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Effects of Seaweed-Extract-Based Organic Fertilizers on the Levels of Mineral Elements, Sugar–Acid Components and Hormones in Fuji Apples

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Abstract: Seaweed extracts, which are naturally degradable and environmentally friendly, have become important components of organic fertilizers for fruit. In this study, the effects of seaweed-extract-based organic fertilizers on the levels of mineral elements, sugar–acid components, and hormones in 'Fuji' apples were evaluated. Eleven-year-old 'Fuji' apple ('Yanfu 3'/M9/*Malus robusta*) trees were sprayed with seaweed-extract-based fertilizers SE1 (contained ≥20 g/L of algal polysaccharides, ≥100 g/L of amino acids, and ≥30 g/L of EDTA-Ca) and SE2 (contained ≥100 g/L of algal polysaccharides, ≥160 g/L of Ca, and ≥10 g/L of Mg) from early May to early October at two-week intervals in 2020. Water spraying was used as a control treatment. The preliminary results showed that SE1 and SE2 significantly increased the net photosynthetic rate, chlorophyll content and Rubisco enzyme activity in 'Fuji' apple leaves. SE1 and SE2 improved the quality of 'Fuji' apples. Compared to the single-fruit weight, soluble solid content (SSC), soluble sugar content, sugar–acid ratio, vitamin C (VC) content, and free amino acid content of control apples, those of SE1-treated and SE2-treated apples increased by 10.74% and 8.94%, 12.16% and 9.76%, 21.96% and 11.90%, 45.12% and 28.55%, 56.12% and 47.96%, and 17.15% and 13.42%, respectively. SE1 and SE2 significantly improved the levels of fructose, glucose, sucrose, and sorbitol, but decreased the levels of malic acid, oxalic acid, and tartaric acid in 'Fuji' apples. Meanwhile, SE1 and SE2 increased the levels of potassium, calcium, magnesium, iron, zinc, and boron in 'Fuji' apples. SE1 and SE2 significantly improved the levels of indole-3-acetic acid, zeatin riboside, and gibberellic acid, but significantly decreased the level of abscisic acid in 'Fuji' apples. In conclusion, spraying seaweed-extract-based foliar fertilizer is beneficial to the nutrient accumulation and flavor development in 'Fuji' apples.

Keywords: seaweed extract; organic fertilizer; mineral elements; sugar–acid components; hormones

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1. Introduction

Apples, which are rich in dietary fiber, vitamins, sugars, organic acids, minerals, and bioactive compounds, are fruits that are widely cultivated for their sweetness, sourness, aroma, and texture [1–3]. The main bioactive compounds in apples include flavonols, dihydrochalcones, proanthocyanidins, and hydroxycinnamic acids [4,5]. Phenolic compounds extracted from apples may be used in cosmetics and/or medicines because they can protect cells from ultraviolet radiation [6,7]. On the other hand, dihydrochalcones, which are special polyphenols, may reduce blood sugar levels and prevent diabetes [8,9].

China's apple industry plays an important role in worldwide apple production. With the development and expansion of China's apple industry, the sustainable utilization of resources and the maintenance of market competitiveness have become increasingly prominent matters [10]. Compared with biofertilizers, synthetic fertilizers are more widely used in agriculture [11]. Asian consumers have become increasingly concerned about the quality and safety of fruit; therefore, the application of synthetic fertilizers in fruit production should be reduced, and effective, environmentally friendly alternatives to the fertilizers should be increased [12,13]. Natural biostimulants (such as seaweed extracts, microbial antagonists, protein hydrolysates, humic acid, and fulvic acid) have been used as environmentally friendly fertilizers for sustainable apple production [14]. Seaweed extracts are rich in macronutrients, micronutrients, and secondary metabolites [15–18]. Therefore, they may stimulate plant growth by improving the uptake of nutrients by plants, efficiency of nutrient use by plants, and resistance of plants to stresses [19–22].

The beneficial effects of fertilization are influenced by plant varieties, climatic conditions, soil conditions, and agricultural management measures [14,23]. Recent studies have shown that fertilization affects not only the size and color of apples, but also the levels of sugars, acids, and minerals in the fruits [24–26]. Compared with soil fertilization, foliar fertilization can enhance the effectiveness of synthetic fertilizers, avoid soil contamination, and effectively meet the nutritional requirements of plants [11,27]. Seaweed extracts have become important components of foliar fertilizers for fruit and vegetable crops [18,19,28–30]. The extracts are naturally degradable and environmentally friendly. Therefore, they are safe for humans and the environment [31].

Previous studies have focused on the effects of the foliar application of seaweed extract on the growth and physiological parameters of maiden apple trees [27,32]. Presently, there is limited information about the effects of seaweed-extract-based foliar fertilizer on the quality of 'Fuji' apples at harvest. Therefore, this study evaluates the effects of seaweed-extract-based foliar fertilizers on the quality of 'Fuji' apples and the levels of mineral elements, sugar–acid components, and hormones in the apples. This study provides a scientific basis for promoting the application of seaweed-extract-based foliar fertilizer in apple production.

2. Materials and Methods

2.1. Site Description and Experimental Design

The experimental site was an orchard in the Tianpinghu Base of the Shandong Institute of Pomology (36°21′ N, 117°05′ E), Tai'an City, Shandong Province. The climate in the area is a monsoon-influenced humid subtropical climate. In 2020, the annual average temperature, annual total sunshine, and annual precipitation of the test base were 14.5 °C, 3247.9 h, and 1035.6 mm, respectively. The soil in the orchard was sandy loam, the pH of the soil was 6.32, and the levels of organic matter, alkaline-hydrolyzable nitrogen, available potassium, and available phosphorus in the soil were 9.84 g/kg, 62.78 mg/kg, 72.35 mg/kg, and 28.79 mg/kg, respectively.

Eleven-year-old 'Fuji' apple ('Yanfu 3'/M9/*Malus robusta*) trees with the same level of vigor were selected for the experiment. The directionality of the tree rows was from north to south, and the spacing between the tree rows was 1.5 m × 3 m. During the experiment, all of the trees were treated with the same cultivation measures (such as irrigation and fruit bagging), except they were sprayed with different fertilizers. Foliar-spraying treatments were performed using the following two commercially available water-soluble seaweed-extract-based fertilizers: SE1 (Interplant, Weifang, China; contained ≥20 g/L of algal polysaccharides, ≥100 g/L of amino acids, and ≥30 g/L of EDTA-Ca) and SE2 (Xijian, Qingzhou, China; contained ≥100 g/L of algal polysaccharides, ≥160 g/L of Ca, and ≥10 g/L of Mg). These fertilizers are obtained by the combination of the biological enzyme hydrolysis process and biological processing technology of brown algae. The fertilizers were diluted 1000 times, and they were sprayed onto apple leaves according to their manufacturers' instructions. The following three treatment groups were formed: SE1, SE2, and control. Each treatment group comprised three replicates with ten apple trees in each replicate. Apple trees were sprayed with SE1 or SE2 from early May to early October at two-week intervals. Control apple trees were sprayed with distilled water.

2.2. Measuring Methods

2.2.1. The Net Photosynthetic Rate, Chlorophyll Content, and Rubisco Activity in 'Fuji' Apple Leaves

Five healthy leaves were selected randomly from autumn shoots in the middle of the outer canopy of each apple tree on a sunny morning. The net photosynthetic rate in the leaves was measured by a CIRAS-4 Portable Photosynthesis System (PP Systems, Amesbury, MA, USA) from 9:00 a.m. to 11:00 a.m., with other gas exchange parameters (1000 μmol/$m^2 \cdot$s, 25 °C), the CO_2 concentration (400 μmol (CO_2)/mol) and relative humidity (60–65%). The chlorophyll content of the leaves was determined by ethanol extraction, and the activity of ribulose-1,5-biphosphate carboxylase (Rubisco) in the leaves was measured after incubating the leaf extract in assay solution without ribulose-1,5-biphosphate (RuBP) for 15 min at room temperature.

2.2.2. Fruit Quality Assessment

On 20 October, on which the apples grown in the area reached maturity, the apple maturity stage was determined according to the flavor, color, hardness and other indicators of the apples. In addition, 10 healthy apples without any pest infestation or disease infection were collected randomly from the equator around the canopy of each tree. The apples were put into plastic bags, transferred to the laboratory, and stored at a low temperature.

Five apples were randomly selected for one repeat and repeated three times to determine the fruit quality. Single-fruit weight was measured by an electronic platform scale. The longitudinal and transverse diameters of each apple were measured with electronic calipers. The hardness of each apple was determined by a GY-B hardness tester (Kexing, Shenzhen, China). The color of each apple was measured by a CR-410 chroma meter (Konica Minolta, Osaka, Japan). The levels of soluble sugars and titratable acids in the 'Fuji' apples were determined by the anthrone colorimetric method and acid–base titration, respectively. On the other hand, the levels of vitamin C (VC) and free amino acids in the apples were determined by titration with 2,6-dichloroindophenol sodium salt and the ninhydrin colorimetric method, respectively.

Sugar and acid components were identified and quantified by high-performance liquid chromatography (HPLC) [33,34]. The HPLC system was equipped with a YMC-Pack Polyamine II column (250 mm $\times$ 4.6 mm) and an RID-20A differential refractive index detector (Shimadzu, Kyoto, Japan) for the identification and quantification of sugars. On the other hand, the system was equipped with an SPD-20A UV/Vis detector (Shimadzu, Kyoto, Japan) and a Shim-pack HR-ODS 3 column (250 mm $\times$ 3.0 mm) for the identification and quantification of organic acids.

The extraction of mineral elements from the 'Fuji' apples and quantification of the mineral elements were performed according to the methods described by Roussos et al. [35]. Five apples were randomly selected for one repeat and repeated three times to determine the fruit minerals. The levels of nitrogen (N) and phosphorus (P) in the apples were determined by the Kjeldahl method and the vanadate–molybdate method, respectively. The levels of potassium (K), calcium (Ca), and magnesium (Mg) in the apples were determined by atomic absorption spectrophotometry. The levels of boron (B), zinc (Zn), iron (Fe), and manganese (Mn) in the apples were determined by inductively coupled plasma atomic emission spectroscopy (OPTIMA 3300 DV, Perkin Elmer, Waltham, USA). The argon flow rate was 15 L/min, and the injection volume was 1.5 mL/min.

The levels of indole-3-acetic acid (IAA), zeatin riboside (ZR), gibberellic acid (GA3), and abscisic acid (ABA) in the 'Fuji' apples were determined by HPLC according to a method described by Almeida-Trapp et al. [36]. The HPLC system was equipped with an SPD-20A UV/Vis detector (Shimadzu, Kyoto, Japan) and a Venusil XBP C18 column (100 mm $\times$ 4.6 mm).

2.3. Statistical Analysis

Microsoft Excel 2013 was used for data processing. OriginPro 9.8 (OriginLab, Northampton, MA, USA) was used for graphing. The single-factor analysis of variance was performed with SPSS version 20.0 (IBM, Chicago, IL, USA). *p*-values less than 0.05 were considered to be statistically significant.

3. Results

3.1. Net Photosynthetic Rate, Chlorophyll and Rubisco Enzyme Activity

The amount of photosynthate supplied to fruit affects the growth and development of the fruit, and the amount of photosynthate formed by its leaves depends on the photosynthetic capacity of the leaves. As shown in Table 1, SE1 increased the net photosynthetic rate, chlorophyll content, and Rubisco activity in the leaves by 29.63%, 23.21%, and 15.73%, respectively. On the other hand, SE2 increased the net photosynthetic rate, chlorophyll content, and Rubisco activity in 'Fuji' apple leaves by 23.36%, 17.86%, and 11.47%, respectively. The net photosynthetic rate, chlorophyll content, and Rubisco activity in the apple leaves sprayed with SE1 were higher than those in apple leaves sprayed with SE2. However, there were no significant differences in the three parameters between the two groups of apple leaves.

Table 1. Effects of organic fertilizer on the net photosynthetic rate, chlorophyll content, and Rubisco activity in 'Fuji' apple leaves.

Treatment	Net Photosynthetic Rate (μmol/m^2·s)	Chlorophyll Content (mg/g)	Rubisco Enzyme Activity (μmol (CO_2)/g·min)
CK	13.40 ± 0.80 b	2.24 ± 0.15 b	6.80 ± 0.23 b
SE1	17.37 ± 0.88 a	2.76 ± 0.09 a	7.87 ± 0.10 a
SE2	16.53 ± 0.65 a	2.64 ± 0.08 a	7.58 ± 0.13 a

Note: Different lowercase letters in each column indicate significant differences at the 0.05 level.

3.2. Effects of Organic Fertilizer on the Qualities of 'Fuji' Apples

SE1 and SE2 significantly increased the single-fruit weight of 'Fuji' apples (Table 2; *p*-values < 0.05). The single-fruit weights of SE1-treated apples and SE2-treated apples were 10.74% and 8.94% higher than those of the control apples, respectively. Neither SE1 nor SE2 had a significant effect on the shape (represented by the L/D ratio) of the 'Fuji' apples. The L* a* b* value is an important index of fruit appearance. The L* value represents brightness, the a* value represents a red or green color (a positive a* value represents a red color, and a negative a* value represents a green color), and the b* value represents a yellow or blue color (a positive b* value represents a yellow color, and a negative b* value represents a blue color) [24,37]. As shown in Table 2, SE1 and SE2 significantly increased the L* and a* values, but significantly decreased the b* value of 'Fuji' apples. The a* value of SE1-treated apples was significantly higher than that of SE2-treated apples.

Table 2. Effects of organic fertilizer on the appearance quality of the apple fruit.

Treatment	Single Fruit Weight (g)	Fruit Shape (L/D)	Chromatic Aberration		
			L*	a*	b*
CK	203.27 ± 4.41 b	0.876 ± 0.020 a	42.61 ± 0.97 b	32.73 ± 1.20 c	14.45 ± 0.86 a
SE1	225.10 ± 9.25 a	0.882 ± 0.018 a	47.92 ± 1.90 a	36.87 ± 0.87 a	10.97 ± 0.68 b
SE2	221.43 ± 6.60 a	0.877 ± 0.008 a	46.52 ± 0.86 a	34.54 ± 1.17 b	12.84 ± 1.39 b

Note: Different lowercase letters in each column indicate significant differences at the 0.05 level.

SE1 and SE2 significantly improved the sugar–acid ratio and levels of soluble solids, soluble sugars, VC, and free amino acids in 'Fuji' apples (Table 3). However, they significantly decreased the level of titratable acids in the apples. Compared with the soluble solid content (SSC), soluble sugar content, and sugar–acid ratio in the control apples, those in the SE1-treated apples increased by 12.16%, 21.96%, and 45.12%, respectively. On the other hand, compared with the SSC, soluble sugar content, and sugar–acid ratio in the control apples, those in the SE2-treated apples increased by 9.76%, 11.90%, and 28.55%, respectively. The levels of VC in SE1-treated apples and SE2-treated apples were 56.12% and 47.96% higher than those in the control apples, respectively, and the levels of free amino acids in SE1-treated apples and SE2-treated apples were 17.15% and 13.42% higher than those in the control apples, respectively. SE1 and SE2 significantly decreased the level of titratable acids in 'Fuji' apples by 15.15% and 12.12%, respectively. However, they exhibited no significant effect on the firmness of the apples.

Table 3. Effects of organic fertilizer on the internal quality of apple fruit.

Treatment	Firmness (kg/cm^2)	SSC (%)	Titratable Acid Content (%)	Soluble Sugar Content (%)	Sugar–Acid Ratio	VC Content (mg/100 g)	Free Amino Acid (g/kg)
CK	7.23 ± 0.35 a	13.73 ± 0.55 b	0.33 ± 0.02 a	10.84 ± 0.59 b	32.99 ± 2.44 b	0.98 ± 0.07 b	7.23 ± 0.40 b
SE1	8.07 ± 0.61 a	15.40 ± 0.70 a	0.28 ± 0.02 b	13.22 ± 0.49 a	47.90 ± 4.16 a	1.53 ± 0.10 a	8.47 ± 0.38 a
SE2	7.53 ± 0.31 a	15.07 ± 0.47 a	0.29 ± 0.02 b	12.13 ± 0.71 a	42.41 ± 2.80 a	1.45 ± 0.07 a	8.20 ± 0.56 a

Note: Different lowercase letters in each column indicate significant differences at the 0.05 level.

3.3. Effects of Organic Fertilizer on the Accumulation of Sugars and Acids in 'Fuji' Apples

As shown in Table 4, SE1 and SE2 significantly improved the levels of fructose, glucose, sucrose, and sorbitol in 'Fuji' apples. Compared with the level of fructose in the control apples, those in the SE1-treated apples and SE2-treated apples were 12.16% and 9.76% higher, respectively. The levels of glucose in SE1-treated apples and SE2-treated apples were 31.24% and 20.88% higher than those in the control apples, respectively. SE1 and SE2 increased the level of sucrose in 'Fuji' apples by 37.61% and 21.25%, respectively, and they increased the level of sorbitol in the apples by 67.84% and 44.31%, respectively. The levels of fructose, sucrose, and sorbitol in SE1-treated apples were significantly higher than those in SE2-treated apples.

Table 4. Effects of bio-organic fertilizer on the contents of fructose, glucose, sucrose and sorbitol in 'Fuji' apples.

Treatment	Fructose (mg/g)	Glucose (mg/g)	Sucrose (mg/g)	Sorbitol (mg/g)
CK	55.37 ± 1.03 c	19.40 ± 1.88 b	28.24 ± 1.01 c	5.10 ± 0.26 c
SE1	62.80 ± 1.86 a	25.46 ± 2.68 a	38.86 ± 0.50 a	8.56 ± 0.52 a
SE2	58.41 ± 0.72 b	23.45 ± 1.15 a	34.24 ± 1.38 b	7.36 ± 0.71 b

Note: Different lowercase letters in each column indicate significant differences at the 0.05 level.

SE1 and SE2 significantly decreased the levels of malic acid, oxalic acid, and tartaric acid in 'Fuji' apples, but they did not significantly affect the level of citric acid in the apples (Table 5). Compared with the levels of malic acid, oxalic acid, and tartaric acid in the control apples, those in the SE1-treated apples decreased by 35.23%, 35.46%, and 32.30%, respectively. On the other hand, compared with the levels of malic acid, oxalic acid, and tartaric acid in the control apples, those in the SE2-treated apples decreased by 23.56%, 25.81%, and 27.48%, respectively. The levels of malic acid, oxalic acid, and tartaric acid in SE1-treated apples were not significantly different from those in SE2-treated apples.

Table 5. Effects of organic fertilizer on the contents of malic acid, citric acid, oxalic acid and tartaric acid in 'Fuji' apples.

Treatment	Malic Acid (mg/g)	Citric Acid (mg/g)	Oxalic Acid (mg/g)	Tartaric Acid (mg/g)
CK	4.440 ± 0.288 a	0.083 ± 0.007 a	0.441 ± 0.037 a	0.293 ± 0.046 a
SE1	2.876 ± 0.170 b	0.072 ± 0.008 a	0.285 ± 0.011 b	0.198 ± 0.017 b
SE2	3.394 ± 0.328 b	0.080 ± 0.007 a	0.327 ± 0.037 b	0.212 ± 0.031 b

Note: Different lowercase letters in each column indicate significant differences at the 0.05 level.

3.4. Effects of Organic Fertilizer on the Levels of Mineral Elements in 'Fuji' Apples

Minerals are important to the development, quality, and yield of apples. K, Ca, Mg, N, and P are macronutrients required for plant growth and development. On the other hand, Fe, Zn, and B are examples of micronutrients required for plant growth and development. As shown in Figure 1, SE1 and SE2 significantly increased the levels of K, Ca, and Mg in 'Fuji' apples, but they had no significant effect on the levels of N and P in the apples. Compared to the levels of K, Ca, and Mg in the control apples, those in the SE1-treated apples increased by 31.02%, 54.99%, and 64.69%, respectively. On the other hand, compared to the levels of K, Ca, and Mg in the control apples, those in the SE2-treated apples increased by 25.71%, 43.12%, and 58.60%, respectively. SE1 and SE2 significantly increased the levels of Fe, Zn, and B in 'Fuji' apples, but they had no significant effect on the level of Mn in the apples. SE1 increased the levels of Fe, Zn, and Boron in 'Fuji' apples by 42.00%, 28.09%, and 37.86%, respectively. On the other hand, SE2 increased the levels of Fe, Zn, and B in the apples by 39.19%, 25.80%, and 28.17%, respectively.

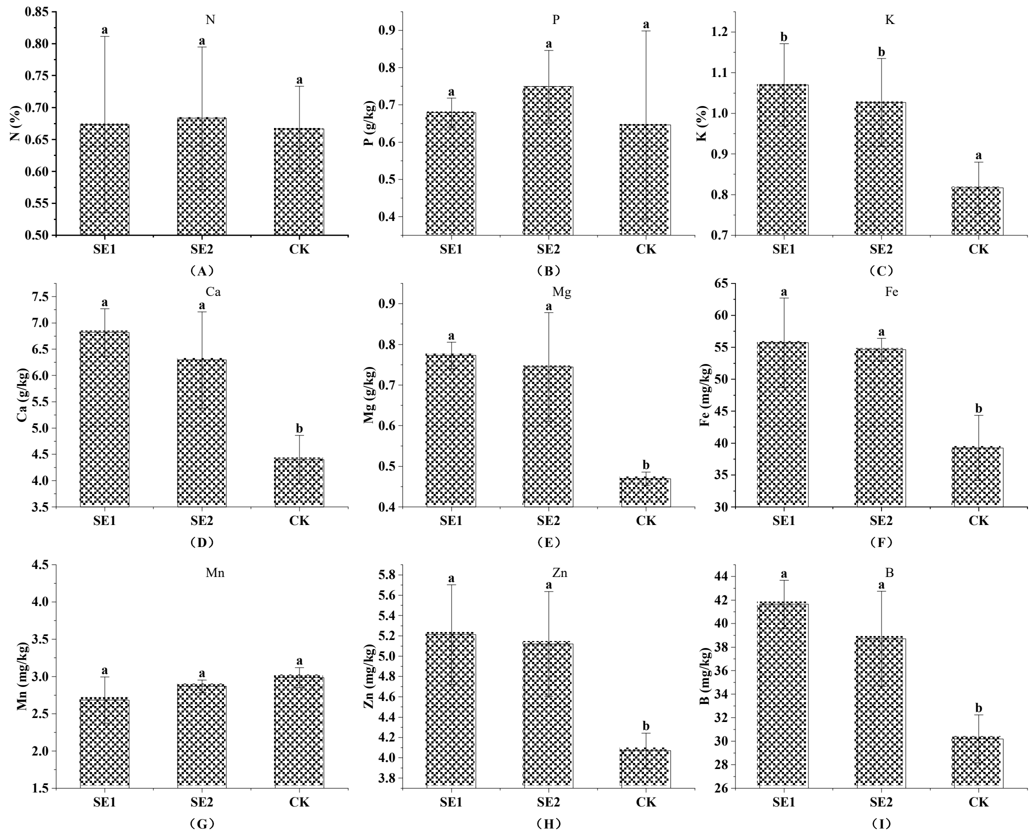

Figure 1. Effects of organic fertilizer on the levels of mineral elements (**A**) nitrogen, (**B**) phosphorus, (**C**) potassium, (**D**) calcium, (**E**) magnesium, (**F**) iron, (**G**) manganese, (**H**) zinc, and (**I**) boron in 'Fuji' apples. Different lowercase letters indicate significant differences between treatments ($p < 0.05$).

3.5. Effects of Organic Fertilizer on the Levels of Hormones in 'Fuji' Apples

SE1 and SE2 significantly improved the levels of IAA, ZR, and GA3 in 'Fuji' apples, but they significantly decreased the level of ABA in the apples (Table 6). Compared with the levels of IAA, ZR, and GA3 in the control apples, those in the SE1-treated apples increased by 70.25%, 74.16%, and 48.51%, respectively. On the other hand, compared with the levels of IAA, ZR, and GA3 in the control apples, those in the SE2-treated apples increased by 40.05%, 66.92%, and 29.54%, respectively. Compared with the level of ABA in the control apples, those in the SE1-treated apples and SE2-treated apples decreased by 40.78% and 35.84%, respectively.

Table 6. Effects of organic fertilizer on the levels of hormones in 'Fuji' apples.

Treatment	Indole Acetic Acid (μg/g)	Zeatin (μg/g)	Gibberellin (μg/g)	Abscisic Acid (μg/g)
CK	0.154 ± 0.006 b	0.125 ± 0.008 b	0.539 ± 0.122 b	0.643 ± 0.073 a
SE2	0.2084 ± 0.010 a	0.184 ± 0.012 a	0.755 ± 0.113 a	0.513 ± 0.030 b
SE1	0.226 ± 0.006 a	0.197 ± 0.010 a	0.801 ± 0.053 a	0.429 ± 0.057 b

Note: Different lowercase letters in each column indicate significant differences at the 0.05 level.

4. Discussion

Fierce competition requires growers to meet consumers' demand for high-quality apples. Shape, size, texture, color, levels of volatile compounds, levels of phenolic compounds, and levels of minerals are important parameters that determine apple quality [24,38,39]. The levels of primary and secondary metabolites in apples depend on apple varieties, rootstocks, agricultural management measures (fertilization, irrigation, and pruning), climates, picking time, storage methods, processing methods, biotic stresses, and abiotic stresses [40,41].

Seaweed extract effectively stimulates the growth of 'Jonathan' apple trees and significantly improves the area of their leaves, chlorophyll content of the leaves, and photosynthetic rate in the leaves [42]. In this study, SE1 and SE2 significantly increased the net photosynthetic rate, chlorophyll content, and Rubisco activity in 'Fuji' apple leaves (Table 1). These results are consistent with those reported by Spinelli et al. [43], who detected increases in the chlorophyll content and photosynthetic activity after the application of a seaweed-extract-based commercial metabolic enhancer to 'Fuji' apple trees. Seaweed-extract-based fertilizer increases the level of chlorophyll in grape leaves [44].

The application of seaweed extracts and amino acids improves the yield and quality of fruit [23]. Color intensity and distribution are essential parameters for red apples [42,45,46]. The foliar application of seaweed extract improves the intensity and distribution of the red color of apple peel [47], which may be due to the ability of the extract to induce anthocyanin biosynthesis in fruit peel [42]. Basak [48] found that spraying seaweed-extract-based products Kelpak® and Goemar BM 86® improves the size and red color of apples. In this study, SE1 and SE2 significantly increased the a* value and single-fruit weight of 'Fuji' apples (Table 2). It may be due to the fact that seaweed fertilizer stimulates the cell division of young fruit, improves fruit size and increases single fruit weight. The foliar application of seaweed extract improves the yield and size of strawberries [49]. Moreover, the foliar application of seaweed extract improves the yield and quality of pears [50]. This study showed that SE1 and SE2 improved the sugar–acid ratio and the levels of soluble solids, soluble sugars, VC, and free amino acids in 'Fuji' apples. The improvements in SE1-treated apples (the fertilizer contains amino acids) were greater than those in the SE2-treated apples (Tables 2 and 3). The foliar application of a mixture of amino acids and seaweed extract significantly improves the weight, yield, and quality of grapes [51]. Khan et al. [23] confirmed that the application of 'Primo' (a mixture of seaweed extract and amino acids) significantly increases the weight, SSC, SSC–TA ratio, and VC content of citrus fruit.

The levels, types, and ratio of sugar and acid components jointly affect the formation of flavor. Flavor, which is an important criterion for evaluating fruit quality, is an important parameter in the evaluation of new varieties, evaluation of new cultivation technologies, and screening of germplasm resources for sources of flavor improvements [34,52,53]. The most dominant sugars and sugar alcohols present in apples were sucrose, fructose, glucose and sorbitol [54,55]. Sucrose and fructose were the most abundant sugars, followed by glucose [52]. Sorbitol and sucrose, which are formed by photosynthesis in leaves, are transferred to fruit tissues and converted into fructose, glucose, malic acid, or starch [56,57]. During fruit ripening, sucrose is converted into glucose and fructose. Sorbitol is preferentially converted to fructose, while glucose is preferentially converted to starch. Therefore, the level of fructose in fruit tissues is higher than that of glucose in the tissues [38]. In most apples, the levels of fructose and sucrose are higher than those of glucose and sorbitol [58].

Our results are consistent with those of previous studies [53,54]. As shown in Table 4, SE1 and SE2 significantly increased the levels of fructose, glucose, sucrose, and sorbitol in 'Fuji' apples. It may be due to fact that the seaweed fertilizer can improve the photosynthetic efficiency of leaves and the promotion of the transportation and accumulation of assimilates to fruits. The levels of fructose, sucrose, and sorbitol in SE1-treated apples were significantly higher than those in SE2-treated apples, which may be due to the amino acid contents of SE1. Amino acids are important signaling molecules that may stimulate the production of plant metabolites [59]. Malic acid is the most abundant organic acid in apples [34,58]. As shown in Table 5, the level of malic acid in 'Fuji' apples was higher than those of citric acid, oxalic acid, and tartaric acid in the apples. SE1 and SE2 significantly decreased the levels of malic acid, oxalic acid, and tartaric acid in 'Fuji' apples, but they did not significantly affect the level of citric acid in the apples.

Apples are rich sources of minerals, such as N, P, K, Ca, Mg, Zn, and Fe. These minerals participate in the physiological processes of the fruits [53,60]. The proportions of Ca, Mg, and K in mature apples affect the quality, cell wall structure, and storage life of the fruits. On the other hand, the lack of these minerals causes physiological disorders in apples [61]. Previous studies have shown that the foliar application of seaweed extract promotes the absorption of nutrients by plants and increases the levels of macro- and micronutrients (such as N, P, K, Ca, Mg, Zn, and Fe) in the plants [62,63]. The results of this study are consistent with those of previous studies. As shown in Figure 1, SE1 and SE2 significantly increased the levels of K, Ca, Mg, Fe, Zn, and B in 'Fuji' apples. However, they did not significantly affect the levels of N and P in the apples. This may be due to the fact that the seaweed fertilizer can improve the absorption of minerals and promote the transportation and accumulation of mineral salts to fruits. These results are consistent with the results reported by Basak [48].

Endogenous hormones play important regulatory roles in fruit growth and development, affecting the assimilation of carbon and the transportation and distribution of photosynthate [64,65]. Seaweed-extract-based fertilizer is able to modulate the activity of endogenous hormones in fruit [66]. A previous study has shown that the levels of ABA, IAA, ZR, and GA_3 in fruit vary during fruit development. The levels of IAA and ABA increase and then decrease, while the level of ZR continuously decreases and remains low. On the other hand, the level of GA_3 decreases, increases, and then decreases. At harvest, the levels of these hormones in fruit are relatively stable [67]. This study showed that the foliar application of SE1 and SE2 increased the levels of GA_3, IAA, and ZR and reduced the level of ABA in 'Fuji' apples at harvest. IAA can regulate the transport of nutrients [68]. GA_3 improves the metabolism of sorbitol and sucrose and synergizes with IAA [67]. At the late stage of fruit development, increasing the levels of IAA and GA_3 and reducing the level of ABA in fruit can effectively reduce pre-harvest fruit drop [69].

5. Conclusions

SE1 and SE2 significantly improved the photosynthetic function of 'Fuji' apple leaves. Moreover, they significantly improved the quality, weight, and red color of 'Fuji' apples. The fertilizers increased the levels of sugars and decreased the levels of acids in 'Fuji' apples, improving the flavor of the apples. Furthermore, they regulated the levels of IAA, ZR, GA_3, and ABA in these apples, promoting carbohydrate accumulation in the fruits. In addition, the fertilizers improved the levels of soluble solids, VC, free amino acids, sugars, and mineral elements in the apples. In conclusion, SE1 and SE2 promote nutrient accumulation in 'Fuji' apples and improve the quality, appearance, nutritional value, and market competitiveness of the apples. Further analysis should confirm whether the beneficial effects of the seaweed-extract-based foliar fertilizers last during storage and the subsequent growing season. The study was only conducted for one year and the conclusions formed from this study are only preliminary.

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References

1. Mignard, P.; Beguería, S.; Giménez, R.; Font i Forcada, C.; Reig, G.; Moreno, M. Effect of Genetics and Climate on Apple Sugars and Organic Acids Profiles. *Agronomy* **2022**, *12*, 827. [CrossRef]
2. Corona-Leo, L.S.; Meza-Márquez, O.G.; Hernández-Martínez, D.M. Effect of in vitro digestion on phenolic compounds and antioxidant capacity of different apple (Malus domestica) varieties harvested in Mexico. *Food Biosci.* **2021**, *43*, 101311. [CrossRef]
3. Jakobek, L.; Ištuk, J.; Buljeta, I.; Voća, S.; Šic Žlabur, J.; Skendrović Babojelić, M. Traditional, Indigenous Apple Varieties, a Fruit with Potential for Beneficial Effects: Their Quality Traits and Bioactive Polyphenol Contents. *Foods* **2020**, *9*, 52. [CrossRef]
4. Salazar-Orbea, G.L.; García-Villalba, R.; Bernal, M.J.; Hernández, A.; Tomás-Barberán, F.A.; Sánchez-Siles, L.M. Stability of phenolic compounds in apple and strawberry: Effect of different processing techniques in industrial set up. *Food Chem.* **2023**, *401*, 134099. [CrossRef]
5. Salazar-Orbea, G.L.; García-Villalba, R.; Barberán, F.A.T.; Sánchez-Siles, L.M. High–Pressure Processing vs. Thermal Treatment: Effect on the Stability of Polyphenols in Strawberry and Apple Products. *Foods* **2021**, *10*, 2919. [CrossRef]
6. Raphaelli, C.D.O.; Azevedo, J.G.; Pereira, E.D.S.; Vinholes, J.R.; Camargo, T.M.; Hoffmann, J.F.; Ribeiro, J.A.; Vizzotto, M.; Rombaldi, C.V.; Wink, M.R.; et al. Phenolic-rich apple extracts have photoprotective and anti-cancer effect in dermal cells. *Phytomedicine Plus* **2021**, *1*, 100112. [CrossRef]
7. Barreira, J.C.; Arraibi, A.A.; Ferreira, I.C. Bioactive and functional compounds in apple pomace from juice and cider manufacturing: Potential use in dermal formulations. *Trends Food Sci. Technol.* **2019**, *90*, 76–87. [CrossRef]
8. Kobori, M.; Masumoto, S.; Akimoto, Y.; Oike, H. Phloridzin reduces blood glucose levels and alters hepatic gene expression in normal BALB/c mice. *Food Chem. Toxicol.* **2012**, *50*, 2547–2553. [CrossRef]
9. Mei, X.; Zhang, X.; Wang, Z.; Gao, Z.; Liu, G.; Hu, H.; Zou, L.; Li, X. Insulin Sensitivity-Enhancing Activity of Phlorizin Is Associated with Lipopolysaccharide Decrease and Gut Microbiota Changes in Obese and Type 2 Diabetes (*db/db*) Mice. *J. Agric. Food Chem.* **2016**, *64*, 7502–7511. [CrossRef] [PubMed]
10. Sun, Y.; Deng, Y.; Lu, Y.; Li, M. Competitiveness and sustainable development of Chinableapple industry. *PLoS ONE* **2022**, *17*, e0268476. [CrossRef]
11. Srivastava, A.; Wu, Q.-S.; Mousavi, S.M.; Hota, D. Integrated Soil Fertility Management in Fruit Crops: An Overview. *Int. J. Fruit Sci.* **2021**, *21*, 413–439. [CrossRef]
12. Liang, X.; Zhang, R.; Gleason, M.L.; Sun, G. Sustainable Apple Disease Management in China: Challenges and Future Directions for a Transforming Industry. *Plant Dis.* **2022**, *106*, 786–799. [CrossRef] [PubMed]
13. Chen, R.; Xue, X.; Wang, G.; Wang, J. Determination and dietary intake risk assessment of 14 pesticide residues in apples of China. *Food Chem.* **2021**, *351*, 129266. [CrossRef] [PubMed]
14. Admane, N.; Cavallo, G.; Hadjila, C.; Cavalluzzi, M.M.; Rotondo, N.P.; Salerno, A.; Cannillo, J.; Difonzo, G.; Caponio, F.; Ippolito, A.; et al. Biostimulant Formulations and *Moringa oleifera* Extracts to Improve Yield, Quality, and Storability of Hydroponic Lettuce. *Molecules* **2023**, *28*, 373. [CrossRef]
15. Quitério, E.; Grosso, C.; Ferraz, R.; Delerue-Matos, C.; Soares, C. A Critical Comparison of the Advanced Extraction Techniques Applied to Obtain Health-Promoting Compounds from Seaweeds. *Mar. Drugs* **2022**, *20*, 677. [CrossRef]
16. Lomartire, S.; Gonçalves, A.M.M. Novel Technologies for Seaweed Polysaccharides Extraction and Their Use in Food with Therapeutically Applications—A Review. *Foods* **2022**, *11*, 2654. [CrossRef]
17. Čmiková, N.; Galovičová, L.; Miškeje, M.; Borotová, P.; Kluz, M.; Kačániová, M. Determination of Antioxidant, Antimicrobial Activity, Heavy Metals and Elements Content of Seaweed Extracts. *Plants* **2022**, *11*, 1493. [CrossRef]
18. El Boukhari, M.E.M.; Barakate, M.; Bouhia, Y.; Lyamlouli, K. Trends in Seaweed Extract Based Biostimulants: Manufacturing Process and Beneficial Effect on Soil-Plant Systems. *Plants* **2020**, *9*, 359. [CrossRef]
19. AMLANI, M.; Yetgin, S. Seaweeds: Bioactive Components and Properties, Potential Risk Factors, Uses, Extraction and Purification Methods. *Mar. Sci. Technol. Bull.* **2022**, *11*, 9–31. [CrossRef]

20. Deolu-Ajayi, A.O.; van der Meer, I.M.; van der Werf, A.; Karlova, R. The power of seaweeds as plant biostimulants to boost crop production under abiotic stress. *Plant Cell Environ.* **2022**, *45*, 2537–2553. [CrossRef]
21. Rouphael, Y.; Carillo, P.; Garcia-Perez, P.; Cardarelli, M.; Senizza, B.; Miras-Moreno, B.; Colla, G.; Lucini, L. Plant biostimulants from seaweeds or vegetal proteins enhance the salinity tolerance in greenhouse lettuce by modulating plant metabolism in a distinctive manner. *Sci. Hortic.* **2022**, *305*, 111368. [CrossRef]
22. Craigie, J.S. Seaweed extract stimuli in plant science and agriculture. *J. Appl. Phycol.* **2011**, *23*, 371–393. [CrossRef]
23. Khan, A.; Munir, M.; Shaheen, T.; Tassawar, T.; Rafiq, M.; Ali, S.; Anwar, R.; Rehman, R.; Hasan, M.; Malik, A. Supplemental foliar applied mixture of amino acids and seaweed extract improved vegetative growth, yield and quality of citrus fruit. *Sci. Hortic.* **2022**, *296*, 110903. [CrossRef]
24. Yang, A.; Yang, L.; Cheng, C.; Xie, B.; Zhang, Y.; Li, X.; Li, Y.; Li, Z. Effect of Different Ratios of Cow Manure and Chemical Fertilizers on Fruit Quality of Gala Apples. *Agronomy* **2022**, *12*, 2735. [CrossRef]
25. Musacchi, S.; Serra, S. Apple fruit quality: Overview on pre-harvest factors. *Sci. Hortic.* **2018**, *234*, 409–430. [CrossRef]
26. Amiri, M.E.; Fallahi, E.; Golchin, A. Influence of Foliar and Ground Fertilization on Yield, Fruit Quality, and Soil, Leaf, and Fruit Mineral Nutrients in Apple. *J. Plant Nutr.* **2008**, *31*, 515–525. [CrossRef]
27. Świerczyński, S.; Antonowicz, A.; Bykowska, J. The Effect of the Foliar Application of Biostimulants and Fertilisers on the Growth and Physiological Parameters of Maiden Apple Trees Cultivated with Limited Mineral Fertilisation. *Agronomy* **2021**, *11*, 1216. [CrossRef]
28. Jumadi, O.; Annisi, A.D.; Djawad, Y.A.; Bourgougnon, N.; Amaliah, N.A.; Asmawati, A.; Manguntungi, A.B.; Inubushi, K. Brown algae (*Sargassum* sp) extract prepared by indigenous microbe fermentation enhanced tomato germination parameters. *Biocatal. Agric. Biotechnol.* **2023**, *47*, 102601. [CrossRef]
29. Aitouguinane, M.; El Alaoui-Talibi, Z.; Rchid, H.; Fendri, I.; Abdelkafi, S.; El-Hadj, M.D.O.; Boual, Z.; Dubessay, P.; Michaud, P.; Traïkia, M.; et al. Polysaccharides from Moroccan Green and Brown Seaweed and Their Derivatives Stimulate Natural Defenses in Olive Tree Leaves. *Appl. Sci.* **2022**, *12*, 8842. [CrossRef]
30. Hernández-Herrera, R.M.; Santacruz-Ruvalcaba, F.; Zañudo-Hernández, J.; Hernández-Carmona, G. Activity of seaweed extracts and polysaccharide-enriched extracts from Ulva lactuca and Padina gymnospora as growth promoters of tomato and mung bean plants. *J. Appl. Phycol.* **2016**, *28*, 2549–2560. [CrossRef]
31. Mishra, A.; Sahni, S.; Kumar, S.; Prasad, B.D. Seaweed—An Eco-friendly Alternative of Agrochemicals in Sustainable Agriculture. *Curr. J. Appl. Sci. Technol.* **2020**, *39*, 71–78. [CrossRef]
32. Świerczyński, S.; Antonowicz, A. The Effects of Reduced Mineral Fertilisation Combined with the Foliar Application of Biostimulants and Fertilisers on the Nutrition of Maiden Apple Trees and the Contents of Soil Nutrients. *Agronomy* **2021**, *11*, 2438. [CrossRef]
33. Hu, Z.Q.; Wang, H.C.; Hu, G.B. Measurement of sugars, organic acids and vitamin C in litchi fruit by high performance liquid chromatography. *J. Fruit Sci.* **2005**, *5*, 582–585. [CrossRef]
34. Li, Y.N.; Yan, L.Y.; Zhang, B.; Yang, S.B.; Zhao, Z.Y. A study on sugar and organic acid components in different apple cultivars. *J. Fruit Sci.* **2021**, *38*, 1877–1889. [CrossRef]
35. Roussos, P.A.; Gasparatos, D. Apple tree growth and overall fruit quality under organic and conventional orchard management. *Sci. Hortic.* **2009**, *123*, 247–252. [CrossRef]
36. Trapp, M.A.; De Souza, G.D.; Rodrigues-Filho, E.; Boland, W.; Mithã¶fer, A. Validated method for phytohormone quantification in plants. *Front. Plant Sci.* **2014**, *5*, 417. [CrossRef]
37. Wang, G.; Wang, J.; Han, X.; Chen, R.; Xue, X. Effects of Spraying Calcium Fertilizer on Photosynthesis, Mineral Content, Sugar–Acid Metabolism and Fruit Quality of Fuji Apples. *Agronomy* **2022**, *12*, 2563. [CrossRef]
38. Aprea, E.; Charles, M.; Endrizzi, I.; Corollaro, M.L.; Betta, E.; Biasioli, F.; Gasperi, F. Sweet taste in apple: The role of sorbitol, individual sugars, organic acids and volatile compounds. *Sci. Rep.* **2017**, *7*, 44950. [CrossRef]
39. Jaeger, S.R.; Antúnez, L.; Ares, G.; Swaney-Stueve, M.; Jin, D.; Harker, F. Quality perceptions regarding external appearance of apples: Insights from experts and consumers in four countries. *Postharvest Biol. Technol.* **2018**, *146*, 99–107. [CrossRef]
40. Oszmiański, J.; Lachowicz, S.; Gławdel, E.; Cebulak, T.; Ochmian, I. Determination of phytochemical composition and antioxidant capacity of 22 old apple cultivars grown in Poland. *Eur. Food Res. Technol.* **2017**, *244*, 647–662. [CrossRef]
41. Akšić, M.F.; Zagorac, D.D.; Gašić, U.; Tosti, T.; Natić, M.; Meland, M. Analysis of Apple Fruit (*Malus* × *domestica* Borkh.) Quality Attributes Obtained from Organic and Integrated Production Systems. *Sustainability* **2022**, *14*, 5300. [CrossRef]
42. Soppelsa, S.; Kelderer, M.; Casera, C.; Bassi, M.; Robatscher, P.; Andreotti, C. Use of Biostimulants for Organic Apple Production: Effects on Tree Growth, Yield, and Fruit Quality at Harvest and During Storage. *Front. Plant Sci.* **2018**, *9*, 1342. [CrossRef] [PubMed]
43. Spinelli, F.; Fiori, G.; Noferini, M.; Sprocatti, M.; Costa, G. Perspectives on the use of a seaweed extract to moderate the negative effects of alternate bearing in apple trees. *J. Hortic. Sci. Biotechnol.* **2009**, *84*, 131–137. [CrossRef]
44. Sabir, A.; Yazar, K.; Sabir, F.; Kara, Z.; Yazici, M.A.; Goksu, N. Vine growth, yield, berry quality attributes and leaf nutrient content of grapevines as influenced by seaweed extract (Ascophyllum nodosum) and nanosize fertilizer pulverizations. *Sci. Hortic.* **2014**, *175*, 1–8. [CrossRef]
45. Xue, X.; Tian, S.; Chen, R.; Han, X.; Wang, J.; Zhao, X. Clarifying the mechanisms of the light-induced color formation of apple peel under dark conditions through metabolomics and transcriptomic analyses. *Front. Plant Sci.* **2022**, *13*, 946115. [CrossRef]

46. Deng, X.; Shu, H.; Hao, Y.; Xu, Q.; Han, M.; Zhang, S. Review on the centennial development of pomology in China. *J. Agric.* **2018**, *8*, 34. [CrossRef]
47. Malaguti, D.; Rombolà, A.; Gerin, M.; Simoni, G.; Tagliavini, M.; Marangoni, B. Effect of seaweed extracts-based leaf sprays on the mineral status, yield and fruit quality of apple. *Acta Hortic.* **2002**, *594*, 357–359. [CrossRef]
48. Basak, A. Effect of Preharvest Treatment with Seaweed Products, Kelpak®and Goëmar BM 86®, on Fruit Quality in Apple. *Int. J. Fruit Sci.* **2008**, *8*, 1–14. [CrossRef]
49. Masny, A.; Basak, A.; Zurawicz, E. Effect of foliar application of Kelpak SL and Goemar BM 86 preparations on yield and fruit quality in two strawberry cultivars. *J. Fruit Ornamen. Plant Res.* **2004**, *12*, 23–27.
50. Colavita, G.; Spera, N.; Blackhall, V.; Sepulveda, G. Effect of Seaweed Extract on Pear Fruit Quality and Yield. In Proceedings of the XI International Pear Symposium, Patagonia, Argentina, 31 October 2011; pp. 601–607. [CrossRef]
51. Khan, A.S.; Ahmad, B.; Jaskani, M.J.; Ahmad, R.; Malik, A.U. Foliar application of mixture of amino acids and seaweed (Ascophylum nodosum) extract improve growth and physico-chemical properties of grapes. *Intl. J. Agri. Biol.* **2012**, *14*, 383–388.
52. Wu, J.; Gao, H.; Zhao, L.; Liao, X.; Chen, F.; Wang, Z.; Hu, X. Chemical compositional characterization of some apple cultivars. *Food Chem.* **2007**, *103*, 88–93. [CrossRef]
53. Akšić, M.F.; Nešović, M.; Ćirić, I.; Tešić, Ž.; Pezo, L.; Tosti, T.; Gašić, U.; Dojčinović, B.; Lončar, B.; Meland, M. Polyphenolics and Chemical Profiles of Domestic Norwegian Apple (Malus × domestica Borkh.) Cultivars. *Front. Nutr.* **2022**, *9*, 941487. [CrossRef]
54. Zhang, Y.; Li, P.; Cheng, L. Developmental changes of carbohydrates, organic acids, amino acids, and phenolic compounds in 'Honeycrisp' apple flesh. *Food Chem.* **2010**, *123*, 1013–1018. [CrossRef]
55. Füzfai, Z.; Katona, Z.F.; Kovács, E.; Molnár-Perl, I. Simultaneous Identification and Quantification of the Sugar, Sugar Alcohol, and Carboxylic Acid Contents of Sour Cherry, Apple, and Ber Fruits, as Their Trimethylsilyl Derivatives, by Gas Chromatography−Mass Spectrometry. *J. Agric. Food Chem.* **2004**, *52*, 7444–7452. [CrossRef]
56. Zhang, Y.; Yan, Y.; Fu, C.; Li, M.; Wang, Y. Zinc sulfate spray increases activity of carbohydrate metabolic enzymes and regulates endogenous hormone levels in apple fruit. *Sci. Hortic.* **2016**, *211*, 363–368. [CrossRef]
57. Yamaki, S. Metabolism and Accumulation of Sugars Translocated to Fruit and Their Regulation. *J. Jpn. Soc. Hortic. Sci.* **2010**, *79*, 1–15. [CrossRef]
58. He, Y.J.; Ma, Z.H.; Wei, X.X.; Li, Y.M.; Li, Y.B.; Ma, W.F.; Ding, S.L.; Mao, J.; Chen, B.H. Comparative Analysis of Sugar and Organic Acid Contents of Different Apple Cultivars in Dryland of Loess Plateau. *Sci. Technol. Food Ind.* **2021**, *42*, 248–254. [CrossRef]
59. Rouphael, Y.; Colla, G.; Giordano, M.; El-Nakhel, C.; Kyriacou, M.C.; De Pascale, S. Foliar applications of a legume-derived protein hydrolysate elicit dose-dependent increases of growth, leaf mineral composition, yield and fruit quality in two greenhouse tomato cultivars. *Sci. Hortic.* **2017**, *226*, 353–360. [CrossRef]
60. Akšić, M.F.; Mutić, J.; Tešić, Z.; Meland, M. Evaluation of fruit mineral contents of two apple cultivars grown in organic and integrated production systems. *Acta Hortic.* **2020**, *1281*, 59–66. [CrossRef]
61. Zavalloni, C.; Marangoni, B.; Tagliavini, M.; Scudellari, D. DYNAMICS OF UPTAKE OF CALCIUM, POTASSIUM AND MAGNESIUM INTO APPLE FRUIT IN A HIGH DENSITY PLANTING. *Acta Hortic.* **2001**, *564*, 113–121. [CrossRef]
62. Zodape, S.T.; Kawarkhe, V.J.; Patolia, J.S.; Warade, A.D. Effect of liquid seaweed fertilizer on yield and quality of okra (Abelmoschus esculentus L.). *J. Sci. Ind. Res.* **2008**, *67*, 1115–1117.
63. Rathore, S.; Chaudhary, D.; Boricha, G.; Ghosh, A.; Bhatt, B.; Zodape, S.; Patolia, J. Effect of seaweed extract on the growth, yield and nutrient uptake of soybean (Glycine max) under rainfed conditions. *South Afr. J. Bot.* **2008**, *75*, 351–355. [CrossRef]
64. Huang, J.; Tu, D.-P.; Ma, X.-J.; Mo, C.-M.; Pan, L.-M.; Bai, L.-H.; Feng, S.-X. [Study on exogenous hormones inducing parthenocarpy fruit growth and development and quality of Siraitia grosvenorii]. *China J. Chin. Mater. Med.* **2015**, *40*, 3567–3572.
65. Wang, C.; Liu, Y.; Li, S.-S.; Han, G.-Z. Insights into the Origin and Evolution of the Plant Hormone Signaling Machinery. *Plant Physiol.* **2015**, *167*, 872–886. [CrossRef] [PubMed]
66. Wally, O.S.D.; Critchley, A.T.; Hiltz, D.; Craigie, J.S.; Han, X.; Zaharia, L.I.; Abrams, S.R.; Prithiviraj, B. Erratum to: Regulation of Phytohormone Biosynthesis and Accumulation in Arabidopsis Following Treatment with Commercial Extract from the Marine Macroalga Ascophyllum nodosum. *J. Plant Growth Regul.* **2012**, *32*, 340–341. [CrossRef]
67. Sha, J.; Wang, F.; Xu, X.; Chen, Q.; Zhu, Z.; Jiang, Y.; Ge, S. Studies on the translocation characteristics of 13C-photoassimilates to fruit during the fruit development stage in 'Fuji' apple. *Plant Physiol. Biochem.* **2020**, *154*, 636–645. [CrossRef]
68. Srivastava, A.; Handa, A.K. Hormonal regulation of tomato fruit development: A molecular perspective. *J. Plant Growth Regul.* **2005**, *24*, 67–82. [CrossRef]
69. Zhao, H.Y.; Jiang, C.Y.; Qi, J.L.; Zhao, M.J.; Jin, G.M.; Wu, W.J. The law of olive fruit falling and the changes of soluble sugar, starch and endogenous hormone content in leaves during fruit development. *China Fruits* **2022**, *10*, 43–48. [CrossRef]