded at 38 days in the 20% compost + EC 1.85 dS m^{-1} application. Overall, GP compost showed positive effects on all growth and development parameters; in particular, treatments using 40% compost combined with high EC (1.85 dS m^{-1}) yielded the best results in plant development.

All observations were found to be statistically significant when combining different compost rates with different EC levels of fertilization. In the study, it was found that the addition of 40% compost to the growing medium and fertilization at different EC levels produced better results in plant growth compared to the control. Especially increasing compost rates and increasing fertilization levels had positive effects on plant growth (Figure 1).

When plant biomass parameters were examined, plant fresh weight reached its highest level at 81.0 g with the application of 40% compost + EC 1.85 dS m^{-1}. Plant dry weight was determined to be 41.5 g with the same application and was the highest value among all trials. The highest root fresh weight was recorded at 21.5 g in the 20% compost + EC 0.75 dS m^{-1} treatment. Root dry weight reached its highest level at 15.4 g in the 0% compost + EC 1.10 dS m^{-1} treatment. This indicates that certain EC levels promote root development more than others, regardless of the compost ratio. Root length remained at similar levels across all treatments, with the highest value recorded at 24.8 cm in the 20% compost + EC 0.75 dS m^{-1} treatment. The highest SPAD value was recorded at 37.5 in the 40% compost + EC 0.75 dS m^{-1} application. Increasing compost ratio generally increased chlorophyll content, indicating an increase in photosynthetic capacity.

Overall, compost derived from GP significantly improved plant biomass and leaf nutrition status, especially when applied with high EC levels (Figure 2).

The effects of the applications made within the scope of the study on Dahlia plant are given in Figure 3, with the visuals taken as of the 40th day.

3.2 | Macro- and Micronutrient Contents of Dahlia Leaf Samples

When leaf nutrient elements were examined, the nitrogen (N) content reached its highest value (8.41%) in the 40% compost + EC 1.10 dS m^{-1} application. The phosphorus (P) amount

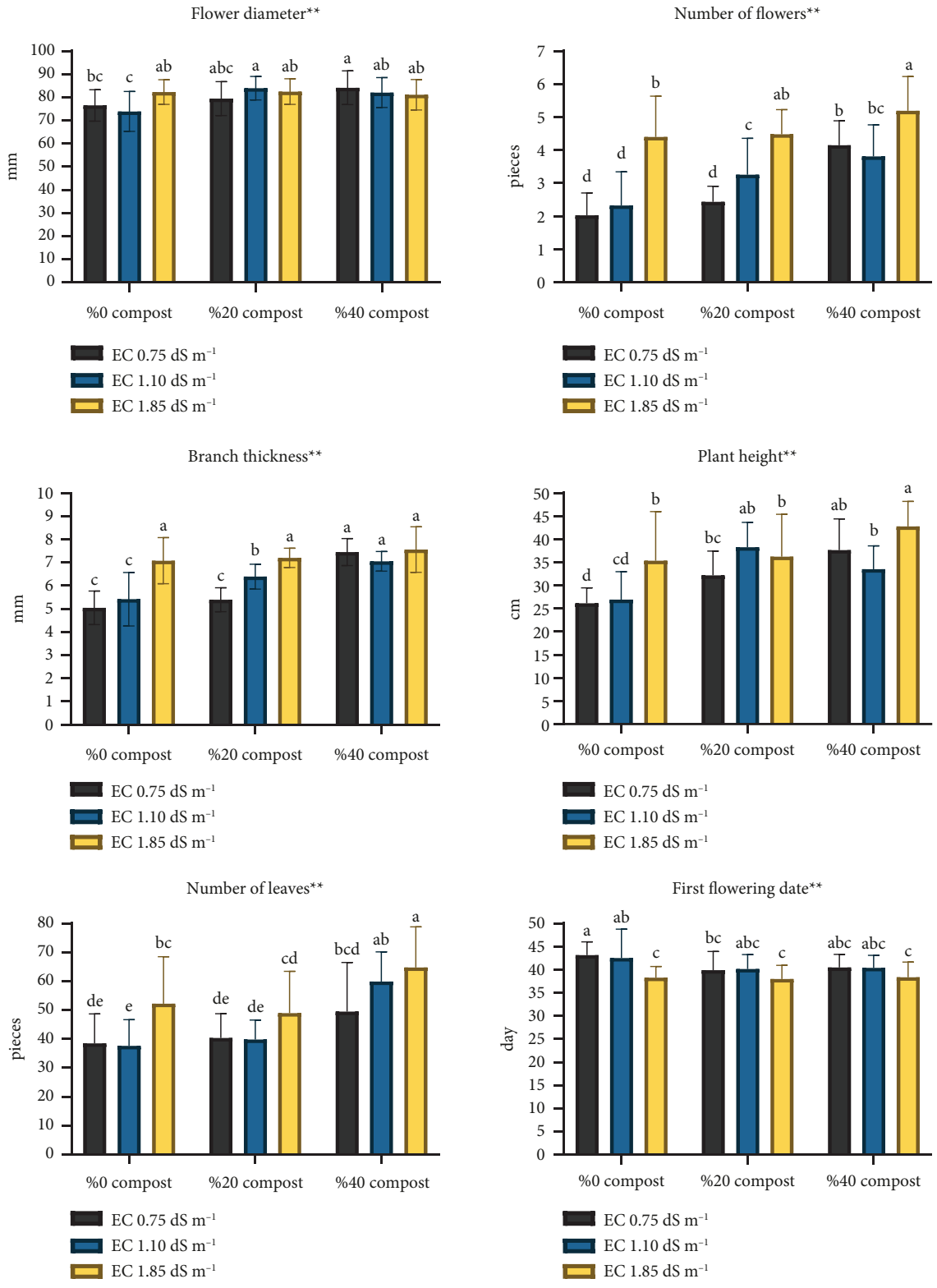


FIGURE 1 | Effect of different EC and compost levels on plant growth and flowering parameters; the columns represent means, and the bars represent standard errors of the three replicates, $^{**}p < 0.001$.

reached its highest level (357 mg kg^{-1}) in the 40% compost + EC 1.85 dS m^{-1} application. The potassium (K) content reached its maximum value of 709 mg kg^{-1} in the 40% compost + EC 1.10 dS m^{-1} application. The calcium (Ca) content reached its highest value at 79 mg kg^{-1} in the 40% compost + EC 1.85 dS m^{-1} application, while the magnesium (Mg) content reached its highest value at 184 mg kg^{-1} in the 40% compost + EC 1.85 dS m^{-1} application. Among the micronutrients, iron (Fe) reached

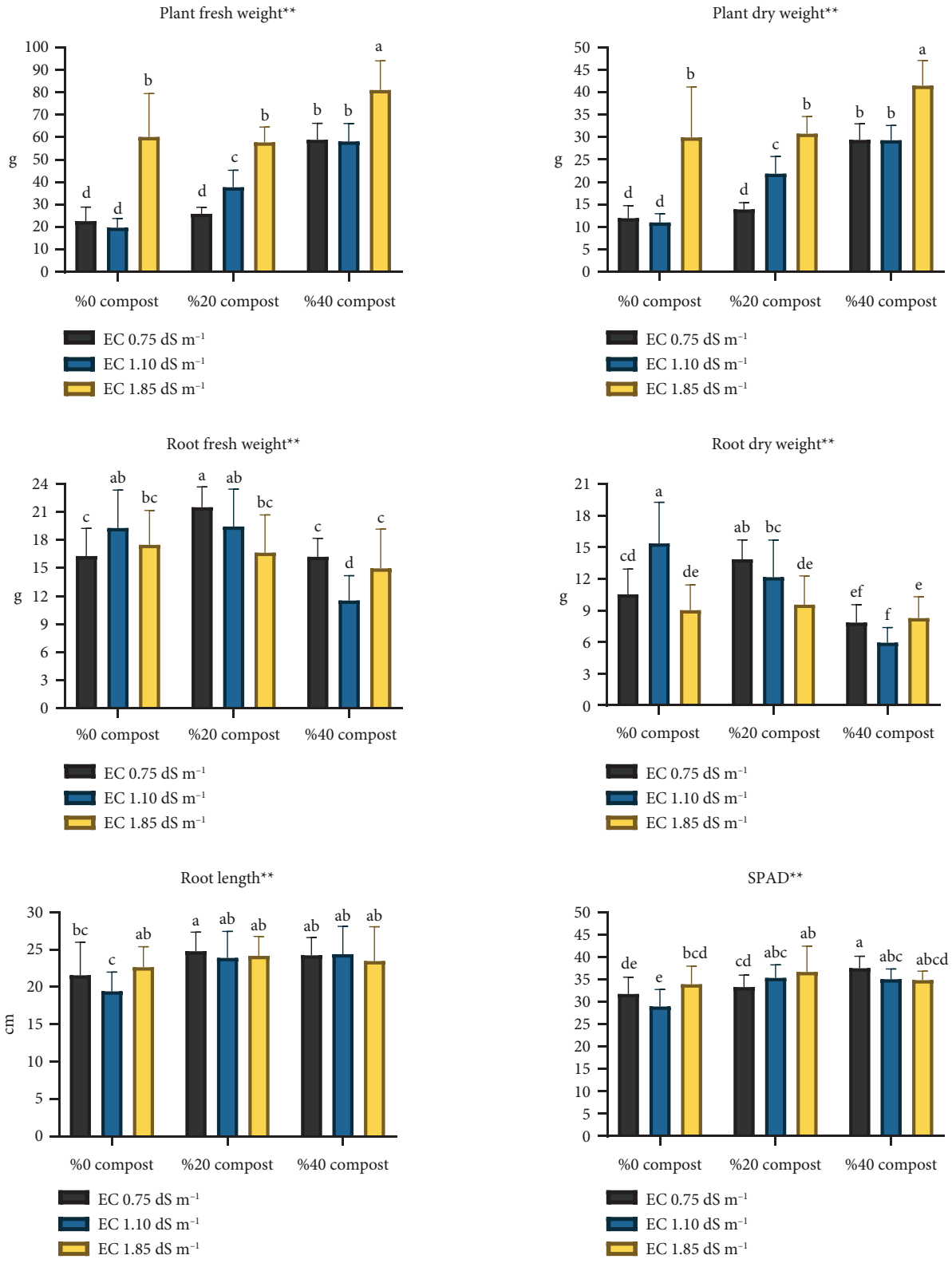


FIGURE 2 | Effects of different EC and compost levels on plant growth; the columns represent means, and the bars represent standard errors of the three replicates, $^{**}p < 0.001$.

0.90 mg kg^{-1} in the 40% compost + EC 1.85 dS m^{-1} application, copper (Cu) was 0.26 mg kg^{-1} in the 40% compost + EC 1.85 dS m^{-1} application, and manganese (Mn) was 2.30 mg kg^{-1} in the 40% compost + EC 1.10 dS m^{-1} application. Molybdenum (Mo) content reached its highest level (0.40 mg kg^{-1}) in the 40% compost + EC 1.85 dS m^{-1} application. Boron (B) content showed its highest value at 1.49 mg kg^{-1} in the 40% compost + EC 0.75 dS m^{-1} application. Overall, GP compost applications

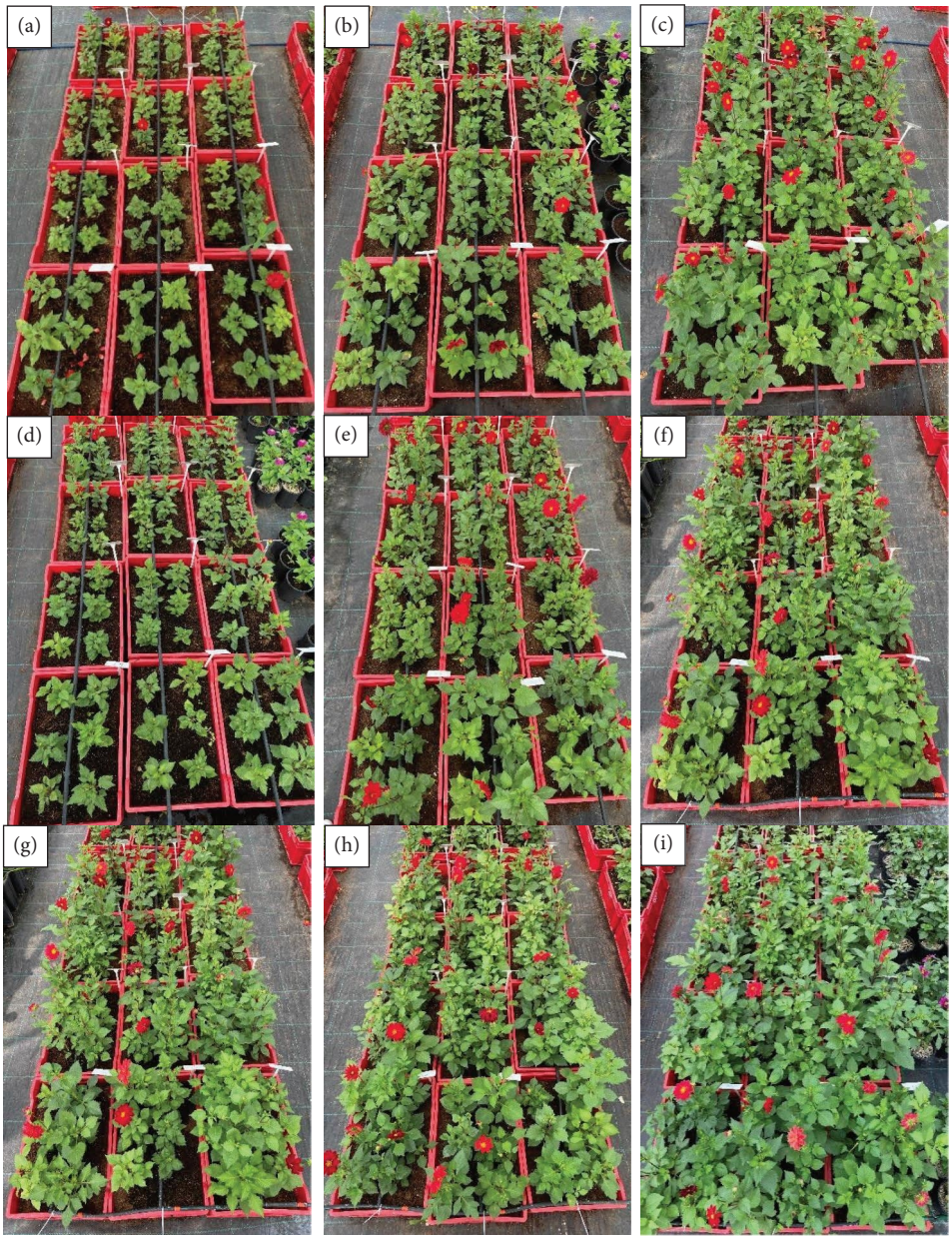


FIGURE 3 | Views of the effects of different treatments on the growth and development of Dahlia plants on day 40 ((a) 0% compost + EC 0.75 dS m^{-1}, (b) 20% compost + EC 0.75 dS m^{-1}, (c) 40% compost + EC 0. 75 dS m^{-1}, (d) 0% compost + EC 1.10 dS m^{-1}, (e) 20% compost + EC 1.10 dS m^{-1}, (f) 40% compost + EC 1.10 dS m^{-1}, (g) 0% compost + EC 1.85 dS m^{-1}, (h) 20% compost + EC 1.85 dS m^{-1}, (i) 40% compost + EC 1.85 dS m^{-1}).

increased most macro- and micronutrients, with the 40% compost and high EC (1.85 dS m^{-1}) combinations maximizing nutrient uptake (Figure 4).

4 | Discussion

The best results were obtained when compost was added to the growing media and compost application was at the highest level of 40%, stem diameter, flower diameter, number of flowers, plant height, number of leaves, SPAD value, plant fresh weight, and plant dry weight. Khomami et al. [36] added compost at 0%, 15%, 30%, 45%, 60%, 45%, 60%, and 100% v v^{-1} rates in *Dieffenbachia amoena* plant and reported that as the rates increased, it limited plant growth and caused significant differences in plant height (32.06 cm), stem diameter (11.66 mm), stem and leaf fresh weight (57.52 g), and stem and leaf dry weight (5.10 g) compared to the control. Cristiano et al. [37] added peat and sewage sludge-based compost (Co.) at 0% (control), 30%, or 60%, respectively, to the growing medium in *Lantana montevidensis* and reported that replacing peat with compost at 30% and 60% doses gave the worst results in terms of plant diameter, shoots, leaves, flowers, and fresh and dry mass and that these substrates may be the main factors governing plant growth rate. Baran et al. [38], in their study on *Hypostases phyllostagya*, prepared seven media using grape marc (CGM) mixed with natural peat and perlite in different proportions. As a result of their study, they reported that up to 50% composted grape marc in mixtures with peat gave the best results in plant growth. Zulfiqar et al. [39], who tested different compost materials on *Dracaena deremensis* cv. "Lemon Lime," reported that the addition of 10% compost to the growing

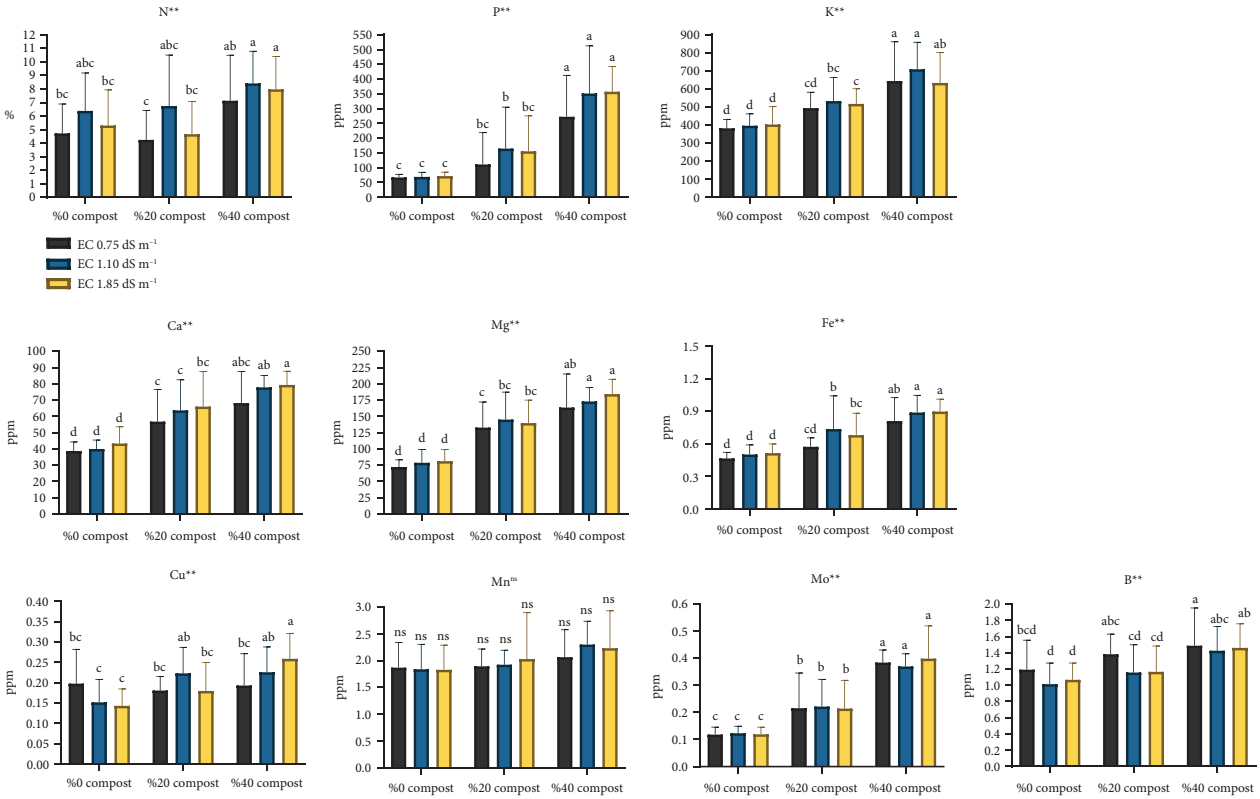


FIGURE 4 | Effects of fertilization treatments with different compost rates and different EC levels on macro- and micronutrient contents in leaves of Dahlia "Figaro" cv.; the columns represent means, and the bars represent standard errors of the three replicates, $^{**}p < 0.001$, ns: non-significant.

medium increased the vegetative growth (plant height, number of leaves, leaf area, and fresh biomass) of *Dracaena* by 10%–30% compared to peat + perlite mixture (90%–10% v:v). Papafotiou et al. [40] reported that 25% compost application increased the main stem thickness and root dry weight of *Ficus benjamina* compared to the control. Aji et al. [41], who examined the effects of compost made from food waste and unshredded dry leaves on *Tabernaemontana divaricata* plant, stated that compost applications in the range of 5%–20% showed the greatest growth improvement in the plant. In *Coleus* sp., the effects of 20% food waste compost and biochar application on plant height (65.75 cm), number of leaves (59), chlorophyll content (29.70 µmol m^{-2}), photosynthesis rate (23.53 µmol CO_2 s^{-1}), stomatal conductance (0. 009 mmol m^{-2} s^{-1}), transpiration rate (0.269 mmol m^{-2} s^{-1}), water use efficiency (WUE) (88), and total biomass (62.50 g) [42] were studied. Studying the effects of compost produced from sugarcane bagasse on the growth of *Pelargonium x hortorum*, Najarian and Souri [43] reported that the application of low rates of 20% resulted in the highest values in terms of many morphological traits, including the number of leaves, lateral stems, flowering shoots, flowers, inflorescence diameter, main shoot diameter, shoot and root biomass, and phosphorus concentration, and nitrogen and potassium concentrations reached the highest values in 40% compost application.

In the studies in the literature, compost has been used in the cultivation of many ornamental plants in order to meet the nutrient needs of plants and to protect the physical, biological, and chemical structures of the growing environment and the results have been shared. As can be understood from the studies, different results are obtained depending on factors such as the raw material from which the compost is obtained, the amount of compost application, application time, and plant species. However, it is generally mentioned that compost has a multifaceted positive effect. In addition, in most studies, it has been reported that compost applied to the growing medium restricts plant growth as the rate increases. Based on the studies in the literature, it is stated that the best results in compost utilization rates vary between 5% and 50%. In the Dahlia study, it was observed that the increase in the compost rate mostly encouraged plant growth, and it suggests that better results may be obtained if the compost rate specified in the study exceeds 40%.

Generally, farmers use chemical fertilizers to improve soil fertility and thus increase the yield of their crops. However, the use of chemical fertilizers causes great damage to soil quality and the environment [44]. In this study, fertilization with different EC levels (EC 0.75–EC 1.10, and EC 1.85 dS m^{-1}) was applied and it was aimed to reduce the amount of fertilization by using compost. In the light of the results obtained, the best results were found at EC 1.85 dS m^{-1} level in stem diameter, flower diameter, number of flowers, plant height, number of leaves, plant fresh, and plant dry weights. Considering the studies in the literature, Boboc et al. [45] reported that a 20–20–20 compound fertilizer significantly increased plant growth in Passiflora caerulea and plant growth and quality increased as the fertilization level increased. Vâşcă-Zamfir et al. [46] reported that the number of leaves, number of branches, and plant height increased as a result of fertilization in *Murraya exotica* L. (*Rutaceae*) and that fertilization provided beneficial effects on plant growth and quality. Baltazar-Bernal and Jaen-Contreras [47] reported that vegetative growth of *Heliconia* cv. Tropics was stimulated by fertilization at

NPK doses of 100–30–150 kg ha^{-1} and plant height, stem diameter, number of shoots, leaf area, chlorophyll content, and root dry weight were better than the control. Similar to this Dahlia study, Andrzejak et al. [48] reported that *Begonia x tuber hybrida* Voss "Picotee Sunburst" plants were fertilized with three different fertilizer concentrations (0%, 0.2%, and 0.3%), which resulted in intense flowering and the largest flowers in 0.3% fertilizer treatments. It was also reported that the higher the fertilizer concentration, the higher the content of microelements in the plants. The results reported in the literature coincide with the findings of this study. Similarly, Brînză et al. [49] fertilized *Lilium regale* at different rates (4 g fertilizer $plant^{-1}$, 6 g fertilizer $plant^{-1}$, and 8 g fertilizer $plant^{-1}$) and reported that fertilizer application stimulated the flowering capacity and flower length growth of the plant, regardless of the dosage used. In addition, in this study, compared to the control, all parameters except root fresh weight, root dry weight, and root length increased with increasing fertilizer concentration. Nofal et al. [3] reported that as a result of 0.1 g pot^{-1} and 2 g pot^{-1} fertilization applications in *Tagetes erecta* plant, 2 g pot^{-1} application showed better development compared to the control in terms of plant growth and the development increased as the fertilizer rate increased. Ali and Çığ [44] obtained the highest flower number (37.69) from 2 kg $decar^{-1}$ application and the highest flower length (26.76 mm) from 4 kg $decar^{-1}$ application as a result of nitrogen and phosphorus fertilization at doses of 2 kg $decar^{-1}$, 4 kg $decar^{-1}$, and 8 kg $decar^{-1}$ in hyacinth plant. At 8 kg $decar^{-1}$ application, they reported that the highest leaf diameter (28.86 mm) and plant height (179.54 mm) were obtained. Winhelmann et al. [50] fertilized *Angelonia integerrima* at five different doses (0 g L^{-1}, 2.5 g L^{-1}, 5.0 g L^{-1}, 7.5 g L^{-1}, and 10.0 g L^{-1}) and the best shoot length was 7.2 g L^{-1}, the stem length was 6.7 g L^{-1}, the stem diameter and root system were 5.9 g L^{-1}, and the open flower, bud, old flower, and total flower number were measured at 7.7 g L^{-1}. It was reported that there was no difference between the number of stems, number of fruits, total chlorophyll, and chlorophyll a and b. As a result of the study, it was reported that the most suitable slow-release fertilizer dose for the cultivation of potted species was 7.2 g L^{-1}.

Increasing compost concentration had a significant positive effect on most plant growth parameters compared to the control treatment (0% compost). Plants grown with 20% and 40% compost showed increased stem diameter, plant height, and leaf number, indicating improved vegetative growth due to the enhanced nutrient availability and organic matter content of the compost. Flower diameter and number of flowers also increased, suggesting that the combined effect of organic matter and nutrient enrichment promoted reproductive development.

In contrast, the control group exhibited lower growth performance, likely due to reduced nutrient and microbial activity in the growth medium. The highest values for fresh and dry biomass were obtained under 40% compost application, which aligns with findings reported by Durmuş and Kızılkaya [51], who also observed improved biomass accumulation with compost-amended substrates. However, excessive compost rates sometimes led to slight increases in EC, which may have influenced root physiological processes.

The interaction between compost rate and EC level revealed that moderate EC (1.10 dS m^{-1}) combined with 20% compost yielded the most balanced growth, reflecting optimal nutrient uptake and osmotic conditions. Similar trends were reported in studies using organic waste-derived composts under controlled cultivation systems [52, 53]. Overall, these results highlight the positive role of waste GP compost in improving plant growth and nutrient efficiency compared with the control treatment.

The superior performance observed under 40% compost application can be attributed to the improvement of both soil physicochemical and biological properties. Compost addition enhances soil structure, aeration, and water-holding capacity, creating a more favorable rhizosphere environment for root development and nutrient absorption [54, 55]. Moreover, compost increases CEC and microbial activity, which in turn enhances the mineralization and release of essential nutrients such as nitrogen, phosphorus, and potassium [56]. These processes improve the root nutrient uptake efficiency, leading to greater biomass accumulation and plant vigor.

Physiologically, plants grown with 40% compost exhibited higher chlorophyll content (SPAD values), suggesting improved nitrogen assimilation and photosynthetic performance. The organic matter in compost also supplies humic and fulvic acids, which can stimulate root elongation and membrane permeability, thereby facilitating the uptake of both macro- and micronutrients [51]. Enhanced nutrient supply supports greater enzyme activity and hormonal balance within the plant, promoting both vegetative and reproductive development. Consequently, the synergistic effects of improved nutrient availability, microbial stimulation, and root physiological activity under 40% compost treatment explain the significant increases observed in growth and flowering parameters compared with the control.

According to the data obtained from the literature, in the development of plants, the deficiency of essential nutrients is a physiological effect that causes not only a reduction in ornamental characteristics but also a reduction in plant development. Fertilization treatments provided the necessary nutritive elements for the proper development of plants during the entire vegetative period and were found to give better results compared to the results obtained from control treatments. In the present study, the direct effect on plant growth as a result of the increase in EC level, especially nitrogen, phosphorus, and potassium from macroelements, was confirmed by studies in the literature.

Organic fertilizers are widely used in cultivation in addition to or instead of synthetic fertilizers because they help to improve soil physical and biological properties and provide nutrients [32, 57]. Organic fertilizers can improve soil physical properties such as increased porosity, water retention, and saturated hydraulic conductivity [57, 58]. The incorporation of organic fertilizers has been reported to help with increased soil biological activity, possibly resulting from the enrichment of organic matter in the soil [57–60]. In organic systems, combining pre-plant compost applications with organic fertilizer application is preferred to increase nutrient availability to plants during the early stages of growth [61]. However, each plant may respond differently to these treatments and a different method may be preferred for a given organic fertilizer source and application rate [62, 63]. As stated in the literature, plant growth and development are accelerated considerably when compost, which is rich in organic material, is combined with synthetic fertilizers. However, the aim of the study was to minimize the amount of synthetic fertilizer as the compost ratio increases. This aim was also achieved

in the results obtained in root fresh weight, root dry weight, and root length.

The generalizability of the positive responses we observed in Dahlia variabilis in this study is directly dependent on the composition of the GP used and the processing (winemaking) procedures. The phenolic profile, C/N ratio, pH–EC, and cation content (especially K) of the GP can vary significantly depending on the grape variety, vineyard management, maceration/pressing intensity, and technological applications such as sulfiting; therefore, reporting material characterization (OM, C/N, pH, EC, phenolics, ripeness indicators, etc.) is critical when transferring results to other batches/broader contexts. The literature shows that the phenolic content of GP and differences in winemaking (such as red/white processing) significantly affect its composition [27]. The enhancement of plant growth and foliar nutrition by composted GP is explained by multiple mechanisms: (i) physical structure: porosity–water retention–aeration improves, root development and water/nutrient access increase. (ii) Microbial activation: microbial communities are stimulated; mineralization and chelation accelerate. (iii) Gradual nutrient release: N–P–K–Ca–Mg are released over time, leaching decreases, and foliar nutrients increase. (iv) Phenolic detoxification: composting reduces phenolic-induced phytotoxicity, bringing the germination index to a safe level. This framework is consistent with the circular bioeconomy/biofertilizer literature and explains the positive responses in our study despite the potential limitations of raw UP [64]. When we compare our results with controls (0% UP, mineral fertilizer at the same EC) and UP applications, the practical superiority becomes clear. For example, under EC 1.85 dS m^{-1} conditions, compared to 0% UO, 40% UO increased flower number from 4.39 to 5.19 per plant (+18%), leaf number from 52.3 to 64.7 (+24%), and plant fresh/dry weight from 60.1 to 81.0 g (+35%), and 29.9 ⟶ 41.5 g (+39%), and increased the branch diameter from 7.08 ⟶ 7.56 mm (+6.7%). Significant gains were also observed in leaf nutrients: P ∼+400%, K +57%, Ca +83%, Mg +127%, Fe +75%, Cu +81%, Mn + 22%, Mo +235%, B +37%, N +50% (all compared to 0% U at the same EC). In contrast, a small change in flower diameter (−1.4%) and a limited decrease in root fresh/dry weight (−14%/−8%) suggest a reallocation of biomass toward shoots under high EC + UPP. These comparisons are clearly presented in the text and tables to eliminate criticism regarding the difficulty of interpretation without references. Raw (unprocessed) UPP application may suppress germination and early root development due to phenolic/tannin load and slow nitrification and negatively affect microbial groups sensitive to phenolics. Composting/conditioning breaks down these components, reducing phytotoxicity and bringing maturity thresholds to GI ≥ 60–80%. Since UPP batches are mostly K-rich, high doses may increase the risk of EC/ionic load; additionally, Cu and pesticide residues from the source may accumulate. Therefore, the use of processed UP, careful management of dosage and EC, and reporting of material characterization and residue monitoring are mandatory [65]. To place this discussion in the broader literature context suggested by the referee, we referenced recent studies highlighting compost/organic conditioners and soil fertility restoration, bio-/phytoremediation and plant–microbe interactions, biofertilizers, and circular bioeconomy themes. These studies demonstrate that organic inputs can permanently improve plant nutrition and increase biomass/product quality through microbial activation and gradual nutrient release; this general framework is consistent with our Dahlia results obtained with UP compost [64].

In conclusion, the batch-to-batch variability in the chemistry of UPP, when read in conjunction with the detailed characterization presented in this study, facilitates the transferability of the results. Applying UP in its mature compost form, compared to EC-matched mineral fertilizer conditions, is the most reliable way to maximize gains in growth, flowering, and leaf nutrition while managing risks of phenolic/salinity and microbial imbalances. We proposed practical pretreatment methods and composting strategies to reduce risks associated with raw GP (phenolic phytotoxicity, salinity/K load, and microbial changes). In addition, composting GP with C- and N-rich bulking agents to target C/N ≈ 25–30 and moisture content of 50%–60% under aerated static piles or turned piles; (ii) optional polyphenol extraction prior to composting or biochar conditioning (1%–10% by weight) to adsorb phenols and maintain EC at a medium level; and (iii) curing/vermicomposting until maturity criteria are met (e.g., germination index ≥ 60–80%) is recommended.

5 | Conclusion

The compost used in this study was produced from waste grape pomace (WGP) obtained from local fruit juice processing plants. Incorporating this organic material into the growing medium significantly enhanced plant growth and development. Among all treatments, the 40% compost rate produced the best results, leading to higher stem diameter, plant height, and overall vegetative performance. When combined with synthetic fertilization, particularly at 1.85 dS·m^{-1} EC, this treatment yielded the highest improvements in growth parameters, demonstrating a synergistic effect between organic and mineral nutrient sources. From a sustainability perspective, these findings are highly relevant for soilless and ornamental plant production systems, where imported substrates such as peat and cocopeat are used for economic and environmental challenges. The results indicate that WGP compost can partially substitute conventional growing media, reducing dependency on nonrenewable imports while improving nutrient efficiency. Additionally, the partial replacement of synthetic fertilizers with organic materials contributes to more sustainable nutrient management. Overall, the valorization of WGP as compost represents a practical and environmentally sound approach to circular horticultural production. For commercial nurseries and greenhouses located in grape-producing regions, this practice offers scalability and cost advantages when mature compost (maturity index 60%–80%) with controlled pH, EC, and heavy metal quality is used. Future studies should focus on large-scale pilot applications and cost–benefit analyses to assess long-term feasibility and environmental impact.

Author Contributions

Nurullah Bayram: installation of the experiment, data collection, preparation of compost and making leaf analyses, and critical review of the article. Onur Sefa Alkaç: experiment idea, installation of the experiment, field analysis, data collection and analysis, interpretation of data, and critical review of the article.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

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

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