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Research Article

Water footprint of melon production under different nutrient and plant growth regulator management

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ABSTRACT

Applying environmentally friendly technology in melon cultivation aims to create sustainable agriculture. Nutrient and plant growth regulators management are simple to apply and have a relatively rapid effect on melon fruit production. Water footprint assessment in melon cultivation is crucial for ensuring sustainable agricultural practices and efficient water use. This study aimed to evaluate the electroconductivity of nutrient solutions and GA_3 concentration in increasing fruit production and water footprint efficiency. This research was conducted from June to September 2022 at Tefa SGH Polije. This research used a completely randomized design with treatments that consisted of nine combinations of nutrient solution electrical conductivities (2.8, 3.2, and 3.6 mS cm^{-1}) and GA_3 concentrations (0, 60, and 120 mg L^{-1}). Observation variables were fruit diameter, edible part thickness, fruit sweetness level, fruit weight, and water footprint. Data were analyzed using ANOVA and DMRT. Applying 2.8 mS cm^{-1} nutrient solution (NS) + 60 mg L^{-1} GA_3 was the best treatment according to fruit diameter, edible part thickness, and fruit sweetness level. Although statistically, it had no significant effect, 2.8 mS cm^{-1} NS + 60 mg L^{-1} GA_3 increased fruit weight by 18.75% and water footprint efficiency by 15.48% compared to control.

Keywords: blue water footprint; evapotranspiration; gibberellins; nutrient solution

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INTRODUCTION

Melon is one of the agricultural commodities increasingly attracting attention in various parts of the world, including Indonesia. Melon fruit is known for its sweet, refreshing taste, and nutritional content that benefits health (Tara et al., 2024). Currently, melon cultivators are facing various challenges that come not only from consumer demand but also climate change. With rapid population growth, extreme climate change, and declining soil and water quality, the agricultural sector must adapt to ensure sustainable production while maintaining environmental health (Yang et al., 2023). Therefore, farmers and researchers continue to strive to develop environmentally friendly melon cultivation techniques to face these challenges. The implementation of sustainable farming activities is crucial in facing the increasingly complex global challenges in today's era. Climate change is causing a global water crisis that impacts the quality and availability of water resources. Environmentally friendly farming techniques such as drip irrigation, rainwater harvesting, and mulching can significantly reduce water consumption and increase water use efficiency.

The water footprint is an important tool for evaluating the water use efficiency in melon cultivation. Water footprint consists of three components: blue water footprint, green water footprint, and gray water footprint. Blue water footprint is the use of water by plants from surface water and groundwater, such as irrigation. Green water footprint is the use of water by plants from rain (Hoekstra et al., 2011). The gray water footprint is the volume of water needed to dissolve pollutants from using chemical fertilizers and pesticides during the cultivation process so that water quality remains in accordance with standards (Franke et al., 2013). In agriculture, water footprint can be described by the volume of water used in each production unit during the cultivation process. Therefore, the efficiency of the water footprint of melon cultivation can be improved by increasing fruit production.

Melon fruit with maximum quality can be harvested between 61-79 days after planting (Huda et al., 2019). The growth and production of melon plants are not only influenced by genetic factors (Pawitra, 2020) and microclimate (Anggara et al., 2020) but also by cultivation techniques. Research on the development of melon cultivation techniques to increase fruit production has been widely reported, including planting systems (Darwiyah et al., 2021), planting media composition (Bilalang & Maharia, 2021), irrigation (Malik & Arif, 2023), application of organic (Annisa & Gustia, 2017; Maruapey & Soekamto, 2022; Palandro et al., 2023) and inorganic fertilizer (Ginting et al., 2017; Triadiati et al., 2019), application of growth regulators (Ikhsan & Aini, 2023; Purba et al., 2019), topping (Laudji et al., 2021) and fruit pruning (Siregar et al., 2019). Nutrient management and plant growth regulators are technologies that are simple to apply and have a relatively rapid effect on melon fruit production. One of the nutrients widely used for hydroponically cultivated melon plants is AB mix. Plant growth regulators widely used to increase fruit size are the gibberellin group, for example, gibberellic acid (GA_3).

Nutrient solutions of AB Mix are a mixture of nutrients specifically designed to meet the nutrient needs of plants at every stage of their growth. These nutrients include macronutrients such as nitrogen (N), phosphorus (P), and potassium (K), as well as important micronutrients such as calcium, magnesium, and sulfur (Furoidah, 2018). Balanced nutrition is essential for optimal plant growth because each element has a specific role in the plant's metabolic processes. Nitrogen plays a role in leaf and stem growth, phosphorus supports root development and flowering, while potassium functions in photosynthesis and increases plant resistance to disease. Proper use of nutrient solutions can ensure that melon plants get all the elements needed for healthy growth to produce fruit with the desired quality (Samsuri et al., 2024).

GA_3 is a plant growth regulator from the gibberellin group. Gibberellin plays an important role in stimulating growth. This plant growth regulator affects various aspects of plant development, including stem elongation, flower formation, and fruit enlargement. It can help accelerate the growth process and increase fruit size, directly affecting the harvest (Anjum et al., 2020; Permatasari et al., 2016). In melon cultivation, gibberellin application can increase fruit size and optimize production results (Kurniasari et al., 2023). However, the effectiveness of gibberellin can be affected by the concentration used, as well as interactions with environmental factors and other nutrients.

Melon production was increased by regulating the provision of nutrient solutions and plant growth regulators. Kurniasari et al. (2023) reported that giving 1600 ppm (3.2 mS cm^{-1}) of nutrients solution showed significantly higher fruit sweetness level compared to 1400 ppm (2.8 mS cm^{-1}). Previously, Ariessandy et al. (2022) reported that 3 mS cm^{-1} nutrient solution responded better to melon fruit weight and sweetness level than 4-5 mS cm^{-1}. The addition of 60 ppm GA_3 showed greater melon fruit weight than 0-40 ppm GA_3 but was not significantly different from 80 ppm GA_3. Based on the results of previous studies, it was necessary to study further the effect of providing nutrient solution at electroconductivities of 2.8, 3.2, and 3.6 mS cm^{-1} and GA_3 at concentrations of 0, 60, and 120 mg L^{-1} on melon production. In addition, considering the limited research in this field, the effect of providing nutrient solutions and GA_3 on the water footprint of melon production also needs to be studied.

Water footprint assessment in melon cultivation with variation of nutrient solution electroconductivity and GA_3 concentration is critical to study. This refers to the efficiency of water resource use in melon cultivation through maximum fruit production. With increasing global population growth and climate change affecting water availability, water use efficiency in agricultural activities is becoming increasingly crucial. Current agricultural activities are not only aimed at increasing yield and product quality but also at contributing to more environmentally friendly and sustainable farming practices. This study aimed to evaluate the electroconductivity of nutrient solutions and GA_3 concentrations in increasing fruit production and water footprint efficiency in melon cultivation.

MATERIALS AND METHODS

Site and materials

The research was conducted at Teaching Factory Smart Green House under the management of the State Polytechnic of Jember in Jember, East Java, Indonesia. The observation period began from June to September 2022. Each Honey Globe cultivar melon plant was planted in cocopeat in polybags with a diameter of 22 cm. The fertigation was distributed using a drip irrigation system on each plant root area. The plant nutrients used were AB mix made by the State Polytechnic of Jember (Polije). GA_3 was obtained from the market commercially.

Treatments and procedure

The research used a completely randomized design with treatments that consisted of nine combinations of the nutrient solution (NS) electrical conductivities and the GA_3 concentrations, namely 2.8 mS cm^{-1} NS + 0 mg L^{-1} GA_3 (control); 2.8 mS cm^{-1} NS + 60 mg L^{-1} GA_3; 2.8 mS cm^{-1} NS + 120 mg L^{-1} GA_3; 3.2 mS cm^{-1} NS + 0 mg L^{-1} GA_3; 3.2 mS cm^{-1} NS + 60 mg L^{-1} GA_3; 3.2 mS cm^{-1} NS + 120 mg L^{-1} GA_3; 3.6 mS cm^{-1} NS + 0 mg L^{-1} GA_3; 3.6 mS cm^{-1} NS + 60 mg L^{-1} GA_3 and 3.6 mS cm^{-1} NS + 120 mg L^{-1} GA_3. Each treatment was repeated three times, so there were 27 experimental units (each consisted of three sample plants). The control treatment was the standard operating procedure of Teaching Factory Smart Green House, State Polytechnic of Jember (Tefa SGH Polije). The research procedures included planting, pruning, pollination, fruit pruning, topping, treatment application, and harvesting (Figure 1).

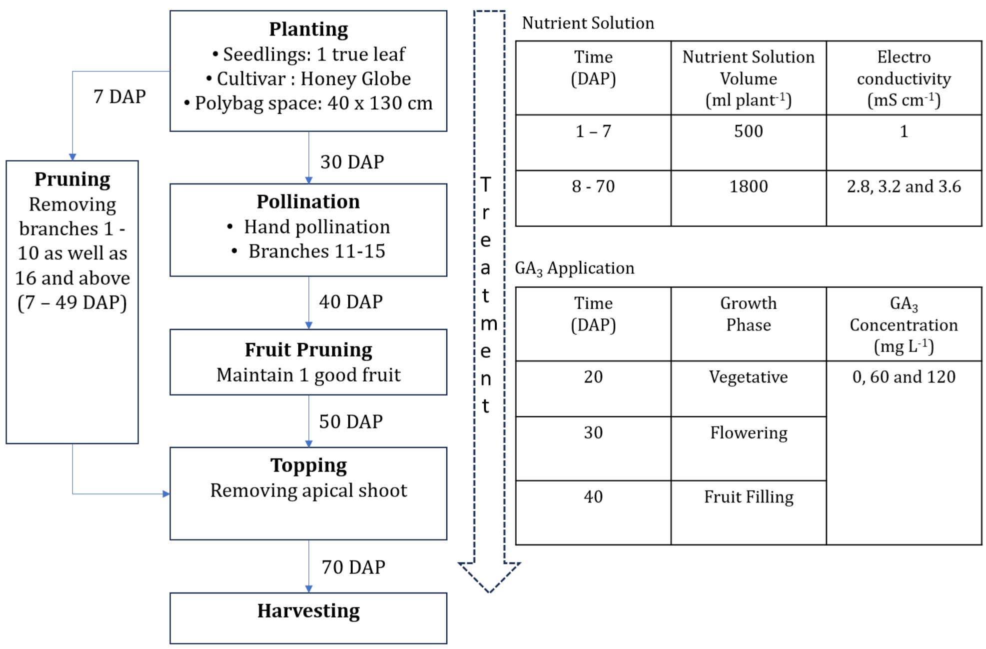

Figure 1. Research procedures.

Observations

Observations were made on production and water footprint variables. Production variables consisted of fruit diameter (cm), edible part thickness (cm), sweetness level (^{o}Brix), leaf chlorophyll content (unit mm^{-2}), and fruit weight (kg). Fruit diameter was measured by dividing fruit circumference by π value. Fruit edible part thickness was obtained by measuring the fruit flesh thickness using a digital caliper. Fruit sweetness level was measured by dropping fruit juice on a hand refractometer. Leaf chlorophyll content was measured using Chlorophyll Meter SPAD-502. Fruit weight was obtained using a digital scale. Plant production was observed during harvest time. The production data was needed to evaluate the water footprint of melon cultivation.

The water footprint (WF) calculation followed the method proposed by Hoekstra et al. (2011), which consisted of three components, namely blue (WF_{blue}), green (WF_{green}), and gray (WF_{gray}) water footprints. The total water footprint was calculated as Equation 1.

$$WF = WF_{blue} + WF_{green} + WF_{gray} \quad (1)$$

Since the research was conducted in a protected environment, WF_{gray} was calculated as zero, according to Franke et al. (2013). WF_{green} was also calculated as zero because the research place was protected from rainwater. WFblue was described as the volume of blue water used by the plant (CWU_{blue}) in each production unit (Y). Y was referred to as the melon fruit weight. WF_{blue} was calculated as Equation 2.

$$WF_{blue} = \frac{CWU_{blue}}{Y} \quad (2)$$

CWU_{blue} was described as plant evapotranspiration from blue water (ET_{blue}) during the growth period (lgp) in the day unit. CWU_{blue} was converted according to the area of the growth media in a 22 cm diameter polybag and calculated as 0.037994 m^2 (Equation 3). The growth period of the melon plant studied was approximately 70 days. ET_{blue} was calculated as crop evapotranspiration (ETc) since the research place was protected from rainfall (effective rainfall (P_{eff}) equaled zero), as in Equation 4.

$$CWU_{blue} = 0.037994 \text{ x } \sum_{d=1}^{lgp} \text{ x } ET_{blue} \quad (3)$$

$$ET_{blue} = \max(0, ET_c - P_{eff}) \quad (4)$$

The melon growth period consists of three phenological stages, according to Peres et al. (2013), which are the initial, intermediate, and final stages. Each of the phenological stages had a specific crop coefficient (Kc), i.e., early stage: 0.20; intermediate stage: 1.10, and final stage: 0.50. The Honey Globe melon plants tested in this study had initial, intermediate, and final stages of approximately 10, 50, and 10 days, respectively. Kc value determined the ETc in each of the phenological stages as well as CWU_{blue}. ETc was obtained by multiplying Kc and reference evapotranspiration (ET_0) (Equation 5).

$$ET_c = K_c \text{ x } ET_0 \quad (5)$$

ET_0 was calculated using Cropwat 8.0 software according to the FAO Penman-Monteith equation proposed by Allen et al. (1998). The climate data required for the ET_0 calculation consisted of minimum temperature, maximum temperature, humidity, wind speed, and duration of exposure.

Data analysis

Data analysis was carried out using analysis of variance (ANOVA). Significant means were further analyzed using Duncan's multiple range test (DMRT). Data was analyzed using SAS 9.4 software.

RESULTS AND DISCUSSION

Melon plants applied with 2.8 mS cm^{-1} nutrient solution (NS) + 60 mg L^{-1} GA_3 produced the fruit with the greatest diameter and significantly greater than the control. The control treatment in this research referred to the standard operating procedure of Tefa SGH Polije. Application of 2.8 mS cm^{-1} NS + 120 mg L^{-1} GA_3 on melon plants produced fruit with a significantly thicker edible part than the control. However, there was no significant difference in the 2.8 mS cm^{-1} NS + 60 mg L^{-1} GA_3 treatment (Table 1). These results were in line with research conducted by Ikhsan & Aini (2023), which showed that spraying gibberellin with a concentration of 20-60 ppm on melon plants significantly increased fruit diameter compared to plants without gibberellin application.

Table 1. Fruit diameter and edible part thickness on various nutrient solution electrical conductivities and GA_3 concentrations.

Treatments	Fruit diameter (cm)	Edible part thickness (cm)
2.8 mS cm^{-1} NS + 0 mg L^{-1} GA_3 (control)	14.10±0.17b	3.07±0.12b
2.8 mS cm^{-1} NS + 60 mg L^{-1} GA_3	15.60±0.40a	3.38±0.20ab
2.8 mS cm^{-1} NS + 120 mg L^{-1} GA_3	14.98±0.91a	3.63±0.32a
3.2 mS cm^{-1} NS + 0 mg L^{-1} GA_3	15.40±0.20a	3.33±0.35ab
3.2 mS cm^{-1} NS + 60 mg L^{-1} GA_3	15.42±0.33a	3.15±0.15b
3.2 mS cm^{-1} NS + 120 mg L^{-1} GA_3	14.07 ± 0.12b	3.17±0.29ab
3.6 mS cm^{-1} NS + 0 mg L^{-1} GA_3	15.03±0.29a	3.17±0.29ab
3.6 mS cm^{-1} NS + 60 mg L^{-1} GA_3	15.03±0.15a	3.03±0.25b
3.6 mS cm^{-1} NS + 120 mg L^{-1} GA_3	14.83±0.42a	3.13±0.15b

Note: Values followed by different letters in the same column were significantly different according to DMRT at α = 5%; NS = nutrient solution; GA_3 = gibberellic acid

GA_3 is one of the plant growth regulators from the gibberellin group. One of the main functions of gibberellin is to stimulate cell division and elongation, which contributes to the growth of fruit diameter. When gibberellin is applied to plants, this hormone will stimulate meristematic activity, increasing the number of cells formed and the volume of tissue, ultimately affecting the size of the fruit (Garmendia et al., 2019). Many studies have been conducted to evaluate the effect of gibberellin on fruit growth. Applying 60 ppm gibberellin could increase the fruit diameter, and 90 ppm gibberellin significantly increases the fruit flesh thickness (Kurniasari et al., 2023). In tomato plants, 45 mg L^{-1} gibberellin treatment increased the thickness of the flesh and the number of fruits (Kasim et al., 2020). In another study, the application of 250 ppm gibberellin on apple plants showed an increase in fruit diameter, as well as improving the size of the fruit. Gibberellic acid intensifies an organ's ability to function as a nutrient sink. It also increases the biosynthesis of IAA in plant tissues, delays the formation of the separation layer, and thus enhances fruit retention (Hassan et al., 2020). The increase in fruit retention could enhance the fruit weight and decrease the water footprint value.

Melon plants treated with 2.8 mS cm^{-1} NS + 60 mg L^{-1} GA_3 produced fruit with higher sweetness levels than control treatments (Tabel 2). The nutrient solution contained potassium and phosphorus, which play crucial roles in the synthesis of sugars within the fruit, increasing the sweetness level. Potassium enhances the sugar content of fruits by facilitating sugar transport throughout the plant. Potassium is critical in transporting sugars, both indirectly through osmotic force and directly influencing phloemic transport. Plants use a K^+ gradient across membranes as an energy source for various transport activities. This method involves the transcription of genes for membrane channels and the modulation of transmembrane potentials to enable the passage of saccharides from cells to the phloem (Ariessandy et al., 2022; Ho et al., 2020). Phosphorus is essential for energy transfer within the plant, enhancing sugar accumulation in fruits (Khan et al., 2023; Wu et al., 2021). Moreover, GA_3 enhances the absorption of essential minerals such as phosphorus, increasing sugar accumulation in fruits. Wang et al. (2024) reported that the application of 30 ppm GA_3 significantly increased the ACPase activity of oilseed flax leaves and phosphorus accumulation during the full growing cycle as well as enhanced the phosphorus accumulation after anthesis and its contribution to grain. These were in line with research conducted by Anjum et al. (2020), which showed that spraying 100 ppm GA_3 on grape plants significantly increased sweetness levels based on total soluble solid content in berries compared to plants without GA_3 application. However, nutrient solution electrical conductivities and GA_3 concentrations tested in this research showed no significant effect on leaf chlorophyll content (Table 2).

Table 2. Fruit sweetness level and leaf chlorophyll content on various nutrient solution electrical conductivities and GA3 concentrations.

Treatments	Sweetness level (°Brix)	Leaf chlorophyll content (unit mm^{-2})
2.8 mS cm^{-1} NS + 0 mg L^{-1} GA_3 (control)	10.50±0.71c	27.47±5.11
2.8 mS cm^{-1} NS + 60 mg L^{-1} GA_3	13.00±0.00a	23.80±3.17
2.8 mS cm^{-1} NS + 120 mg L^{-1} GA_3	12.00±1.00ab	23.97±2.10
3.2 mS cm^{-1} NS + 0 mg L^{-1} GA_3	12.00±0.00ab	22.94±1.29
3.2 mS cm^{-1} NS + 60 mg L^{-1} GA_3	13.00±0.00a	22.79±9.18
3.2 mS cm^{-1} NS + 120 mg L^{-1} GA_3	13.00±1.00a	19.53±6.91
3.6 mS cm^{-1} NS + 0 mg L^{-1} GA_3	12.33±0.58ab	22.76±3.11
3.6 mS cm^{-1} NS + 60 mg L^{-1} GA_3	12.67±0.58ab	20.25±4.04
3.6 mS cm^{-1} NS + 120 mg L^{-1} GA_3	11.67±0.58b	25.45±7.67

Note: Values followed by different letters in the same column were significantly different according to DMRT at α = 5%; NS = nutrient solution; GA_3 = gibberellic acid.

Statistically, nutrient solution electrical conductivities and GA_3 concentrations tested in this research showed no significant effect on fruit weight or the water footprint of melon production. However, the treatment of 2.8 mS cm^{-1} NS + 60 mg L^{-1} GA_3 on melon plants showed a better response than other treatments in quantity (Table 3). The application of 2.8 mS cm^{-1} NS + 60 mg L^{-1} GA_3 on melon plants increased fruit weight by 18.75% and water footprint efficiency by 15.48% compared to the control treatment. As the fruit weight increased, the water footprint decreased, indicating increased efficiency in using water resources.

Table 3. Fruit weight and water footprint on various nutrient solution electrical conductivities and GA_3 concentrations.

Treatments	Fruit weight (kg)	Water footprint (L kg^{-1})
2.8 mS cm^{-1} NS + 0 mg L^{-1} GA_3 (control)	1.28±0.10	8.85±0.70
2.8 mS cm^{-1} NS + 60 mg L^{-1} GA_3	1.52±0.11	7.48±0.55
2.8 mS cm^{-1} NS + 120 mg L^{-1} GA_3	1.47±0.35	7.94±1.79
3.2 mS cm^{-1} NS + 0 mg L^{-1} GA_3	1.37±0.08	8.30±0.55
3.2 mS cm^{-1} NS + 60 mg L^{-1} GA_3	1.34±0.09	8.46±0.58
3.2 mS cm^{-1} NS + 120 mg L^{-1} GA_3	1.37±0.15	8.31±0.97
3.6 mS cm^{-1} NS + 0 mg L^{-1} GA_3	1.32±0.13	8.62±0.93
3.6 mS cm^{-1} NS + 60 mg L^{-1} GA_3	1.43±0.14	7.95±0.85
3.6 mS cm^{-1} NS + 120 mg L^{-1} GA_3	1.30±0.10	8.74±0.68

Note: NS = nutrient solution; GA_3 = gibberellic acid.

The water footprint calculation in this study was based on blue crop water usage (CWU_{blue}), which was the accumulation of melon plant evapotranspiration on the surface area of the media in the polybag during the growth period. Based on the melon growth phase, CWU_{blue} was measured in the initial, intermediate, and final phases with durations of 10, 50, and 10 days, respectively. The total CWU_{blue} in each melon plant tested was 11.31 L, which distributed the most water usage in the intermediate phase, up to 89% (Figure 2). Melon plants in the intermediate phase had the largest crop coefficient (Kc) value and the longest growth period. Kc value will affect plant evapotranspiration. The higher the Kc value, the more water is consumed by plants during a certain growing period (Allen et al., 1998; Peres et al., 2013).

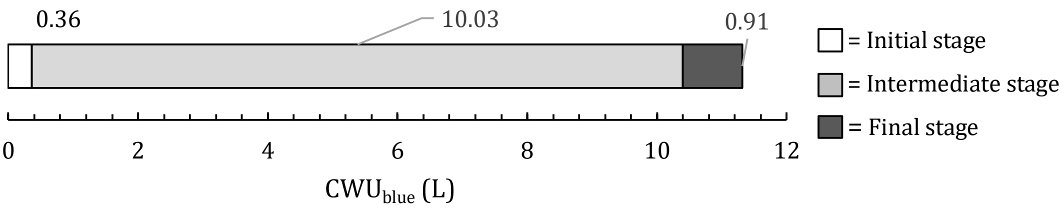

Figure 2. CWU_{blue} during the initial, intermediate, and final stages.

The lower the water footprint value, the more efficient the water usage for production in crop cultivation. Melon plants applied with 2.8 mS cm^{-1} NS + 60 mg L^{-1} GA_3 had the highest water use efficiency, which was related to fruit production with the greatest weight (Table 3). Water footprint had an inverse or negative relationship with several observed production variables with a very strong correlation to fruit weight. In addition, there was a significant influence between fruit weight and water footprint. Based on the determination coefficient value, fruit weight had a 97.98% effect on water footprint (Figure 3).

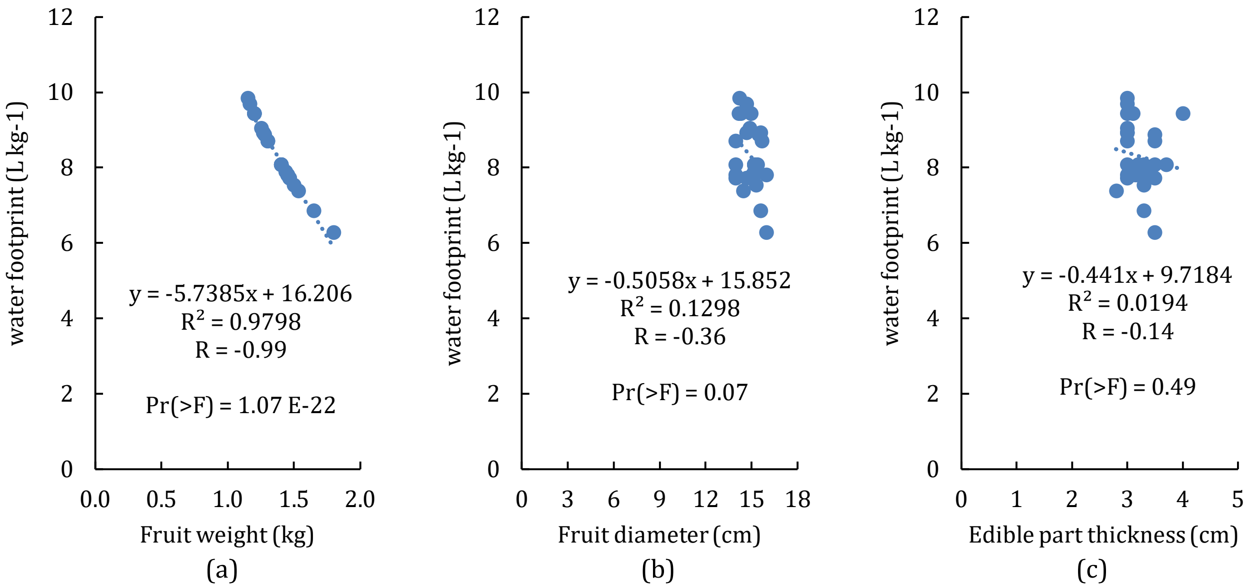

Figure 3. Regression of several production variables on water footprint: (a) fruit weight, (b) fruit diameter, (c) edible part thickness.

Nutrient management of melon cultivation in Tefa SGH Polije, which was set as the control treatment (2.8 mS cm^{-1} NS + 0 mg L^{-1} GA_3), produced fruit with a weight that was not significantly different from other treatments. However, its standard operating procedures can still be improved. Fruit diameter, edible part thickness, and sweetness level of melon fruit could be significantly increased by adding 60 mg L^{-1} GA_3. Besides, although the effect was not statistically significant, water use efficiency increased based on the water footprint value assessed in this study. Thus, by applying such nutrient and plant growth regulator management, melon cultivation can produce fruit with excellent quantity and quality and efficiently use water resources.

CONCLUSIONS

Based on the research results, the application of 2.8 mS cm^{-1} NS + 60 mg L^{-1} GA_3 was the best nutrient and plant growth regulator management on melon cultivation according to fruit diameter (15.60 cm), edible part thickness (3.38 cm) and fruit sweetness level (13 ^{o}Brix). Although statistically, it had no significant effect, 2.8 mS cm^{-1} NS + 60 mg L^{-1} GA_3 treatment increased fruit weight by 18.75% and water footprint efficiency by 15.48% compared to control.

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