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ORIGINAL PAPER

Fruit Peel Soil Supplementation Induces Physiological and Biochemical Tolerance in *Schefflera arboricola* L. Grown Under Heat Conditions

Rasha S. El-Serafy[1] · Abdel-Nasser A. El-Sheshtawy[2] · Abeer A. Dahab[3]

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Abstract
Schefflera plant is propagated and grown under greenhouse cultivation, and most of these greenhouses are low-cost. In the summer, the heat generated in greenhouses becomes a limiting factor for plant growth and, subsequently, limits the production of high-quality species under greenhouse conditions. The powder of banana (B), orange (O), and pomegranate (P) peels and their combinations were added as soil supplementation at rates of 8 and 16 g/pot to the pots of *Schefflera* plants, which were grown during the summer season under a low-cost greenhouse. The growth analysis was estimated after 150 and 180 days from planting. Heat conditions significantly inhibited the relative growth rate, crop growth rate, and absolute growth rate (AGR) of *Schefflera* plants, but fruit peel applications were shown to markedly mitigate its negative impact. Fruit peel applications augmented the shoot and root growth rates and leaf pigments, decreased AGR reduction, promoted relative water content, increased membrane stability index (MSI), and alternated the phenotypic plasticity index (PPI). Fruit peels significantly increased total phenol and flavonoid levels as well as the antioxidant activity (DPPH), which positively alleviated the oxidative damage (decreased H_2O_2 and MDA contents) that occurred in plant leaves, and induced heat-shock protein synthesis, leading to plants with greater heat tolerance. Orange peel application at the rate of 16 g/pot to the potting soil is more beneficial for root initiation and development during the early phases of *Schefflera* plant life, as well as more effective in increasing the aerial portions and inducing resistance to heat conditions in low-cost polyethylene greenhouses.

Keywords Heat · Pot plant · Greenhouse · Fruit peel · Heat shock protein

1 Introduction

Schefflera arboricola L. is an important indoor ornamental plant with economic value in the international market. It is considered one of the main commercial ornamental plants grown in pots as well as in landscapes. Moreover, it has been used for medical purposes, as it is used to treat a variety of non-neurological diseases and conditions, including ulcers, cancer, hypertension, atherosclerosis, eczema, wounds, and leprosy (Alharbi 2019). *Schefflera* is typically propagated from cuttings in a nursery under protected conditions until they reach a saleable size. However, in Egypt, most protected greenhouses used for cultivating ornamentals lack acclimatization facilities, which might increase costs. During the summer season, generated heat in greenhouses becomes a limiting factor for plant growth and, subsequently, prevents the production of high-quality species under greenhouse conditions (Tonhati et al. 2020).

Heat is a major abiotic stress that restricts plant growth and development. According to the Intergovernmental Panel on Climate Change (IPCC 2018), the maximum temperature and heatwaves have increased in the last decade. It is predicted that, by the end of the current century, the global temperature will increase by about 1.5 to 5.8 °C. Heat stress occurs when temperatures cause irreversible injury or damage to plant tissues. However, it is considered to strongly hamper plant growth, especially at the preliminary stages. Tropical plants suffer from heat stress in

✉ Rasha S. El-Serafy
rasha.elserafi@agr.tanta.edu.eg

[1] Horticulture Department, Faculty of Agriculture, Tanta University, Tanta, 31527, Egypt

[2] Environment and Bio-Agriculture Department, Faculty of Agriculture, Al-Azhar University, Cairo 11651, Egypt

[3] Medicinal and Aromatic Plants Research Department, Horticulture Research Institute, ARC, Giza, 12619, Egypt

temperature ranges of 35–45 °C, but it is variable for different plant species (Mahmood et al. 2010; Ulukan 2011). Heat stress caused visible symptoms such as leaf folding, dehydration, and tip burning, and it eventually led to plant death (Vollenweider and Günthardt-Goerg 2005). Heat tolerance can be increased by the application of exogenous nutrients and organic substances (Sakamoto and Murata 2002).

Fruit peels are the waste materials that are produced by fruit processing. These wastes are considered excellent mediums for microbial spoilage, causing environmental pollution. Peels play a critical role in protecting fruit parenchyma from pathogenic microorganisms since they have antimicrobial properties and contain prominent levels of antioxidants. Many fruit wastes contained more phytochemicals and nutritional components than fruit pulp (Rudra et al. 2015), for example, orange peels contained over 15% more phenolic concentrations than fruit pulp (Soong and Barlow 2004). Recently, exploiting these wastes as a by-product for many industries has gained great interest because of the high quality of their products and their economic attractiveness.

Banana peel is a rich source of phytochemicals and antioxidants such as phenolic compounds, flavonoids, vitamins, beta-carotene, potassium, calcium, and magnesium elements, in addition to nutritional ingredients such as proteins, dietary fiber, essential amino acids, particularly tryptophan, and polyunsaturated fatty acids (Emaga et al. 2007). It is used as a plant growth-promoting substance that might be used for foliar or soil applications (Anwar et al. 2011; Dayarathna and Karunarathna 2021). El-Awadi et al. (2021) reported that banana peel soil supplementation was effective in decreasing the deleterious impact of water stress.

The orange fruit is one of the most important fruits used in agro-industrial activities, producing 60–65% peels and 0–10% seeds and membranes (Tuttobene et al. 2009). Orange wastes are used for energy recovery (Ingram and Doran 1995), producing flavor and fragrance as food supplementation and cleaning supplies for household materials (Gentry et al. 2001), as well as using them in livestock feed (Wagner et al. 1983). Soil fertility has been proven by using orange wastes as organic fertilizer and by increasing crop yields with mineral fertilization by long-term addition (Intrigliolo et al. 2005). The growth of fenugreek, okra, and sage plants has been enhanced after pomegranate peel supplementation (Dayarathna and Karunarathna 2021; Abd-Rabbu et al. 2021), which may be due to the high content of macro-nutrients, vitamins, antioxidants, and bioactive components in pomegranate peel, as the peel contains 249.4 mg/g of phenolic compounds while the pulp contains 24.4 mg/g (Li et al. 2006). Based on the foregoing, it is possible to conclude that fruit wastes, which are one of the leading causes of environmental pollution, can be used as a natural source of plant growth nutrients and antioxidants as an alternative to synthetic materials and to create abiotic stress tolerance.

To the best of our knowledge, this is the first time a *Schefflera arboricola* L. cultivation has been subjected to different fruit peel soil supplementation under heat conditions. This study aimed to examine the differential influence of different fruit peels on *Schefflera* plants cultivated in low-cost greenhouse conditions. So, for achieving this goal, the impact of banana, orange, and pomegranate powder peels as well as their combinations on the morpho-physiological traits of *Schefflera,* including growth, photosynthetic pigments, oxidative stress, antioxidant activity, and protein content, was estimated.

2 Materials and Methods

This investigation was performed at the Horticulture Department, Faculty of Agriculture, Tanta University (30°49′32.5″N 30°59′44.4″E), under a polyethylene greenhouse at the nursery of ornamental plants from February to September.

2.1 Processing Fruit Peels and Chemical Analysis

The peels of banana, orange, and pomegranate fruits were collected and washed with distilled water three times to remove any unwanted materials. The peels were cut into small pieces (3 − 4 cm) and air-dried for 10 days. They were then oven-dried at 60 °C until they reached a constant weight. The feedstock was ground in a household blender, sieved, and stored at room temperature. The chemical analysis of fruit peels is presented in Table 1.

2.2 Planting Methodology and Fruit Peel Supplementation

A uniform single-stem *Schefflera arboricola* stock plant was cut into single-node leaf bud cuttings with a small portion

Table 1 The chemical analysis of banana, orange, and pomegranate peels

Components	Banana	Orange	Pomegranate
DPPH (%)	68.5	80.6	74.2
Total phenols (%)	2.11	2.96	2.15
Total flavonoids (%)	1.15	1.78	2.45
Minerals (mg/100 g)			
P	169.2	246.5	126.4
K	5.36	7.57	158.3
Ca	62.45	96.21	50.89
Mg	50.73	1.84	0.65

of the stem, petiole, compound leaf, and an axillary bud (El-Serafy 2020). The cuttings were planted on February 1st in pots (30 cm) containing 8 kg of soil under a polyethylene greenhouse without cooling facilities (low-cost polyethylene greenhouse). After cultivation by 30 days, the pots were divided into nine groups and supplemented with the powdered peels of banana (B), orange (O), and pomegranate (P) at rates of 8 and 16 g/pot as follows: (1) B1 (8 g/pot), (2) B2 (16 g/pot), (3) O1 (8 g/pot), (4) O2 (16 g/pot), (5) P1 (8 g/pot), (6) P2 (16 g/pot), (7) B1 + O1 + P1 (8 g B + 8 g O + 8 g P/pot), (8) B2 + O2 + P2 (16 g B + 16 g O + 16 g P/pot), and (9) untreated pots (control). Soil supplements were applied to the surface of the soil and turned over five times every 30 days. The agricultural practices were done regularly. A daily temperature was recorded and is presented in Fig. 1. Nine treatments were performed and arranged in a completely randomized design with three replicates, each consisting of six pots with one plant ($n = 6$). The experiment was carried out twice. The soil analysis was as follows: sand: 67.24%, clay: 21.62%, and silt: 11.14%, pH: 7.28, EC: 1.53 dS m^{-1}, Ca^{+2}: 8.11 meq L^{-1}, N: 0.31%, P: 0.045%, and K: 0.07%.

2.3 Growth Analysis

To conduct a growth analysis, six plants were randomly collected at 150 and 180 days after planting (DAP) from each treatment and divided into aerial parts (shoots) and roots, and their dry mass was recorded after being over-dried at 70 °C for 48 h. Growth traits were calculated and presented in Table 2. At 180 DAP, leaf samples were collected and immediately submerged in liquid nitrogen before being pulverized to a fine powder with a mortar and kept at 80 °C for biochemical analysis.

2.4 Membrane Stability Index (MSI)

The MSI of fresh leaf samples was determined as previously mentioned by El-Serafy (2019) according to Sairam et al., (1997). Two leaf samples were immersed in two glass flasks containing 20 mL of double-distilled water. The first flask was heated for 30 min at 40 °C, and its conductivity was measured as C_1, while the second flask was heated in a boiling water bath at 100 °C for 15 min and its conductivity was recorded as C_2. The membrane stability index was expressed using the formula $MSI = [1 - (C_1/C_2)] \times 100$.

2.5 Relative Water Content (RWC)

In order to estimate RWC, the methods of Weatherley (1950) were performed. The RWC was calculated as $RWC\ (\%) = (W_{fresh} - W_{dry}) \div (W_{turgid} - W_{dry}) \times 100$. The W_{fresh} and W_{turgid} are the weights of the fresh leaf sample and after saturation in double-distilled water for 24 h at 4 °C, respectively, while the W_{dry} is the weight of the same leaf sample after being oven-dried at 70 °C for 48 h.

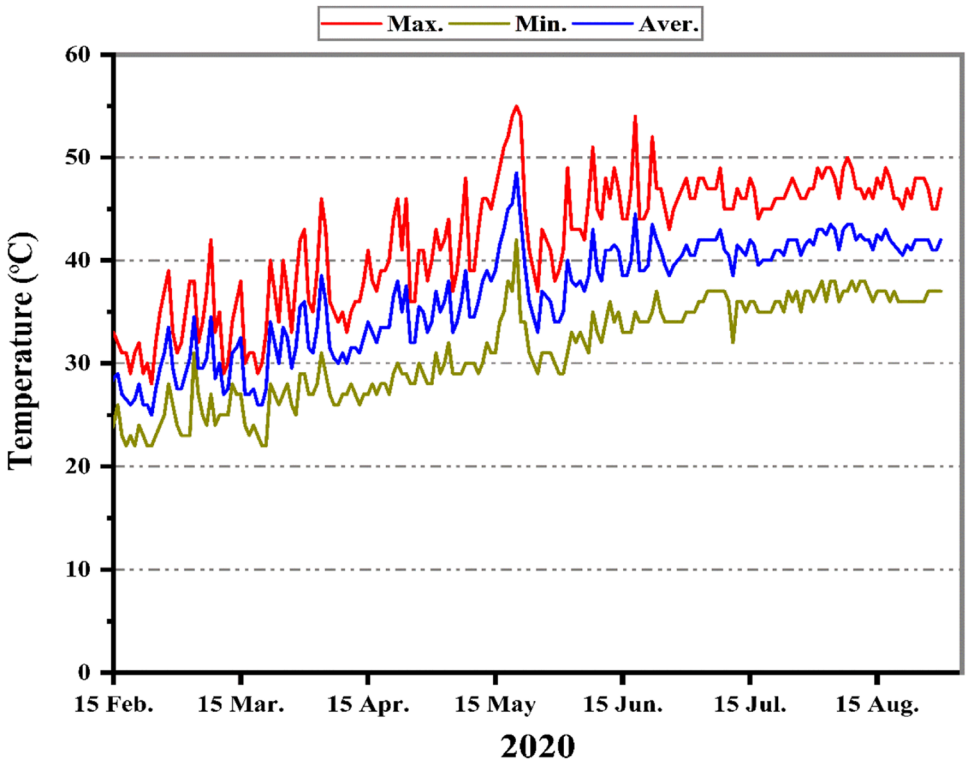

Fig. 1 Daily maximum, minimum, and average temperature collected throughout the experimental period

Table 2 Growth analysis, abbreviation, formula, unit, and reference

Trait name	Formula	Abbreviation	Unit	Reference
Relative growth rate for aerial parts	$(\ln M_2 - \ln M_1)/(T_2 - T_1)$	RGR_A RGR_R RGR_P	g g^{-1} day^{-1}	Williams (1946)
Crop growth rate	$(M_2 - M_1)/q\ (T_2 - T_1)$	CGR_A CGR_R CGR_P	g m^2 day^{-1}	Watson (1958)
Absolute growth rate	$(M_2 - M_1)/(T_2 - T_1)$	AGR	g day^{-1}	–
Phenotypic plasticity index	(Maximum mean − minimum mean)/(maximum mean)	PPI	–	Valladares et al. (2000)

Subscripts refer to the first and second times of sampling (150 and 180 days after planting, respectively)

P plant dry mass (g), *A* aboveground mass, *R* root mass, *M* biomass of plant parts, *q* ground area on which M_1 and M_2 were estimated, *T* time

2.6 Photosynthetic Pigments

Leaf pigments: chlorophyll a, b, and carotenoids were estimated spectrophotometrically using acetone as a solvent extract, according to Mitic et al. (2013), at wavelengths of 662, 644, and 440 nm. Leaf pigment concentrations were calculated using the formula of Holm (1954) and Von Wettstein (1957):

$$\text{Chlorophyll a} = 9.784 \times \text{OD662} - 0.990 \times \text{OD644}$$

$$\text{Chlorophyll a} = 9.784 \times \text{OD662} - 0.990 \times \text{OD644}$$

$$\text{Chlorophyll b} = 21.426 \times \text{OD644} - 4.650 \times \text{OD662}$$

$$\text{Carotenoids} = 4.695 \times \text{OD440} - 0.268 \times (\text{a} + \text{b})$$

Pigment content was calculated using the following formula:

$$\text{Pigment content } (C) = (c1 \times vr) \div m$$

C = pigment content (g kg^{-1} fresh weight), c_1 = pigment concentration (mg L^{-1}), v = volume of the solvent extract (mL), r = dilution rate, and m = sample fresh weight (g).

2.7 Total Phenol and Flavonoid Content

Phenolic and flavonoid compounds in the dried leaves were extracted by mixing 1 g of dried samples with 50 mL of methanol (80%) and leaving them for two days at room temperature. Total phenols were estimated as previously described by El-Serafy et al. (2021a) using the methods of Dewanto et al. (2002) with gallic acid as a standard. A sample extract was mixed with 0.5 mL and 0.125 mL of distilled water and Folin – Ciocalteu reagent, respectively, and left to stand for 6 min after shaking. After that, Na_2CO_3 (7%) at 1.25 mL was supplemented, and the mixture was completed by using distilled water to 3 mL final volume and was carefully shaken. The mixture was maintained for 90 min in the dark at room temperature, and the absorbance was estimated at 760 nm. Total phenols were given in g GAE kg^{-1} DW. The aluminum chloride approach was used according to Boateng et al. (2008) to determine total flavonoids in *Schefflera* leaves. A mixture of 0.5 mL of the sample extract and 0.5 mL of aluminum chloride (2%) was left at room temperature for 45 min. At 420 nm, the absorbance of the resulting mixture was measured. The flavonoid concentration is measured in g CAE kg^{-1} DW, and the standard curve was created using catechin (CAE).

2.8 Malondialdehyde (MDA) Estimation

The lipid peroxidation in *Schefflera* leaves was estimated as MDA content according to Heath and Packer (1968). A sample of 0.5 g of fresh leaves was mixed with 5.0 mL of TCA (5% w/v) and centrifuged for 10 min at $12.000 \times g$. A total of 2 mL of the extract was added to 2 mL of TBA (0.6%) and then heated for 10 min in a water bath (95 °C). The absorbance was estimated at 532 and 600 nm wavelengths. The MDA content (mmol g^{-1} FW) was calculated using the following formula. MDA content = $6.45 \times (\text{A532} - \text{A600}) - 0.56 \times \text{A450}$.

2.9 Hydrogen Peroxide (H_2O_2) Determination

The generated H_2O_2 in *Schefflera* leaves was determined according to the Patterson et al. (1984) method. Leaf samples (0.5 g) were homogenized in 6 mL of chilled acetone (100%) and then centrifuged for 10 min at 4 °C at $12,000 \times g$. One mL of the final extract was mixed with 0.1 mL of $Ti(SO_4)_2$ (5%) solution and 0.2 mL of NH_4OH solution, respectively. After that, the mixture was centrifuged for 10 min at $3000 \times g$ and dissolved in 4 mL of H_2SO_4 (2 M). To obtain an optical

density estimation, a wavelength of 412 nm was used, and the obtained results were presented as μg g^{-1} FW.

2.10 Scavenging Activity (DPPH Assay)

The free radical-scavenging activity of sample extract (10–80 μg mL^{-1}) was determined according to Chen et al. (2008) spectrophotometrically. A total of 0.5 mL of 1,2-diphenyl-2-picrylhydrazyl (DPPH) (300 μmol L^{-1}) was mixed with 950 mL L^{-1} ethanol, shaken well, and left to stand in the dark at room temperature for 30 min. Ethanol was applied as a blank. The DPPH radical has a deep violet color, and its unpaired electron and radical-scavenging capability can be examined via the absorbance loss at 517 nm when the pale yellow non-radical form is generated. The DPPH declination was assessed by comparison with a control (0.5 mL and 2 mL of DPPH solution and ethanol, respectively). The scavenging DPPH radical activity was calculated using the equation scavenging activity (DPPH %) = [1 − (A517 sample ÷ A517control)] × 100.

2.11 SDS-PAGE Protein Electrophoresis

The separation of proteins was performed by using Sodium Dodecyl Sulfate Polyacrylamide Gel Electrophoresis (SDS − PAGE), according to the method of Laemmli (1970).

2.12 Statistical Analysis

This experiment was arranged in a complete randomized design (RCD) with three replicates (six pots/replicate). The experiment was carried out twice during the same experimental period. The combined analysis of variance (ANOVA) across the two independent experiments was performed according to Gomez and Gomez (1984) using the MSTAT statistical package. Duncan's multiple range test at a 0.05 level of probability was used for comparing mean differences according to Waller and Duncan (1969). The results are presented as mean ± SE ($n = 6$).

3 Results

3.1 Growth Analysis

Growth analysis of *Schefflera* plants grown under heat conditions was significantly enhanced with the fruit peel soil supplementations (Figs. 2 and 3), and the high rate of orange peel (O2) was the most effective in this respect. *Schefflera* plants treated with the low level of the combined banana, orange, and pomegranate (B1 + O1 + P1) had the highest RGR_A (340.7% increase compared to control plants), followed by O2, which had a 278.6% increase

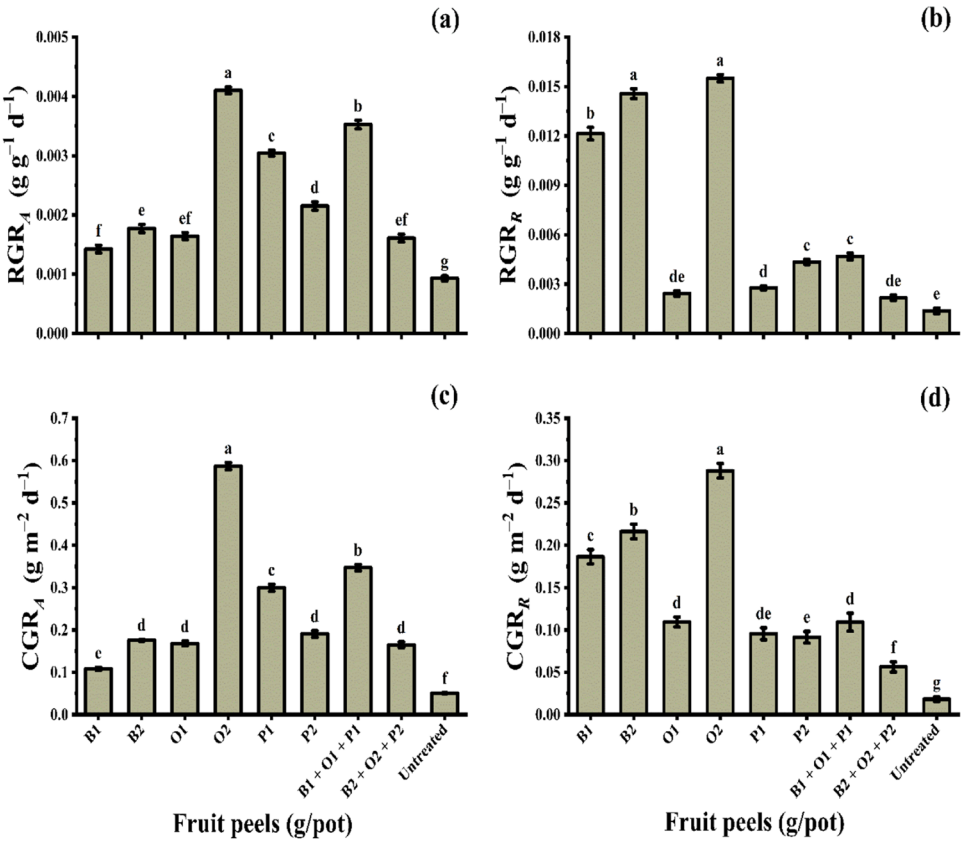

Fig. 2 Impact of banana (B), orange (O), and pomegranate (P) powder peel soil supplementation at levels of 8 and 16 g on **a** relative growth rate (RGR_A), **b** crop growth rate (CGR_A) of aerial parts, **c** relative growth rate (RGR_R), and **d** crop growth rate (CGR_R) of roots of *Schefflera arboricola* L. plants grown under heat conditions. Bars with different letters are significantly different at $P \leq 0.05$. Values are means ± SE, $n = 6$

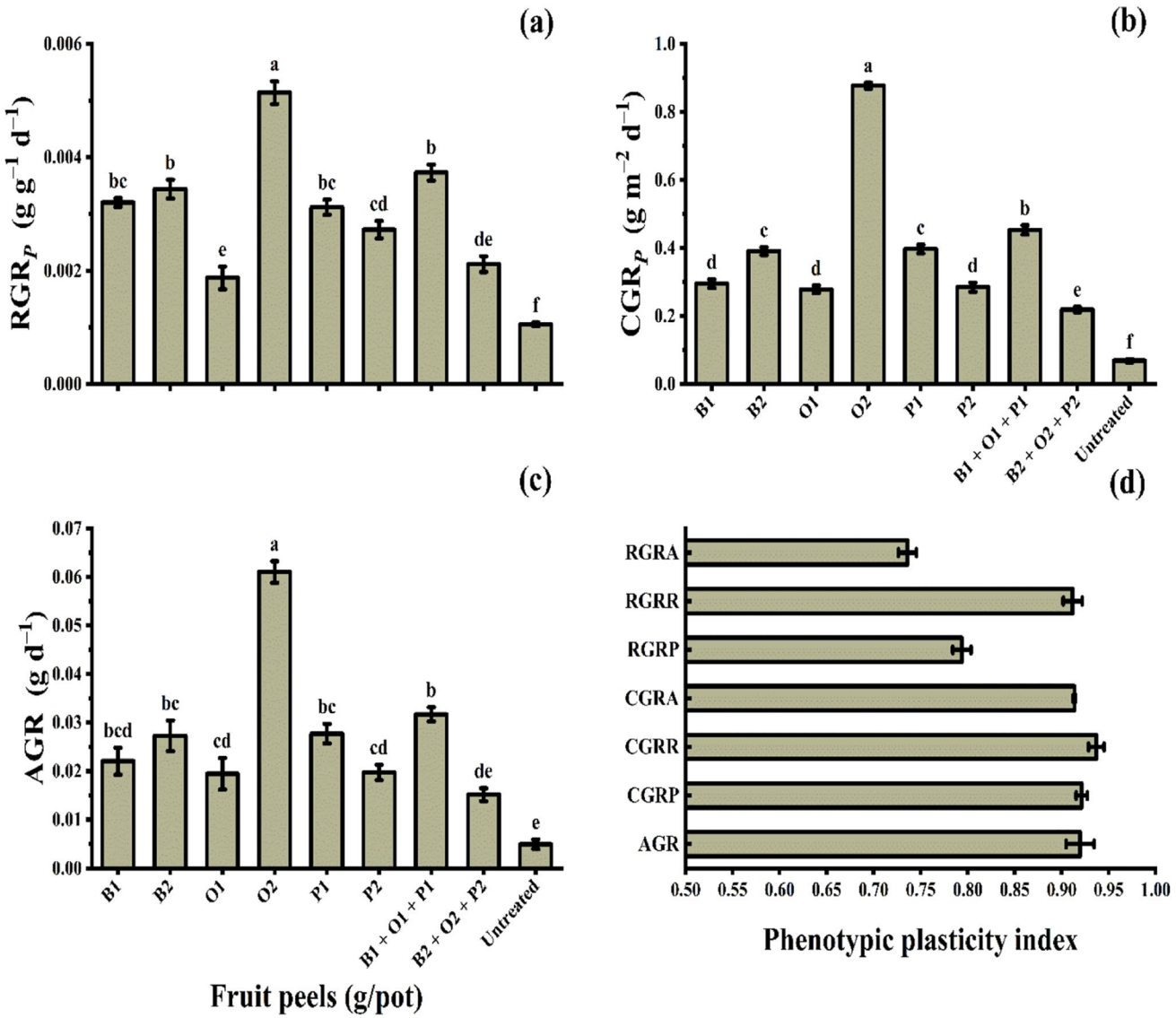

Fig. 3 Impact of banana (B), orange (O), and pomegranate (P) powder peel soil supplementation at levels of 8 and 16 g on **a** relative growth rate (RGR$_P$), **b** crop growth rate (CGR$_P$), **c** absolute growth rate (AGR$_P$), and **d** phenotypic plasticity index (PPI) of *Schefflera arboricola* L. plants grown under heat conditions. Bars with different letters are significantly different at $P \leq 0.05$. Values are means ± SE, $n = 6$

compared to untreated plants (Fig. 2a). Concerning the CGR$_A$, the highest CGR$_A$ value (0.586 g m^{-2} day^{-1}) was given by O2 treatment, followed by 0.347 g m^{-2} day^{-1} which was given by B1 + O1 + P1 treatment (Fig. 2c). The plants subjected to O2 exhibited a significant increments in RGR$_R$ and CGR$_R$ values relative to untreated plants, followed by the B2 treatment, which significantly increased RGR$_R$ and CGR$_R$ values as compared with the others (Fig. 2b, d).

When *Schefflera* plants were subjected to O2 treatment, the values of RGR$_P$ and CGR$_P$ were significantly increased (Fig. 3a, b), followed by B1 + O1 + P1 treatment. In terms of AGR, the maximum AGR value was obtained by the plants exposed to O2 treatment, which gave 1132.7% higher than untreated plants, followed by B1 + O1 + P1 treatment (Fig. 3c). The phenotypic plasticity index (PPI) of *Schefflera* plants grown under heat conditions showed considerable changes in morphological features in response to fruit peel treatments (Fig. 3d). The RGR$_A$ and RGR$_P$ presented a moderate plastic response to fruit peel application under heat conditions. In this respect, CGR$_P$ and AGR revealed growing PPI values (0.92 for both of them). One of the most important characteristics of plant development is the root system's plasticity. The CGR$_R$ of *Schefflera* roots gained the maximum PPI value (0.94).

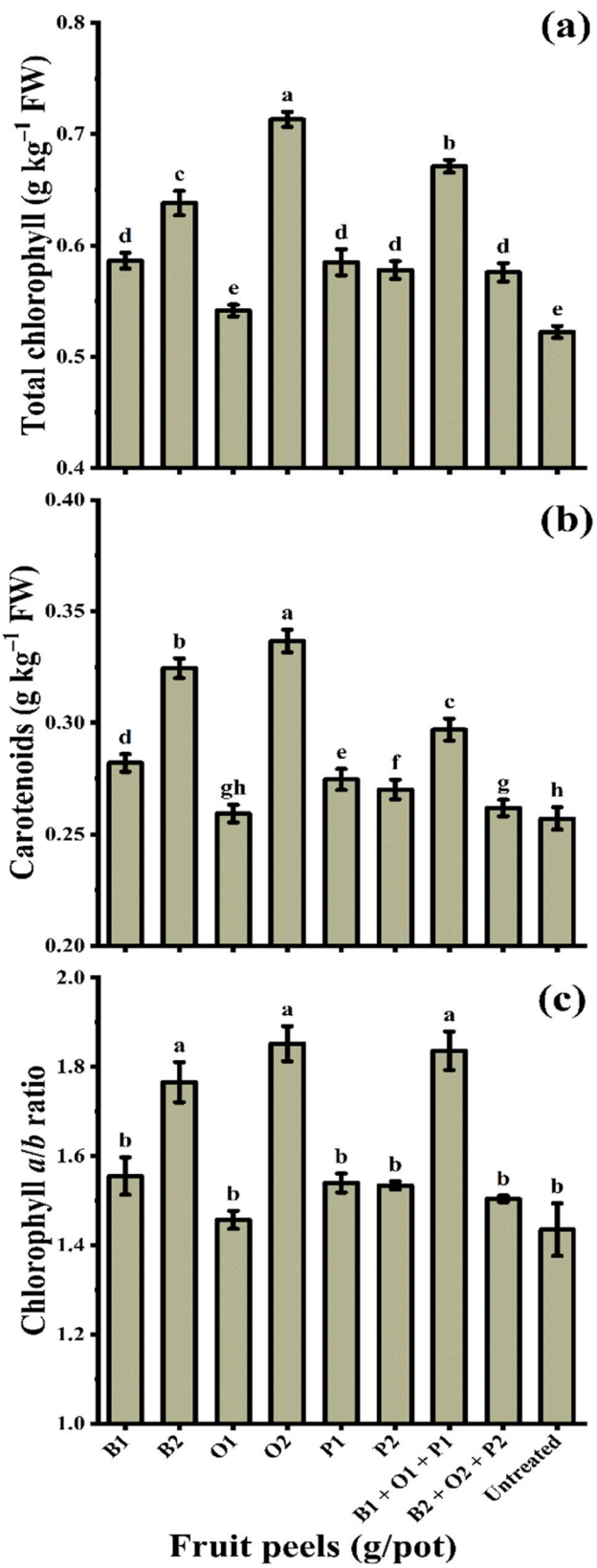

Fig. 4 Impact of banana (B), orange (O), and pomegranate (P) powder peel soil supplementation at levels of 8 and 16 g on **a** total chlorophyll, **b** carotenoids, and **c** chlorophyll a/b ratio of *Schefflera arboricola* L. plants grown under heat conditions. Bars with different letters are significantly different at $P \leq 0.05$. Values are means ± SE, $n = 6$

3.2 Photosynthetic Pigments

Fruit peel applications significantly enhanced leaf pigment content (Fig. 4). The highest chlorophyll and carotenoid levels were produced by O2 plants (0.713 and 0.337 g kg^{-1} FW for total chlorophyll and carotenoids, respectively), followed by B1 + O1 + P1 plants. The untreated control, on the other hand, had the lowest levels of chlorophyll and carotenoids. Regarding the chlorophyll a/b ratio, the O2 treatment significantly recorded the highest a/b ratio (1.85); this ratio decreased to 1.46 when *Schefflera* plants were exposed to the high level of the combined banana, orange, and pomegranate (B2 + O2 + P2). The lowest a/b ratio (1.44) was presented by the untreated plants.

3.3 Membrane Stability Index

Results presented in Fig. 5a revealed a significant raise in MSI with all peel treatments as compared with untreated plants, reaching the maximum value (86.5%) when *Schefflera* plants were subjected to O2 treatment followed by the low level of pomegranate treatment, P1 (83.4%), while the lowest value of MSI was obtained by the untreated plants, which recorded 64.3%.

3.4 Relative Water Content

Schefflera leaves presented the highest RWC by O2 plants, as they gave 86.5%, but with non-significant differences with all treatments except the low dose of banana peel (B1) and untreated plants (Fig. 5b). The P1 and B1 + O1 + P1 treatments recorded the second rank in the RWC values. On the other hand, the lowest RWC value was given by untreated plants (81.8%).

3.5 Total Phenol and Flavonoid Content

Leaf content of phenolic and flavonoid compounds exhibited a significant improvement following fruit peel treatments (Fig. 5c, d). *Schefflera* plants subjected to O treatments significantly presented the highest levels of total phenols (76.4 and 83.9% higher for O1 and O2 treatments, respectively) relative to the untreated plants. The treatment of B2 + O2 + P2 significantly recorded the lowest increase in total phenols (1.32 g GAE kg^{-1} DW). In terms of flavonoid content, all fruit

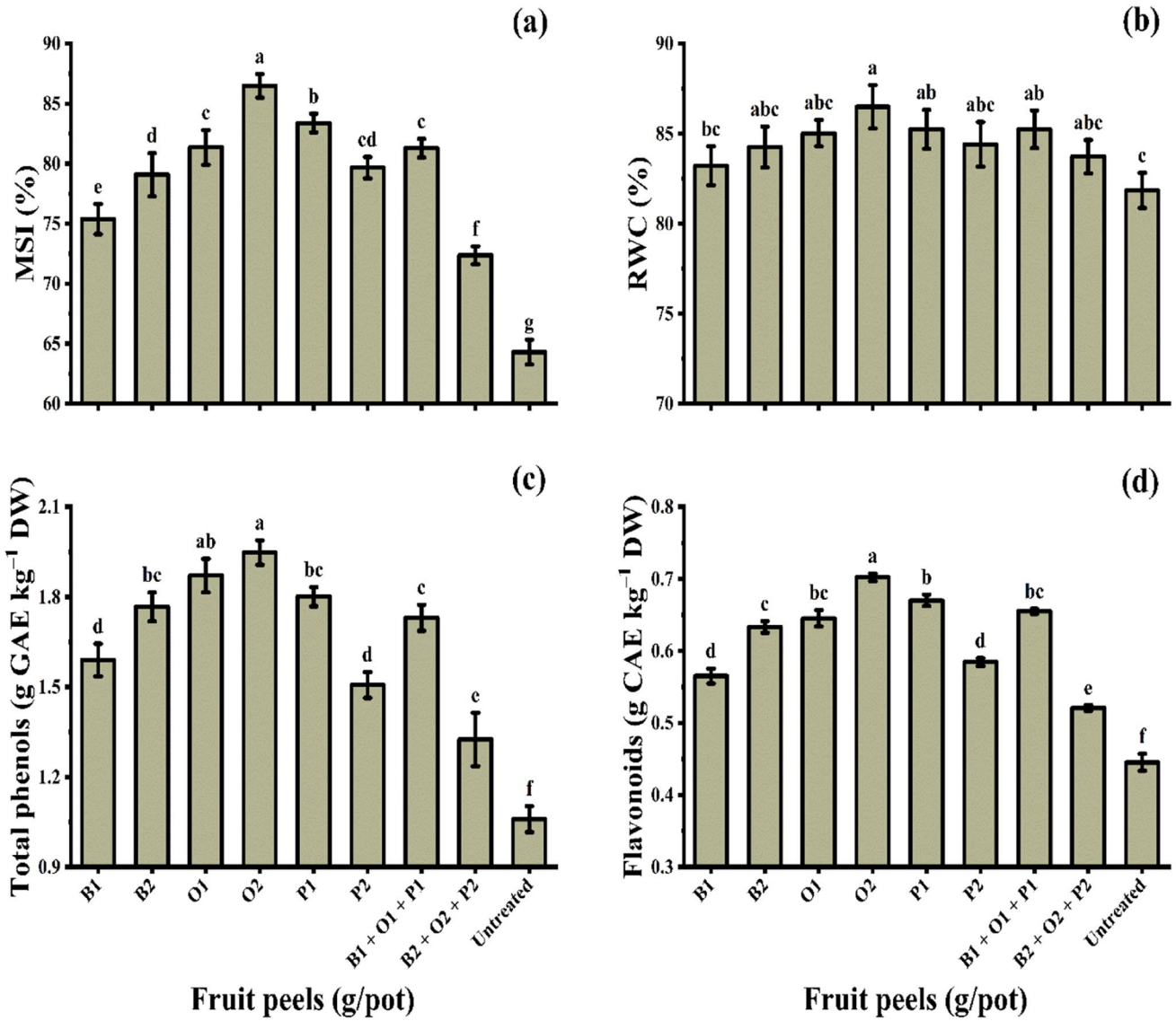

Fig. 5 Impact of banana (B), orange (O), and pomegranate (P) powder peel soil supplementation at levels of 8 and 16 g on **a** membrane stability index (MSI), **b** relative water content (RWC), **c** total phenols, and **d** flavonoid content of *Schefflera arboricola* L. plants grown under heat conditions. Bars with different letters are significantly different at $P \leq 0.05$. Values are means ± SE, $n = 6$

peel treatments significantly improved flavonoid content as compared to the control. The treatment of O2 significantly exhibited the maximum flavonoid level (0.7 g CAE kg^{-1} DW) followed by P1 treatment. The lowest flavonoid level (0.45 g CAE kg^{-1} DW) was presented by untreated plants.

3.6 MDA Content

Fruit peel treatments significantly lessened MDA levels in *Schefflera* leaves (Fig. 6a), as O treatments revealed the lowest levels of MDA (38.7 and 43.97% lower for O1 and O2 treatments, respectively). On the other hand, control plants gained the highest MDA content (1.91 mmol g^{-1} FW).

3.7 H_2O_2 Content

Results presented in Fig. 6b demonstrated that fruit peel treatments significantly decreased H_2O_2 levels in *Schefflera* leaves. The lowest level of H_2O_2 was observed by the treatment of O2 (13.24 µg g^{-1} FW), while the other fruit peel treatments increased H_2O_2 reaching 28.47 µg g^{-1} FW by the treatment of B2 + O2 + P2. The maximum H_2O_2 level was exhibited by untreated plants (29.2 µg g^{-1} FW).

3.8 Scavenging Activity (DPPH Assay)

The radical scavenging activity in fruit peel-treated plants was significantly increased relative to untreated plants

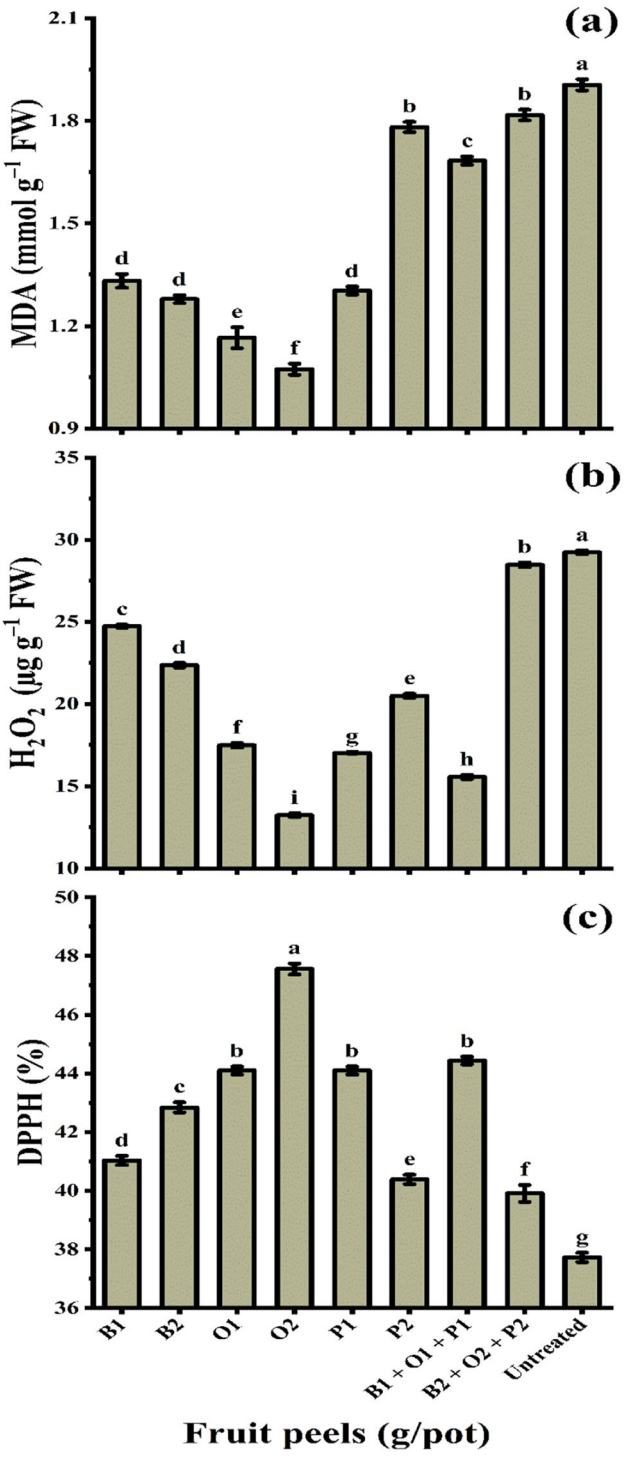

Fig. 6 Impact of banana (B), orange (O), and pomegranate (P) powder peel soil supplementation at levels of 8 and 16 g on **a** malondialdehyde (MDA), **b** hydrogen peroxide (H_2O_2), and **c** DPPH activity of *Schefflera arboricola* L. plants grown under heat conditions. Bars with different letters are significantly different at $P \leq 0.05$. Values are means ± SE, $n = 6$

(Fig. 6c). The highest increase in DPPH activity was produced by *Schefflera* plants subjected to O2 treatment (26.1% higher compared to control plants), followed by the treatment of B1 + O1 + P1, which was recorded 17.8% higher than control plants. While the treatment of B2 + O2 + P2 led to an increase of 5.8% higher than control plants, which recorded the lowest DPPH activity.

3.9 SDS-PAGE Protein Electrophoresis

The protein analysis presented in Fig. 7 reveals a total of 12 bands with molecular weights (MW) ranging from 17 to 103 kDa. Under heat conditions, all treatments showed over-expression in protein bands of 19.59 and 32.07 kDa. Fruit peel treatments except the B2 + O2 + P2 treatment induced the synthesis of new polypeptides (18.86 and 20.88 kDa MW). On the other hand, under heat conditions, treated plants with B2 + O2 + P2 inhibited the synthesis of 53.35 and 57.68 kDa polypeptides. Finally, all treatments induced changes in the protein patterns with varying intensities. The new protein pattern exhibited under heat conditions and fruit peel treatments reflected the expression of *Schefflera* plant heat tolerance.

4 Discussion

Plants undergo a variety of morphological, anatomical, physiological, and biochemical changes as a result of elevated temperatures, which impact growth and development and lead to a significant drop in productive capacity. Heat tolerance is described as the plant's capability to grow and provide an economic yield under high-temperature conditions. Previous reports have shown that low molecular weight organic compounds such as glycine betaine and polyamines, or phytohormones, trace elements, and nutrients can improve heat tolerance in a range of plant species (Wahid and Shabbir 2005; Wahid et al. 2007; Hasanuzzaman et al. 2013).

4.1 Growth Analysis and Phenotypic Plasticity

Heat stress causes morphological damage like leaf and twig burning, scorching, sunburns in leaves, branches, and stems, and leaf senescence and abscission (Wahid et al. 2007). In the current study, heat conditions inhibited the growth rate of *Schefflera* shoots and roots and reduced the absolute growth rates. The heat significantly decreased the relative growth rate, net assimilation rate, shoot and root biomass of pearl millet, and sugarcane plants (Wahid et al. 2007). During the plant life cycle, elevated temperatures (beyond a 30 °C threshold) negatively influence plant growth by impacting the physiological and biochemical processes (Fahad

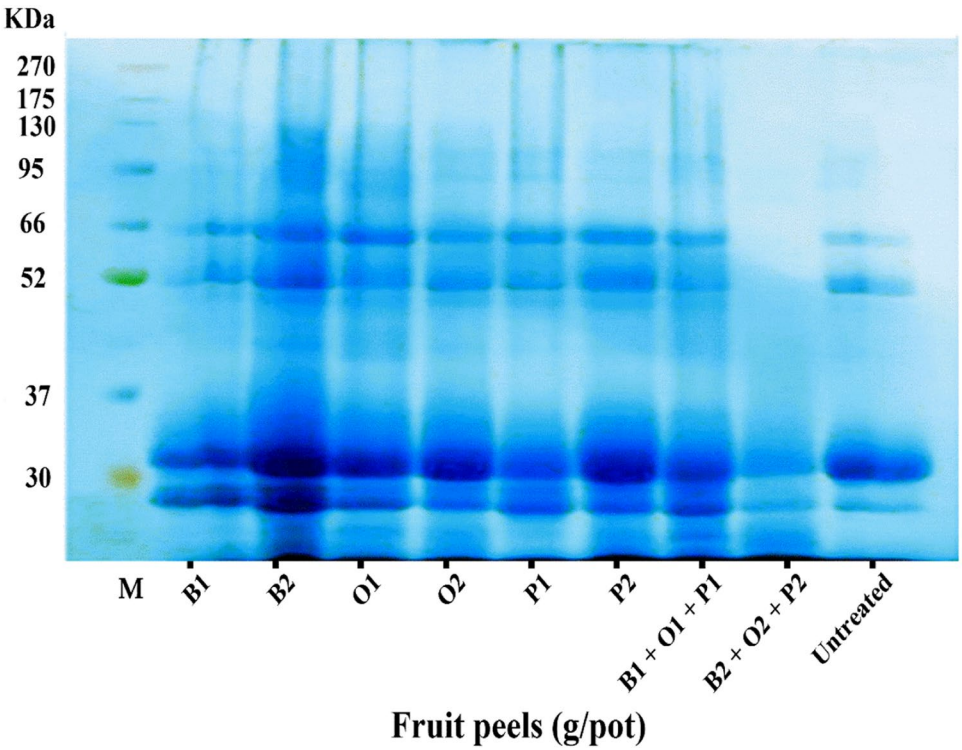

Fig. 7 Electrophoretic banding patterns of *Schefflera arboricola* L. plants grown under heat conditions as impacted by banana (B), orange (O), and pomegranate (P) powder peel soil supplementation at levels of 8 and 16 g and untreated plants. M: molecular weight

et al. 2017). Fruit peel applications exhibited a significant enhancement in the growth and quality of *Schefflera* plants grown under high temperatures as compared with control plants. The peels of bananas, oranges, and pomegranates have prominent levels of macro and micro-nutrients that improve soil fertility and enhance plant growth and development (Nossier 2021; Abd-Rabbu et al. 2021). Moreover, it contains an elevated level of natural phenolic and flavonoid compounds, antioxidants, and nutritional components, all of which are required for plant growth (Emaga et al. 2007; Aboul-Enein et al. 2016). Banana, orange, and pomegranate peels may be utilized as organic fertilizers, regulating soil pH and providing the plants with elements including calcium, zinc, and iron (Abd-Rabbu et al. 2021).

Fruit peel applications significantly enhanced the RGR $_R$ and CGR$_R$ of *Schefflera* roots. An enhancement was observed in the root systems of *Solanum* and okra plants subjected to banana peel supplementations (Sakpere et al. 2018; Dayarathna and Karunarathna 2021). Singh and Prasad (2014) stated that the improvement in root system development after fruit peel treatments might be owing to the presence of cytokinins in fruit peels. Wazir et al. (2018) stated that soil application with banana peel as an organic fertilizer increased the growth rate of pea plants. Foliar application of banana peel extract boosted the shoot and root dry weights of quinoa plants (Bakry et al. 2016). The growth analysis (RGR, CGR, and AGR) of *Schefflera* plants showed the maximum increase following the high rate of orange peel (O2) application (Figs. 2 and 3). Such results were obtained by Belligno et al. (2005) who reported that the high dose of orange peel had a beneficial impact on wheat growth.

The increase in plant growth of *Schefflera* plants under elevated temperatures may be due to the role of orange peels as antioxidants that alleviate heat stress on *Schefflera* plants. The improvement in plant vigor following orange peel soil supplementation has been previously observed in lettuce (Guerrero et al. 1995), wheat (Belligno et al. 2005), sunflowers (Abbate et al. 2008), and okra (Dayarathna and Karunarathna 2021). Increasing the growth rate and plant productivity is an indicator of plant tolerance (El-Serafy et al. 2021a, b). Belligno et al. (2005) reported that the reduction in the soil pH after orange peel application may be due to the organic acids released from by-products of fruit peels by the soil microorganisms, leading to the mobilization of more elements, increments in the soluble cations, and exchangeable K and Ca. Banana and orange peel supplementations significantly enhanced the growth and quality of *Solanum scabrum* plants (Sakpere et al. 2018). Tryptophan, which is found in banana peels, is important for increasing endogenous hormone levels, promoting cell division and/or enlargement, and ultimately promoting plant growth (Emaga et al. 2007; Hussein et al. 2019). The application of pomegranate peel to the soil boosted the productivity of sage (Abd-Rabbu et al. 2021) and okra (Dayarathna and Karunarathna 2021) plants. In this study, the B1 + O1 + P1 treatment showed the second-best results in this respect, as it resulted in a great enhancement in the RGR, CGR, and AGR values, which may be attributed to their role in providing *Schefflera*

plants with more active ingredients, which stimulated plant growth and heat tolerance.

Under heat conditions, fruit peel-treated plants exhibited marked variations in growth analysis and allocations to plant parts, concerning RGR_R and CGR_R, which play an essential role in controlling the viability and productivity of the plant (El-Serafy 2020). The maximal PPI values were obtained by RGR_R and CGR_R, indicating that fruit peels have a positive impact on biomass allocation to roots and root characteristics (Fig. 2d). Phenotypic plasticity of root production and expansion is significant for nutrient uptake in unfavorable environmental conditions, which determines plant distribution and adaptive responses to limited soil resources (Bell and Sultan 1999). According to Hill et al. (2006) and Bossdorf et al. (2008), nutrient availability caused modifications in root morphology and biomass allocation to plant parts. The RGR_A exhibited a lower PPI value than the RGR_R. This is the behavior of non-native populations in response to nutrition supplies, as evidenced by a durable plastic response in roots with a low plastic response in reproductive tissues (Bossdorf et al. 2008; El-Serafy 2020).

4.2 RWC and MSI

Heat conditions led to membrane lipid peroxidation and a reduction in RWC (Xu et al. 2006). Fruit peels exhibited an enhancement in RWC and MSI of *Schefflera* leaves. These improvements may be attributed to the role of K in maintaining cell membrane stability and osmotic adjustment ability under stress conditions (Atteya et al. 2021). Banana, orange, and pomegranate peels are rich in potassium elements. Stomatal movement, enzyme activation, protein synthesis, the balance of cation and anion, energy transfer, phloem transport, and stress tolerance are all dependent on potassium (Hawkesford et al. 2012; Waqas et al. 2021). Potassium addition improved water retention in plant tissues during stress conditions and boosted plant productivity (Lindhauer 1985). Plants subjected to K supplementation adapted better to abiotic stress and maintained cell membrane stability (Wang et al. 2013). Fruit peels are high in antioxidants, which play a vital role in protecting cell membrane integrity and detoxifying ROS generated under heat stress. The ROS causes autocatalytic peroxidation of pigments and membrane lipids, resulting in an alteration in membrane semi-permeability and the loss of its functions (Xu et al. 2006).

4.3 Photosynthetic Pigments

Photosynthetic pigments (Chl a, Chl b, and carotenoids) were significantly reduced under heat conditions (Morsy et al. 2010). Under elevated temperatures, leaf photosynthesis and the Hill reaction decelerated faster than other mechanisms (Al-Khatib and Paulsen 1999). The inhibition of photosynthesis negatively affects the equilibrium between generated ROS and antioxidant defense (Fu and Huang 2001; Cruz de Carvalho 2008). Fruit peel treatments significantly enhanced chlorophyll levels in *Schefflera* leaves grown under hot conditions as compared with control plants. The peels of banana, orange, and pomegranate are rich in antioxidants (Emaga et al. 2007; Wu 2016) which have a critical role in scavenging the ROS molecules generated under conditions, in addition to the important macronutrients, which amended plants with N and Mg, the required elements for chlorophylls synthesis (El-Serafy and El-Sheshtawy 2020; El-Serafy et al. 2021c). Banana and orange peel enhanced photosynthetic pigments in quinoa leaves under water deficit (Bakry et al. 2016; El-Bassiouny et al. 2016). Foliar application of banana peel extract was effective in alleviating chromium toxicity and enhancing chlorophyll levels in *Spinacia oleracea* L. (Danish et al. 2019). Pomegranate peel soil application boosted chlorophyll levels in lupine leaves (Wadi et al. 2017). These findings emphasize our results about the reduction in photosynthetic pigments and a/b ratio in control plants relative to fruit peel treatments. Under high temperatures, *Schefflera* plants treated with peels significantly exhibited higher carotenoid levels as compared with control plants. Carotenoid content in quinoa leaves increased significantly after banana and orange peel applications (Bakry et al. 2016; El-Bassiouny et al. 2016). Carotenoids are more closely related to root growth rate (El-Serafy 2020). These findings support our observations that the highest carotenoid levels were obtained by banana and orange peel treatments, which both presented higher RGR_R values. Carotenoids play a vital role as free radical scavengers that decrease ROS damage, consequently promoting chlorophyll content in plant leaves.

4.4 Total Phenols, Flavonoids, and DPPH

Under heat conditions, *Schefflera* plants subjected to fruit peel treatments presented higher levels of phenols, flavonoids, and DPPH activity relative to untreated plants. These improvements might be attributed to the peels' application, which relies on their antioxidant compounds for scavenging ROS, enhancing antioxidant activity, and promoting photosynthesis. Banana, orange, and pomegranate peels increased total phenols and flavonoid content in quinoa and lupine plants (Bakry et al. 2016; El-Bassiouny et al. 2016; Wadi et al. 2017). The increases in total phenol and flavonoid content under heat conditions may be due to their role in the regulation of plant metabolic processes and plant protection against environmental stress. Furthermore, their reactivity as electron or hydrogen donors, which stabilize and delocalize the unpaired electron, and their role as transition metal ion chelators contribute to their role as free radical scavengers (Huang et al. 2005; Ebrahimian and Bybord 2012). The increment in phenol and

flavonoid content led to an increase in antioxidant activity, as these results obtained by Dahab et al. (2018) and Mahmoud and Dahab (2018). The antioxidant defense system is a part of heat stress adaptation, and its potency is linked to thermotolerance acquisition (Xu et al. 2006).

4.5 Oxidative Stress

Under stress conditions, the production of MDA, which is a by-product of the peroxidation of membrane polyunsaturated fatty acids, is a signal of oxidative stress. Additionally, H_2O_2 overproduction injures cellular macromolecules, which lately has resulted in the death of the cell (Atteya et al. 2022). Anderson (2002) detected a harmful effect of H_2O_2 on plant tissue and an increase in its level under heat conditions. The oxidative stress on membrane lipids and increased H_2O_2 concentration have been seen in untreated *Schefflera*. But, after applying fruit peels to *Schefflera* plants grown under hot conditions, higher decreases in MDA and H_2O_2 levels were shown, along with less ion leakage and better maintenance of membrane functions, indicating their role as antioxidants.

4.6 SDS-PAGE Protein Electrophoresis

The protein patterns of *Schefflera* leaves were significantly altered by heat conditions and fruit peel treatments. This variation has manifested itself in the lack or overexpression of some polypeptides, as well as the novel expression of others. These alterations in protein synthesis might be a result of reprogramming gene expression, resulting in the synthesis of new proteins and more storage proteins that help plants to grow and develop (Sahin et al. 2013; Akladious 2014). New polypeptides (heat shock proteins (HSPs)) with molecular weights of 18.86 and 20.88 kDa were induced in stressed *Schefflera*. HSPs may protect stressed *Schefflera* from the harmful effects of elevated temperatures. Our findings are consistent with those of Efeoglu (2009), who demonstrated that HSPs were elevated in rice cultivars exposed to heat conditions. Furthermore, Akladious (2014) reported that sunflower plants subjected to heat stress using thiourea exhibited an increase in the protein bands in their leaves. Königshofer and Lechner (2002) stated that HSPs have a significant role in preserving the integrity and functions of cell membranes under heat stress.

5 Conclusion

The potential of banana, orange, and pomegranate powdered peels to stimulate heat tolerance in *Schefflera* plants was investigated. Fruit peels applied to the soil produced *Schefflera* plants that were more resistant to heat stress. Fruit peels improved shoot and root growth rates, leaf pigments, and AGR, promoted RWC and MSI, and alternated PPI. Fruit peels significantly increased total phenols and flavonoids as well as DPPH activity, decreased H_2O_2 and MDA contents in plant leaves, and induced heat-shock protein synthesis, leading to plants with more heat tolerance and orange peels at 16 g/pot outperforming the other fruit peels. Using orange peels for heat tolerance in *Schefflera* plants grown under low-cost greenhouses at their early stage not only significantly improved the growth and plant tolerance but also maintained their ornamental appearance and aesthetic value.

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Declarations

Conflict of Interest The authors declare no competing interests.

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