JAPSI (Journal of Agriprecision and Social Impact)
Volume 3 Issue 3 November 2026
e-ISSN: 3032-7849; p-ISSN: 3046-5397, Page 490-513
DOI: https://doi.org/ 10.62793/japsi.v3i3.136
Available online at: https://journal.kdp.co.id/index.php/japsi

Root-Zone Conditions and Fruit Performance of Greenhouse Melon Under Nine Fertigation-Volume and Subtrate Combinations

Sisca Fajriani
Faculty of Bio-Industrial Agriculture and Forestry, Universitas Brawijaya, Malang, Indonesia

Tri Sudaryono
National Research and Innovation Agency, Indonesia

Rifdatul Khoir Rahmat
Faculty of Bio-Industrial Agriculture and Forestry, Universitas Brawijaya, Malang, Indonesia

Address: Jl. Veteran, Ketawanggede, Malang City, East Java, Indonesia
Corresponding author: sisca.fp@ub.ac.id

Abstract. *Substrate-hydroponic melon production requires coordinated irrigation and growing-medium management. This study compared nine combinations of field-capacity-derived daily nutrient-solution volume (100%, 75%, or 50% of the medium-specific nominal dose) and substrate (cocopeat, rice-husk charcoal, or their 1:1 w/w mixture) in greenhouse-grown 'Sweet Lavender' melon. A completely randomized design comprised three independent units per combination (27 units); plant subsamples were averaged within units. Daily doses were divided equally between morning and afternoon. Substrate temperature and moisture were recorded at 05:00 and 13:00 on five dates. One-way ANOVA, Tukey HSD, exploratory Pearson correlations, and moisture permutation sensitivity tests were applied. At 42 days after transplanting (DAT), 13:00 substrate temperature reached 29.50 °C in P5 and P8 versus 26.67 °C in P1 and P7. Stem diameter at 28 DAT ($p = 0.034$) and root volume ($p = 0.045$) had significant omnibus ANOVAs but no significant Tukey pairs. Mean fruit weight ranged from 881.67 g plant^{-1} in P8 to 1165.00 g plant^{-1} in P1; numerical maximum total soluble solids was 14.50 °Brix in P4, P6, and P9. Moisture contrasts persisted in omnibus rank-permutation tests, but the restored Takemura DM-15 readings represent a 1–8 index, not calibrated percentage water content. No combination was superior for all traits. Interpretation remains limited by three replicates, uncalibrated moisture indices, and confounded water and nutrient delivery.*

Keywords: *Cucumis melo, Cocopeat, Rice-husk charcoal, Root-zone microclimate, Substrate hydroponics*

Received: September 26, 2026 ; Accepted: October 29, 2026 ; Published: November 20, 2026
*Corresponding author, e-mail address sisca.fp@ub.ac.id

INTRODUCTION

Greenhouse melon production can reduce exposure to external weather variability, but it does not eliminate the need to manage water, nutrients, and root-zone physical conditions. In substrate systems, irrigation amount and substrate hydraulic properties jointly determine how rapidly water is retained, redistributed, and lost from the root zone. These processes are especially important for melon because fruit expansion and soluble-solids accumulation respond to water availability, while excessive or poorly timed water supply can also alter fruit quality. Recent greenhouse studies therefore increasingly treat irrigation scheduling as a stage-specific management problem rather than a single fixed percentage applied throughout the crop cycle (Aulia et al., 2022; Fang et al., 2026; Xue et al., 2025).

Substrate properties modify the response to solution delivery, but rice husk, rice-husk charcoal, and rice-husk ash are distinct materials. In tomato, Adekiya et al. (2022) found substrate-dependent water-holding capacity and growth; Prompukdee et al. (2023) documented differing retention among coir-based mixtures. M. Li et al. (2024) studied rice-husk ash blends in cucumber and melon, providing evidence for formulation-specific physical and crop responses rather than direct validation of the charcoal used here. Melon studies have examined growing media and field-capacity treatments (Aldiansyah & Hariyono, 2022), substrate volume and irrigation frequency (Andrade et al., 2022), substrate and nutrient-solution EC (Ariessandy et al., 2022), irrigation delivery with growing media (Carsidi et al., 2021), nutrient-solution amount, EC, and frequency (Sun et al., 2023), and media–variety combinations (Yulidasari et al., 2026). These studies motivate evaluating treatment-specific root-zone readings alongside growth and fruit responses without assuming a universally favorable substrate.

In this experiment, a gravimetric water fraction after saturation and drainage was used operationally to define substrate-specific daily nutrient-solution volumes at nominal levels of 100%, 75%, and 50%. These levels defined delivery volumes rather than continuously maintained substrate water contents. Because nutrients were delivered in the irrigation solution, contrasts concern combined water and nutrient delivery within the tested substrates.

Plant subsamples were averaged within each experimental unit, and the analysis retained one-way comparisons among nine treatment combinations. Although the

treatment structure resembles a 3 × 3 factorial, the manuscript makes no claims about separate main effects or interactions because the original analysis treated the nine combinations as the comparison groups and the absolute irrigation volumes differed among substrates.

This study aimed to assess how field-capacity-derived irrigation volumes combined with cocopeat, rice-husk charcoal, or a mixture of the two influenced time-specific root-zone temperature and moisture readings, vegetative and root growth, harvest timing, fruit dimensions, fruit fresh weight, and total soluble solids of greenhouse-grown melon. Previous studies have already examined irrigation and growing media in melon (Aldiansyah & Hariyono, 2022; Carsidi et al., 2021). The specific contribution here is the joint assessment of time-specific substrate readings and multiple growth and fruit responses of Sweet Lavender under a fixed daily, substrate-specific solution-volume schedule, rather than the first use of these treatment factors. The testable hypothesis was that at least one of the nine treatment-combination means differed for each response; no separate water-only, nutrient-only, or factorial interaction hypothesis was tested.

LITERATURE REVIEW

Melon fruit performance in substrate culture depends on coordinated management of the rooting medium and nutrient-solution supply. In protected cantaloupe, Andrade et al. (2022) found that substrate volume affected fruit mass and soluble solids, whereas irrigation frequency did not significantly affect soluble solids. Their soil-containing medium differs from the soilless substrates evaluated here. More directly, Sun et al. (2023) demonstrated that solution amount and electrical conductivity affected yield and aroma in bag-grown melon. In a cucumber–melon cascade hydroponic system, Naounoulis et al. (2024) evaluated water and nutrient reuse. Together, these studies support examining solution delivery and substrate conditions jointly, without attributing combined fertigation responses exclusively to water supply.

Substrate aeration also requires careful interpretation. In a physical characterization of biochar-based media, rather than a melon crop experiment, Banitalebi et al. (2024) showed that appreciable air-filled porosity did not necessarily indicate high oxygen diffusivity. This supports a possible role for gas transport, but does not establish that rice-husk charcoal improves oxygen supply to melon roots. Oxygen availability remains a

mechanistic hypothesis when oxygen concentration, diffusivity and root respiration are not measured.

Evidence from other crops provides methodological guidance rather than direct confirmation in melon. Li et al. (2024) compared sensor-, radiation- and evapotranspiration-based irrigation schedules for cucumber in coconut coir and documented differences in water dynamics. Evaporative cooling is a candidate explanation requiring an independent energy-balance test, not a demonstrated mechanism of the present experiment. Two daily substrate-temperature readings cannot distinguish evaporation from differences in radiation, heat storage, shading or thermal properties.

Fruit quality likewise should not be reduced to a simple water-deficit response. Using sugar quantification and gene-expression measurements in two melon cultivars, Stroka et al. (2024) linked sugar metabolism to maturation characteristics. Such findings provide biological context for soluble-solids differences, but do not demonstrate altered assimilate partitioning in ‘Sweet Lavender’. Total soluble solids (°Brix) do not quantify carbon allocation or individual sugar fluxes. Accordingly, the present study assesses observed responses to nine nominal fertigation-volume–substrate combinations; oxygen supply, evaporative cooling and assimilate partitioning remain literature-supported hypotheses requiring direct measurement. Uncalibrated DM-15 indices cannot establish absolute substrate water content or plant-available water.

RESEARCH METHODS

Study site and plant material

The experiment was conducted from November 29, 2025, to March 9, 2026, in a greenhouse at Sengkkrajan, Bedali Village, Lawang Subdistrict, Malang Regency, East Java, Indonesia. Seedlings of ‘Sweet Lavender’ melon (Cucumis melo L.) were transplanted 13 days after sowing into 26-cm-diameter polybags filled with 2 kg of substrate. The substrates consisted of cocopeat, rice-husk charcoal, and a 1:1 (w/w) cocopeat–rice-husk charcoal mixture.

Treatment combinations and experimental units

Nine treatment combinations were evaluated: P1, 100% + cocopeat; P2, 100% + rice-husk charcoal; P3, 100% + 1:1 mixture; P4, 75% + cocopeat; P5, 75% + rice-husk charcoal; P6, 75% + mixture; P7, 50% + cocopeat; P8, 50% + rice-husk charcoal; and P9, 50% + mixture. Treatments were arranged in a completely randomized design with three

randomized replicates, giving 27 independent experimental units. Each experimental unit contained two polybags and four plants (two plants per polybag). The sampling diagram identified two plants for growth responses and two plants for yield responses; those plant measurements were treated as subsamples and averaged to one value per experimental unit. Repeated observations at different DAT were retained as repeated measurements within the same unit rather than additional independent replicates. For each growth response, the two designated growth-plant observations were averaged; the two designated yield-plant observations were averaged separately for fruit responses. Thus, four plants did not provide four independent replicates of each response. The design comprised 54 polybags and 108 plants. The exact allocation of substrate-probe readings between the two bags was not documented. A prospective sample-size or power calculation was not documented, and three independent units per combination limit power and precision.

Field-capacity-based solution volume and crop management

For each substrate, the nominal reference volume was derived from a gravimetric procedure: substrate in a polybag was saturated until drainage occurred, allowed to drain for 24 h, weighed, and oven-dried at 105 °C for 24 h before reweighing. Drained/dry sample masses were 500/162.60 g for cocopeat, 500/190.00 g for rice-husk charcoal, and 500/107.40 g for the mixture. The operational water fraction was f = (drained mass − dry mass)/drained mass, giving 0.6748, 0.6200, and 0.7852. The dosing calculation was V100 = 2000 × f mL per 2-kg polybag; V75 = 0.75 × V100 and V50 = 0.50 × V100 (Table 1). This wet-mass-based calculation defined the experimental doses; it does not establish a dry-mass-based water content, actual container water storage, or a daily crop water requirement. The moisture basis of the 2-kg substrate mass was not specified. No evapotranspiration, drainage-balance, or plant-demand validation of the fixed daily doses was documented.

The assigned volume was the total daily amount, applied manually to the root zone using a measuring cylinder in the morning and afternoon from transplanting to harvest, rather than the amount for each application. The total daily volume was divided equally between the two applications: 50% in the morning and 50% in the afternoon. Substrates received 300 ppm AB-mix before planting. During cultivation, the stated concentration schedule was 300 ppm initially, 800 ppm at 14 DAT, 1000–1200 ppm around female

flowering at 28 DAT, 1800 ppm during fruit growth, and 2000 ppm during net formation. No separate concentration schedule compensating for treatment volume was specified. Consequently, at a common concentration, lower daily solution volumes also delivered smaller amounts of dissolved nutrients. Exact elemental nutrient masses cannot be reconstructed without solution composition and application records; water and nutrient effects cannot be separated.

Foliar supplements were Gandasil D at 3 g L^{-1} during vegetative growth, Gandasil B at 3 g L^{-1} during reproductive growth, and KNO3 at 2 g L^{-1} during reproductive growth; spray frequency and volume were not specified. Plants were spaced 60 cm between polybags and 100 cm between rows, with two plants 14 cm apart within each bag. Plants were trained vertically and pollinated manually at 06:00–10:00. One fruit per plant was retained at 35–38 DAT, the main stem was topped at approximately 30 leaves or 48 DAT, and leaves below the retained fruit were removed at 55 DAT. Harvest criteria were yellow-orange to orange skin and complete netting extending to the stalk base.

Measurements

Substrate temperature was measured with a rod thermometer inserted to 5 cm depth and read after 1 min; substrate moisture was measured with a Takemura DM-15 soil moisture tester (Takemura Electric Works, Japan) inserted to 8 cm depth. Measurements were made at 05:00 and 13:00 at 7, 14, 28, 42, and 56 DAT. These times are reported directly rather than described as daily minimum and maximum because continuous daily extremes were not measured. Stem diameter was measured 5 cm above the stem base at 7, 14, 21, 28, 35, 42, 49, 56, and 63 DAT. Male and female flowering time, root length, root volume by water displacement, harvest age, fruit weight, fruit diameter, fruit length, and TSS (handheld refractometer, °Brix) were recorded. Roots were measured after harvest, with length measured from the base to the tip and root volume determined as the displacement from an initial 120 mL of water. Individual fruit weight was measured using a digital balance; one retained fruit per plant underlies the g $plant^{-1}$ notation. Fruit diameter was measured at the widest transverse position and fruit length from base to tip. Juice expressed from a thin fruit slice onto the refractometer prism was used for TSS. The DM-15 moisture scale runs from 1 to 8 (Takemura Electric Works, n.d.). Instrument readings were multiplied by 10 during data recording. Before calculating unit means and reporting results, all recorded moisture observations were divided uniformly by 10 to

restore the original 1–8 DM-15 scale. This arithmetic rescaling is not a calibration to water content. No substrate-specific calibration against gravimetric or volumetric water content was performed. Results are expressed as dimensionless DM-15 moisture-index values, not percentage water content. The validity of quantitative comparisons across the three substrate types remains unverified. The interval between fertigation and measurement was not recorded. Concurrent greenhouse-air temperature, relative humidity, and radiation records were unavailable; regional climate descriptions cannot substitute for greenhouse measurements.

Statistical analysis

Paired plant observations were averaged at the experimental-unit level. For each response, the two plant subsamples were averaged to one experimental-unit value, giving $n = 3$ independent replicates per treatment. Each age was analyzed separately for repeated variables. A one-way ANOVA compared the nine treatment combinations at $\alpha = 0.05$; when the omnibus test was significant, Tukey honestly significant difference (HSD) tests were used for pairwise comparisons at $\alpha = 0.05$. This preserves the original combination-level research question and avoids unsupported statements about factorial main effects or interactions. Pearson correlations were exploratory and used 27 unit-level observations: each environmental variable was averaged across five dates per unit, stem diameter across nine dates, and the remaining variables used their unit means. Two-sided unadjusted $p < 0.05$ was the primary exploratory threshold; Benjamini–Hochberg false-discovery-rate adjustment was applied as a sensitivity analysis to one family of 40 tests: four environmental variables crossed with ten growth and fruit responses. Table 5 displays a subset of this family. Adjusted values are denoted q, with $q < 0.05$ used to assess sensitivity to multiple testing.

Correlations are interpreted as associations and may partly reflect treatment-group structure. Calculations used Microsoft Excel, IBM SPSS Statistics, and Python 3.12.14 and SciPy 1.17.0. Residual normality was examined using Shapiro–Wilk tests, and equality of group dispersions using median-centered Levene tests. With only three units per combination, these diagnostics have limited power, and a non-significant diagnostic result does not establish that assumptions hold. ANOVAs were conducted separately by endpoint and date, without familywise adjustment across all 38 omnibus tests; secondary findings are therefore interpreted cautiously. For the ten moisture response-by-date

datasets, an additional randomization sensitivity analysis used a Kruskal–Wallis-equivalent rank statistic and 99,999 permutations of the 27 experimental-unit labels (seed 20261101); Monte Carlo p = (b + 1)/(99,999 + 1). Holm adjustment covered these ten omnibus tests. For each dataset, two-sided exact pairwise permutation tests enumerated all 20 allocations of six units into two groups of three, with Holm adjustment across 36 pairs. Their minimum attainable two-sided p is 0.10; they cannot establish pairwise significance at 0.05 with this replication. Randomization tests assess exchangeable-label null hypotheses, not isolated mean shifts under arbitrary unequal distributions, and do not validate the moisture scale.

Supplementary Tables S1–S4 report diagnostics, sensitivity results, correlations, and unit-level summaries; all 38 ANOVAs are exploratory with respect to endpoint selection. Uniform division of moisture values by 10 rescales means, SD, SE and Tukey HSD thresholds by 1/10 and sums and mean squares by 1/100. It leaves F statistics, ANOVA p values, Tukey pairwise p values and groupings, and Pearson correlation coefficients and their p values unchanged. This numerical invariance does not validate the moisture index as an equal-interval or calibrated water-content measure.

Table 1. Treatment combinations and nominal nutrient-solution delivery volumes

Code	Treatment combination	Nominal daily nutrient-solution volume (mL per 2-kg polybag)
P1	100% + cocopeat	1349.60
P2	100% + rice-husk charcoal	1240.00
P3	100% + cocopeat:rice-husk charcoal (1:1)	1570.40
P4	75% + cocopeat	1012.20
P5	75% + rice-husk charcoal	930.00
P6	75% + cocopeat:rice-husk charcoal (1:1)	1177.80
P7	50% + cocopeat	674.80
P8	50% + rice-husk charcoal	620.00
P9	50% + cocopeat:rice-husk charcoal (1:1)	785.20

The percentages indicate nutrient-solution delivery volumes calculated from the nominal field capacity of each substrate, not substrate moisture contents maintained continuously at those values. The entries are prescribed daily doses, not independently logged cumulative irrigation inputs. The gravimetric calculation is an operational treatment definition, not evidence that the daily volume matches crop water demand. Daily solution was allocated 50% to each application. Mixtures were 1:1 by mass.

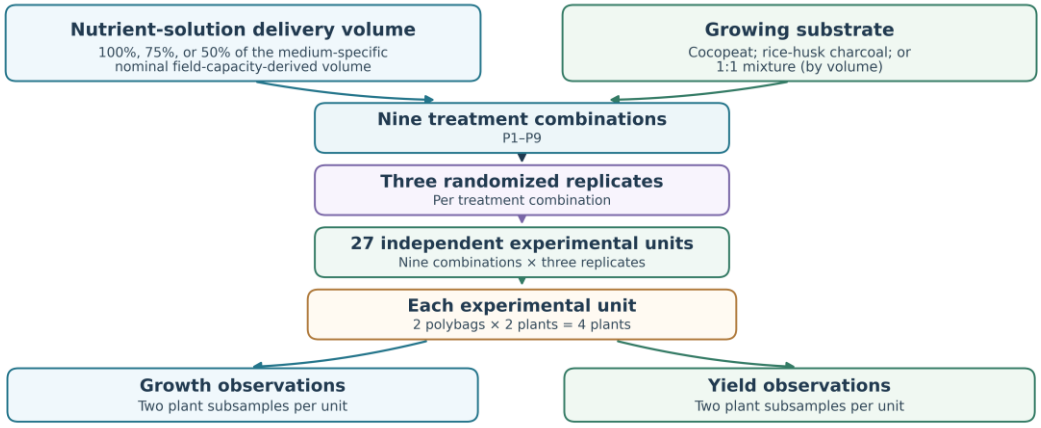


Figure 1. Experimental hierarchy and unit of analysis. Plant subsamples were averaged within each experimental unit; repeated observation dates did not constitute additional independent replicates. The cocopeat–rice-husk charcoal mixture was prepared at a 1:1 ratio by mass (w/w). Each daily dose was applied as 50% in the morning and 50% in the afternoon; this timing did not create additional replicates.

RESULTS AND DISCUSSION

Substrate moisture-index patterns

Recorded moisture-index values differed strongly among combinations. At 28 DAT, 05:00 values ranged from 7.8333 to 8.0000 index units in cocopeat-containing substrates and from 3.3333 to 4.0833 index units in rice-husk-charcoal treatments (Table 2; ANOVA $p < 0.001$). P5 (4.0833 index units) exceeded P8 (3.3333 index units) under the nominal Tukey analysis; P2 (3.6667 index units) did not differ from either. This specific P5–P8 result was not confirmed by the two-sided exact pairwise permutation test (unadjusted $p = 0.10$; Holm $p = 1.00$). At 13:00, corresponding ranges were 7.1667–8.0000 and 2.7500–3.2500 index units. All ten omnibus moisture contrasts remained detectable in rank-permutation sensitivity analyses (Holm-adjusted Monte Carlo $p = 0.00010$; Table S2). This supports distributional separation of recorded scores, not calibrated water-content differences or every Tukey pair. The indices are not calibrated water contents; substrate-specific instrument response remains unverified. The nominal Tukey HSD threshold at 05:00 on 28 DAT was 0.6456 index units; the P5–P8 mean difference was 0.7500 index units.

The moisture-index separation could reflect substrate hydraulic behavior, but instrument–substrate interactions are an alternative explanation. In cucumber Dutch-

bucket production, organic substrates including coir changed drainage relative to perlite (T. Yang et al., 2023). Water retention, air-filled porosity, and oxygen diffusivity are not interchangeable: Banitalebi et al. (2024) showed that appreciable air-filled porosity did not necessarily imply high oxygen diffusivity in biochar-based media. No moisture-release curves, matric potentials, or oxygen measurements were obtained here. Residual Shapiro–Wilk tests indicated non-normality for all ten moisture analyses ($p < 0.006$); median-centered Levene testing also detected unequal dispersion at 13:00 on 42 DAT ($p = 0.045$; Table S1). The nominal ANOVA and Tukey results therefore require qualification despite the omnibus permutation evidence.

Measurements at 05:00 and 13:00 provide two observations rather than a daily water balance. Y.-L. Li et al. (2024) demonstrated schedule-dependent coir moisture trajectories in cucumber using sensor-, radiation-, and evapotranspiration-based scheduling. Here, the interval between fertigation and readings was not recorded, so the observations cannot quantify evaporation or transpiration. Repeated index values of 8.00 coincide with the upper DM-15 scale mark and may indicate ceiling effects. Neither a percentage conversion nor an equal-interval interpretation of the DM-15 index has been validated.

Morning and midday root-zone thermal responses

Afternoon heating was also substrate-dependent. At 42 DAT, 13:00 substrate temperature was 29.50 °C in P5 and P8 but only 26.67 °C in P1 and P7 ($p < 0.001$), whereas 05:00 temperatures differed by only about 1.3 °C between the lowest and highest treatment means ($p = 0.008$). Similar afternoon patterns occurred at the other dates, with rice-husk-charcoal media generally warmer than cocopeat-containing media. Coir-containing mixtures have shown formulation-dependent water retention in other systems (Adekiya et al., 2022; Prompukdee et al., 2023), but this does not establish the thermal mechanism in the present substrates. Nevertheless, the present study did not directly measure substrate porosity, hydraulic conductivity, or evaporation, so those mechanisms remain literature-supported explanations rather than measured causal pathways.

Substrate warming reflects net incoming energy, volumetric heat capacity of the solids–water–air mixture, conductive transport, and latent heat losses. Higher water content can theoretically increase heat-storage capacity and dampen temperature fluctuations, although thermal conductivity also changes with bulk density and particle

contacts. Accordingly, the 13:00 contrast at 42 DAT (29.50 °C in P5/P8 versus 26.67 °C in P1/P7) establishes a treatment-associated thermal difference, not a unique role for dark particle color, absorbed radiation, or evaporative cooling. Reflectance, thermal properties, radiation, and evaporation were not measured.

Root-zone temperature may influence root metabolism, water viscosity, mineral uptake, and root–shoot coordination, yet direction and magnitude depend on the initial temperature relative to each species' optimum. Bi et al. (2022) manipulated heating methods in cucumber under cool-season greenhouse conditions and reported altered growth and photosynthetic responses. Their result underscores thermal context rather than proving that 29.50 °C causes injury in the present melon crop. The lack of coincident greenhouse-air temperature and radiation records also prevents attribution of all thermal variation to substrate composition. The defensible inference is that rice-husk-charcoal combinations produced higher 13:00 substrate readings under the tested schedule, motivating a controlled examination of hydraulic and thermal pathways.

Table 2. Selected root-zone measurements (mean ± SE, n = 3 independent experimental units)

Code	DM-15 moisture index 05.00 — 28 DAT (dimensionless)	DM-15 moisture index 13.00 — 28 DAT (dimensionless)	Temperature 05:00 42 DAT (°C)	Temperature 13:00 42 DAT (°C)
P1	8.0000 ± 0.0000 c	8.0000 ± 0.0000 b	24.00 ± 0.00 b	26.67 ± 0.17 a
P2	3.6667 ± 0.1667 ab	2.8333 ± 0.7407 a	23.83 ± 0.17 ab	28.17 ± 0.17 bcd
P3	7.8333 ± 0.1667 c	7.1667 ± 0.3333 b	23.00 ± 0.29 ab	27.50 ± 0.29 abc
P4	8.0000 ± 0.0000 c	8.0000 ± 0.0000 b	23.67 ± 0.17 ab	27.00 ± 0.29 ab
P5	4.0833 ± 0.0833 b	3.2500 ± 0.1443 a	22.67 ± 0.44 a	29.50 ± 0.29 d
P6	8.0000 ± 0.0000 c	7.5833 ± 0.1667 b	24.00 ± 0.00 b	27.00 ± 0.50 ab
P7	8.0000 ± 0.0000 c	8.0000 ± 0.0000 b	23.50 ± 0.29 ab	26.67 ± 0.17 a
P8	3.3333 ± 0.3005 a	2.7500 ± 0.1443 a	23.00 ± 0.29 ab	29.50 ± 0.00 d
P9	8.0000 ± 0.0000 c	7.9167 ± 0.0833 b	23.33 ± 0.17 ab	28.50 ± 0.29 cd

Within each column, means sharing at least one letter do not differ by Tukey HSD ($\alpha = 0.05$). Omnibus p values: moisture at 05:00, 28 DAT < 0.001; moisture at 13:00, 28 DAT < 0.001; temperature at 05:00, 42 DAT = 0.008; temperature at 13:00, 42 DAT < 0.001. Moisture means and SE use the original dimensionless DM-15 index after division of recorded values by 10; they are not percentage water contents. Moisture letters describe the nominal parametric Tukey analysis; exact pairwise sensitivity tests did not confirm those pairwise distinctions (Table 2). Zero SE denotes identical recorded unit values, not proven absence of physical variation or measurement error.

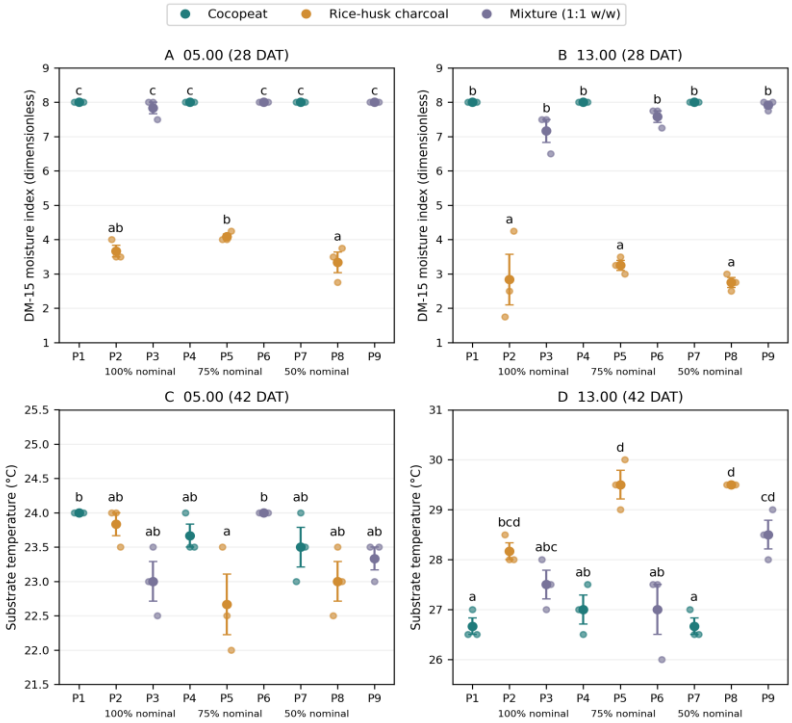


Figure 2. Root-zone moisture readings and substrate temperature at two observation times across nine treatment combinations.

Panels A and B show substrate moisture readings at 05:00 and 13:00 (28 DAT), while panels C and D show substrate temperatures at 05:00 and 13:00 (42 DAT). Small symbols represent the three independent experimental-unit observations; larger symbols indicate treatment means, with error bars denoting SE (n = 3). Letters indicate Tukey HSD groupings within each panel ($\alpha = 0.05$). Moisture is plotted on the original dimensionless DM-15 index scale after dividing recorded values by 10; the instrument was not calibrated to water content. Moisture letters are nominal Tukey results and were not confirmed by exact pairwise sensitivity tests; see Table S2. The two observation times do not represent daily extremes.

Trait-specific vegetative growth and root responses

Treatment effects on stem diameter emerged during crop development. At 28 DAT the one-way ANOVA was significant ($F = 2.78$, $p = 0.034$), but Tukey HSD did not identify any significant pair among the nine treatment means; all treatments therefore share the same pairwise grouping in Table 3. This is statistically possible because the omnibus F test and the family-wise-error-controlled Tukey comparisons answer different questions and have different power. By 42 DAT, P1 had a stem diameter of 10.38 mm

and was significantly larger than P2 (8.47 mm) and P5 (8.27 mm). At 63 DAT, P1 (12.25 mm) and P4 (11.67 mm) were significantly larger than P5 (9.57 mm), while intermediate treatments overlapped both groups.

Stem diameter integrates cell expansion, carbon allocation, and plant water relations, so its response need not mirror an instantaneous substrate-moisture reading. The progression from an omnibus effect without significant Tukey contrasts at 28 DAT to detectable pairwise contrasts at later dates should not be taken as proof of a discrete physiological shift. An independent melon study that varied water and fertilizer linked irrigation and nutrient supply to biomass and photosynthetic responses (Z. Yang et al., 2023). These processes were not measured here, and carbon-assimilation limitation therefore remains a plausible explanation rather than an observed mediator.

Table 3. Selected vegetative growth and root traits (mean ± SE, n = 3 independent experimental units).

Code	Stem diameter 28 DAT (mm)	Stem diameter 42 DAT (mm)	Stem diameter 63 DAT (mm)	Root length (cm)	Root volume (cm^3)
P1	8.75 ± 0.74 a	10.38 ± 0.09 b	12.25 ± 0.51 b	54.50 ± 0.58 cd	29.00 ± 3.21 a
P2	6.52 ± 0.15 a	8.47 ± 0.19 a	10.70 ± 0.34 ab	62.33 ± 0.73 e	25.33 ± 1.45 a
P3	7.68 ± 0.27 a	8.87 ± 0.22 ab	10.70 ± 0.41 ab	56.50 ± 0.58 d	21.67 ± 1.20 a
P4	8.12 ± 0.81 a	9.47 ± 0.79 ab	11.67 ± 0.85 b	56.50 ± 0.58 d	20.33 ± 1.20 a
P5	6.90 ± 0.46 a	8.27 ± 0.39 a	9.57 ± 0.26 a	52.50 ± 0.58 c	25.33 ± 2.60 a
P6	8.37 ± 0.26 a	9.82 ± 0.15 ab	11.18 ± 0.26 ab	45.50 ± 0.58 a	27.67 ± 1.45 a
P7	7.50 ± 0.48 a	9.03 ± 0.15 ab	10.48 ± 0.29 ab	56.50 ± 0.58 d	26.33 ± 3.38 a
P8	7.00 ± 0.28 a	8.70 ± 0.13 ab	10.68 ± 0.15 ab	48.50 ± 0.58 b	22.33 ± 0.88 a
P9	8.48 ± 0.32 a	9.53 ± 0.34 ab	11.22 ± 0.30 ab	48.50 ± 0.58 b	20.00 ± 0.58 a

Tukey HSD letters compare treatment means within each column. Omnibus p values: stem diameter at 28 DAT = 0.034; 42 DAT = 0.007; 63 DAT = 0.018; root length < 0.001; root volume = 0.045. Stem diameter at 28 DAT and root volume measured after harvest showed significant omnibus ANOVA results but no significant Tukey pairwise differences.

Root length and root volume did not show the same treatment ranking. P2 produced the longest roots (62.33 cm) and differed from all other combinations, whereas P6 had the shortest roots (45.50 cm; $p < 0.001$). Root volume showed a significant omnibus effect ($F = 2.59$, $p = 0.045$), but no Tukey pair was significant; means ranged from 20.00 cm^3 in P9 to 29.00 cm^3 in P1. Thus, the experiment supports treatment heterogeneity in overall root-volume means, but it does not support naming a specific pair as different at the Tukey

5% level. Longer roots in P2 do not demonstrate improved aeration: pore structure and root oxygen status were not measured.

Root length alone cannot represent living fine-root surface area, hydraulic conductance, or net nutrient uptake. The long roots in P2 did not coincide with the greatest fruit mass, indicating different response rankings rather than a demonstrated compensatory mechanism. Cucumber substrate experiments also show that vegetative and reproductive rankings can diverge (T. Yang et al., 2023). Fine-root traits, root respiration, and plant water potential would be needed to test functional explanations.

Reduced fruit performance under low solution volume and rice-husk charcoal

Harvest and fruit traits indicated the most consistent disadvantage for P8, the 50% nominal solution-volume treatment with rice-husk charcoal (Table 4; Figure 3). P1 had the highest mean fruit fresh weight (1165.00 g plant^{-1}), whereas P8 had the lowest (881.67 g plant^{-1}), corresponding to a 24.3% lower mean relative to P1; they belonged to different Tukey groups ($p < 0.001$). P8 also produced the smallest fruit diameter (11.07 cm) and shortest fruit length (15.17 cm). P1 was harvested at 69.17 DAT compared with 75.83 DAT for P5. Harvest in P6 occurred at 74.67 DAT, significantly later than in P1.

The fruit-mass contrast between P1 and P8 (1165.00 versus 881.67 g plant−1) is better framed as an integrated response to root-zone conditions and nutrient-solution supply. Fruit expansion requires water influx for cell enlargement together with carbon and mineral delivery for dry-matter accumulation. In melon, Z. Yang et al. (2023) independently crossed irrigation and fertilizer rates and showed that both affected plant growth and yield; greenhouse watermelon fertigation work likewise emphasizes stage-specific coordination of root uptake and nutrient supply (Bao et al., 2023). In the present study, the 50% nominal volume for P8 also reduced the total AB-mix solution applied at a given nominal concentration. Hence, the lower fruit weight cannot be ascribed solely to substrate water deficit.

Neither a long root system nor a relatively large stem at one stage necessarily guarantees large fruits. The fruit sink also depends on flowering timing, active source leaves, fruit selection, and assimilate partitioning. Fruiting-branch position altered fruit dimensions in fertigated melon in a separate greenhouse experiment (Ikhwana et al., 2025). Cultivated melons also undergo developmental changes in phloem unloading

associated with fruit enlargement and subsequent sucrose accumulation (Zhou et al., 2023). These provide plausible biological context, but fruit position, functional leaf area, carbon assimilation, and assimilate transport were not assessed in the present experiment. Delayed harvest in some treatments could reflect distinct developmental rates, although physiological maturity was not independently standardized by a measured marker.

Importantly, P4 (75% + cocopeat) and P6 (75% + mixture) were not significantly different from the corresponding 100% treatments P1 and P3 for fruit weight, diameter, or length. These non-significant pairwise tests do not establish equivalence or noninferiority and therefore cannot be used to claim proven water savings. Such a claim would require direct irrigation totals, drainage or evapotranspiration measurements, and an equivalence-oriented design. Recent deficit-irrigation studies likewise show that melon responses depend on irrigation timing, intensity, and water-status control rather than on a single universal deficit level (di Santo & Barrios-Masias, 2026; Fang et al., 2026; Liu et al., 2024; Xue et al., 2025).

Evidence from monitored deficit-irrigation experiments underscores the importance of treatment timing and plant acclimation. Zapata-García et al. (2025) examined the effects of preconditioning and plant water status in melon, whereas Calaça et al. (2026) evaluated irrigation responses alongside biostimulants under semi-arid conditions. Without measured cumulative irrigation, drainage, evapotranspiration, or nutrient uptake in the present study, neither water-use efficiency nor an optimal deficit regime can be established.

Soluble solids, ripening, and source–sink relationships

TSS showed a different pattern from fruit mass. P4, P6, and P9 each reached 14.50 °Brix and were significantly higher than P2 at 13.50 °Brix, while the remaining treatments were intermediate. Mild, appropriately timed water limitation can increase melon soluble solids in other systems (Barzegar et al., 2018; Xue et al., 2025), but the present experiment did not show a monotonic response to the nominal 100–75–50% volume sequence. In particular, P8 combined lower fruit size with only 13.67 °Brix. This indicates combination-specific fruit responses under a schedule that also changed nutrient-solution amount; it does not demonstrate a water-retention mechanism.

The separation between fruit mass and total soluble solids (TSS) suggests that fresh-mass expansion and soluble-component accumulation need not follow the same ranking.

Fruit enlargement is strongly linked to water influx and cell expansion, whereas sugar profiles depend on assimilate import, sucrose metabolism, and ripening. Zhou et al. (2023) observed developmental changes in melon phloem unloading; Stroka et al. (2024) showed ripening-type-dependent patterns in sugar-metabolism genes. Research comparing melon rootstocks also documented differences in the regulation of sugar and amino acid metabolism associated with taste (Zhang et al., 2026). These studies support the plausibility of source–sink regulation, but they do not demonstrate transporter activity or specific sucrose changes under P4, P6, or P9 in the current cultivar.

Table 4. Harvest timing, fruit dimensions, and total soluble solids (mean ± SE; n = 3 independent experimental units).

Code	Days to harvest (DAT)	Fruit diameter (cm)	Fruit length (cm)	Total soluble solids (°Brix)
P1	69.17 ± 0.33 a	11.80 ± 0.07 b	16.83 ± 0.33 b	13.83 ± 0.17 ab
P2	73.67 ± 0.44 bc	11.74 ± 0.07 b	16.17 ± 0.17 ab	13.50 ± 0.00 a
P3	72.33 ± 0.44 abc	11.53 ± 0.09 ab	17.00 ± 0.50 b	14.33 ± 0.17 ab
P4	70.83 ± 1.01 ab	11.71 ± 0.08 b	16.50 ± 0.00 ab	14.50 ± 0.00 b
P5	75.83 ± 0.33 c	11.61 ± 0.08 b	16.17 ± 0.17 ab	14.00 ± 0.29 ab
P6	74.67 ± 0.83 bc	11.59 ± 0.14 b	16.50 ± 0.29 ab	14.50 ± 0.29 b
P7	71.67 ± 0.67 abc	11.34 ± 0.07 ab	16.17 ± 0.17 ab	14.00 ± 0.29 ab
P8	75.00 ± 2.02 bc	11.07 ± 0.05 a	15.17 ± 0.17 a	13.67 ± 0.17 ab
P9	74.33 ± 0.44 bc	11.43 ± 0.15 ab	16.00 ± 0.58 ab	14.50 ± 0.00 b

Within each column, means sharing one or more letters did not differ according to Tukey HSD ($\alpha = 0.05$). Omnibus p values: days to harvest < 0.001; fruit diameter < 0.001; fruit length = 0.030; and total soluble solids = 0.007. Fruit fresh weight is shown in Figure 3.

The 14.50 °Brix readings for P4, P6, and P9 represent TSS, not concentrations of individual sugars or total sugar mass per fruit. In 'Goldex' melon, TSS was linked to ripening stage rather than responding simply to irrigation salinity (Araújo et al., 2024); field rockmelon similarly showed relatively unchanged TSS despite fruit-mass losses under higher salinity (Kotula et al., 2026). Melon work varying nutrient-solution K/Ca ratios adds a further reason to consider mineral composition alongside water supply (Oliveira et al., 2023). Because harvest date differed among treatments here, maturity is an alternative explanation that cannot be separated from treatment effects. The lower fruit size but only 13.67 °Brix in P8 directly argues against a universal rule that less solution increases sweetness.



Figure 3. Fruit fresh weight and total soluble solids (TSS) across nine irrigation-volume and substrate combinations.

Panel A: fruit fresh weight (g plant^{-1}); panel B: total soluble solids (°Brix). Small points represent observations from individual experimental units; means and SE are based on three independent replicates per treatment. Letters denote Tukey HSD groupings (α = 0.05) following the nine-combination one-way ANOVA. Nominal irrigation-volume treatments also changed the amount of nutrient solution delivered.

Exploratory correlations reflect associations, not mechanisms

At the unit level, mean stem diameter correlated positively with 05:00 substrate temperature (r = 0.60), 13:00 moisture (r = 0.63), and 05:00 moisture (r = 0.64), and negatively with 13:00 temperature (r = −0.57; Table 5). Fruit weight showed positive associations with 13:00 and 05:00 moisture (r = 0.44 and 0.46) and a negative association with 13:00 temperature (r = −0.52). Fruit length and TSS showed similar directions. Across the 40-test environmental–response family, 22 correlations had unadjusted $p < 0.05$ and 19 retained $q < 0.05$. The associations of 05:00 temperature with harvest time ($q = 0.064$), and 13:00 temperature with female flowering and TSS ($q = 0.057$ for each), did not retain significance after adjustment. The 13:00 and 05:00 moisture associations with female flowering did retain $q < 0.05$. Because all 27 observations arose from fixed

treatment groups, part of each correlation can reflect between-treatment clustering; none should be interpreted as proof that changing one environmental variable alone causes the observed crop response.

Table 5. Exploratory Pearson correlations between averaged root-zone readings and melon responses (n = 27 experimental units).

Root-zone reading	Mean stem diameter	Female flowering	Days to harvest	Fruit fresh weight	Fruit length	TSS
Temperature at 05:00	0.60*	-0.22	-0.41*	0.44*	0.58*	0.14
Temperature at 13:00	-0.57*	0.42*	0.60*	-0.52*	-0.45*	-0.42*
Moisture at 13:00	0.63*	-0.46*	-0.57*	0.44*	0.49*	0.56*
Moisture at 05:00	0.64*	-0.45*	-0.55*	0.46*	0.49*	0.57*

An asterisk denotes unadjusted two-sided $p < 0.05$. Root-zone measurements were averaged over five dates per unit and stem diameter over nine dates. Correlations are exploratory and do not establish causation; Benjamini–Hochberg adjustment covered the full family of 40 environmental–response tests, not only the 24 coefficients displayed. Of 22 nominally significant associations in the full family, 19 retained $q < 0.05$. The displayed 05:00 temperature–harvest association ($q = 0.064$) and 13:00 temperature associations with female flowering and TSS ($q = 0.057$ each) did not retain adjusted significance. Asterisks continue to indicate unadjusted p values only.

Moisture correlations use the restored dimensionless DM-15 indices. Uniform division by 10 leaves Pearson r and its p value unchanged; the reported correlations and false-discovery-rate decisions therefore remain the same after rescaling. However, without substrate-specific calibration, these associations cannot quantify relationships with absolute water content or plant-available water. Substrate-dependent sensor response and between-treatment separation may contribute to the observed correlations without a corresponding within-treatment physiological relationship. Table S3 reports all 40 coefficients, p values and BH-adjusted q values.

Nominal and multiplicity-adjusted significance answer different reporting needs. Table 5 retains asterisks for unadjusted $p < 0.05$; Table S3 identifies $q < 0.05$ across the complete 40-test family. Repeated dates were averaged within units, not counted as new replicates. Calibrated, repeated measurements analyzed within experimental units would be required to separate temporal and treatment-group associations.

Agronomic implications and limitations

The strongest practical evidence concerns observed fruit performance under combined substrate and solution-delivery treatments. P8 had the lowest fruit weight, but

lower nominal solution volume also reduced delivered AB-mix nutrient mass. The recording rule is established: values were recorded at ten times the instrument reading and restored by division by 10. Nevertheless, substrate-specific calibration against gravimetric or volumetric water content was not performed. Higher indices therefore cannot establish greater absolute water content or more plant-available water in cocopeat, and differences in sensor response among substrates cannot be excluded. Substrate preparation and packing, probe allocation between bags, greenhouse climate, and cumulative inputs were not fully documented. Future experiments should separate water volume from nutrient mass, monitor EC and drainage, and use calibrated substrate water-content sensors. Equivalence or noninferiority margins would be needed to evaluate reduced-input production.

Agronomically, the data favor evaluating fertigation schedules as substrate-specific rather than applying identical dose–interval rules to all media. In water-retentive substrates, excessive frequency can reduce aerated pore space; in rapidly draining media, long intervals may amplify fluctuations in water and nutrient availability. Y.-L. Li et al. (2024) linked coir irrigation scheduling to radiation and evapotranspiration in cucumber, Samba et al. (2024) examined quantitative nutrient delivery using solar radiation, and Randhe et al. (2026) assessed weight-triggered solution replenishment in cocopeat grow bags. These are candidate approaches for follow-up experiments, not management technologies demonstrated by the current melon trial.

In a greenhouse cucumber–melon cascade system, water and nutrient efficiencies could be calculated because incoming solution, drainage, and nutrient composition were explicitly recorded (Naounoulis et al., 2024). That contrast highlights essential future measurements: actual cumulative input, leachate volume, solution and substrate EC/pH, air temperature and humidity, radiation, and calibrated substrate water content over time. Root function, dry matter and photosynthesis would also need measurement before causal physiological pathways are claimed. With the present instrumentation, the practical outcome is a substrate-sensitive interpretation of observed growth and fruit performance, not proof of an optimized fertigation recipe or reduced input requirements. Future calibration should pair DM-15 readings with independently measured gravimetric or volumetric water content across dry-to-wet conditions for each substrate. Conversion

equations should be estimated from actual calibration data and evaluated for model fit, residuals, and prediction error before use.

CONCLUSION

Field-capacity-derived irrigation volume and substrate composition were associated with differences in root-zone conditions, plant growth, and melon fruit performance under the tested greenhouse conditions. Treatment combinations differed in recorded moisture-index distributions and 13:00 substrate temperature. Rice-husk-charcoal combinations generally had lower recorded moisture scores and higher 13:00 temperatures, but moisture-score separation does not establish calibrated water-content differences. The 50% nominal-volume treatment with rice-husk charcoal (P8) yielded the lowest fruit fresh weight and the smallest fruits, whereas the 100% nominal-volume treatment with cocopeat (P1) produced the highest mean fruit weight. Neither the 75% + cocopeat treatment (P4) nor the 75% + 1:1 mixture treatment (P6) differed significantly from the corresponding 100% treatment for several fruit traits; this does not establish equivalence or irrigation-water savings. The numerically highest TSS occurred in P4, P6, and P9, and no single combination performed best across all measured traits.

These conclusions are confined to the greenhouse, cultivar, substrate formulations, and nutrient-delivery protocol tested. Because nominal irrigation volume also determined the amount of nutrient solution supplied to the root zone, future work should experimentally separate water volume from nutrient supply and directly measure water inputs, drainage, substrate water status, and electrical conductivity before recommending reductions in irrigation. Quantitative moisture-based conclusions remain provisional because the DM-15 index has not been calibrated to water content for these substrates.

DECLARATIONS

Funding: The research was self-funded.

Conflicts of interest: The authors declare no conflicts of interest related to this study.

Author contributions: Sisca Fajriani: Conceptualization, Methodology, Supervision, Validation, Writing – review and editing. Tri Sudaryono: Methodology, Formal analysis, Validation, Writing – review and editing. Rifdatul Khoir Rahmat: Investigation, Data curation, Formal analysis, Visualization, Writing – original draft. All authors reviewed

and approved the final manuscript and agreed to be accountable for the integrity of the work.

Data availability: Experimental-unit data, the corrected DM-15 index workbook and reproducible statistical scripts are provided in the accompanying supporting package. The data supporting the findings of this study, including experimental observations, statistical analyses, and supplementary data, are available from the corresponding author upon reasonable request.

REFERENCES

Adekiya, A. O., Ayeni, J. F., Olayanju, A., Aremu, C., Akpor, O. B., Olaniran, A. F., Ejue, W. S., Ndupuechi, D. I., & Suleiman, O. K. (2022). Potentials of soilless substrates from biochar and rice husk as a replacement for cocopeat in Nigeria on tomato (Solanum lycopersicum). Research on Crops, 23(1), 139–148. https://doi.org/10.31830/2348-7542.2022.020

Aldiansyah, M. K., & Hariyono, D. (2022). Pengaruh berbagai media tanam dan kapasitas lapang terhadap pertumbuhan dan hasil tanaman melon (Cucumis melo L.). Jurnal Produksi Tanaman, 10(7), 357–362. https://doi.org/10.21776/ub.protan.2022.010.07.03

Andrade, S. P., da Silva, T. J. A., Silva, E. M. B., Arantes, S. A. do C. M., & Arruda Júnior, A. (2022). Fruit characteristics of cantaloupe melon in protected environment subjected to irrigation frequencies and substrate volumes. Revista Brasileira de Engenharia Agrícola e Ambiental, 26(10), 706–712. https://doi.org/10.1590/1807-1929/agriambi.v26n10p706-712

Araújo, B. de A., Celin, E. F., da Costa, R. S., Calvet, A. S. F., de Carvalho, H. H., & Bezerra, M. A. (2024). Development and quality of melon fruits grown under salt stress. Revista Brasileira de Engenharia Agrícola e Ambiental, 28(3), e277374. https://doi.org/10.1590/1807-1929/agriambi.v28n3e277374

Ariessandy, I., Triyono, S., Amien, E. R., & Tusi, A. (2022). Pengaruh jenis media tanam hidroponik agregat dan electrical conductivity larutan nutrisi terhadap pertumbuhan dan produksi melon (Cucumis melo L.). Jurnal Agricultural Biosystem Engineering, 1(1), 20–31. https://doi.org/10.23960/jurnal%20abe.v1i1.5549

Aulia, A., Wardani, I. K., & Ichniarsyah, A. N. (2022). Penghitungan evapotranspirasi aktual (ETc) tanaman melon pada fase vegetatif di greenhouse. Jurnal Keteknikan Pertanian Tropis dan Biosistem, 10(3), 170–180. https://doi.org/10.21776/ub.jkptb.2022.010.03.01

Banitalebi, G., Mosaddeghi, M. R., & Shariatmadari, H. (2024). Oxygen diffusion in biochar-based mixtures as plant growth media: Experimental and modelling. Waste Management & Research, 42(12), 1195–1207. https://doi.org/10.1177/0734242X231219631

Bao, L., Zhang, S., Liang, X., Wang, P., Guo, Y., Sun, Q., Zhou, J., & Chen, Z. (2023). Intelligent drip fertigation increases water and nutrient use efficiency of watermelon in greenhouse without compromising the yield. Agricultural Water Management, 282, 108278. https://doi.org/10.1016/j.agwat.2023.108278

Barzegar, T., Heidaryan, N., Lofti, H., & Ghahremani, Z. (2018). Yield, fruit quality and physiological responses of melon cv. Khatooni under deficit irrigation. Advances in Horticultural Science, 32(4), 451–458. https://doi.org/10.13128/ahs-22456

Bi, X., Wang, X., & Zhang, X. (2022). Effects of different root zone heating methods on the growth and photosynthetic characteristics of cucumber. Horticulturae, 8(12), 1137. https://doi.org/10.3390/horticulturae8121137

Calaça, J. dos S. G., Nogueira, J. C., Silva, J. R. I., Oresca, D., Bezerra, A. C., de Lira, R. M., Araújo Júnior, G. do N., Pessoa, L. G. M., dos Santos, A. R. M., da Silva, S. A., e Silva, G. H. L., Lima, D. N., & de Souza, E. S. (2026). Effects of deficit irrigation and biostimulants on melon productivity and quality in semi-arid conditions. Journal of the Science of Food and Agriculture, 106(11), 6348–6364. https://doi.org/10.1002/jsfa.70674

Carsidi, D., Saparso, Kharisun, & Febrayanto, C. R. (2021). Pengaruh media tumbuh dengan aplikasi irigasi tetes terhadap pertumbuhan dan hasil melon. Jurnal Agro, 8(1), 68–83. https://doi.org/10.15575/9514

di Santo, H., & Barrios-Masias, F. (2026). Implementation of deficit irrigation to improve crop water productivity in cantaloupe melons. The Journal of Agricultural Science, 164, e29. https://doi.org/10.1017/S0021859626100665

Fang, S.-L., Tsai, B.-Y., Chang, S.-C., Chang, Y.-L., Yao, M.-H., Chi, M.-K., Wang, W.-L., & Kuo, B.-J. (2026). Regulated deficit irrigation strategy for greenhouse melons based on water status classification model and crop coefficient–reference evapotranspiration approach. Irrigation Science, 44(2), Article 41. https://doi.org/10.1007/s00271-026-01082-9

Ikhwana, M. H., Susila Putra, E. T., & Ambarwati, E. (2025). Pengaruh posisi cabang pembuahan terhadap pertumbuhan, hasil, dan mutu buah melon (Cucumis melo L.) dalam sistem fertigasi hidroponik. Vegetalika, 14(3), 194–205. https://doi.org/10.22146/veg.104670

Kotula, L., Forrest, A., Yeap, S., Kotula, J., Ranathunge, K., & Lantzke, N. (2026). Effect of saline irrigation on yield and fruit quality of tomato and rockmelon grown on sandy soils under Mediterranean climatic conditions. Irrigation Science, 44(2), Article 36. https://doi.org/10.1007/s00271-025-01072-3

Li, M., Ning, X.-P., Gao, T.-T., Fazry, S., Othman, B. A., Najm, A. A. K., & Law, D. (2024). Rice husk ash based growing media impact on cucumber and melon growth and quality. Scientific Reports, 14, 5147. https://doi.org/10.1038/s41598-024-55622-4

Li, Y.-L., Zhang, S.-Q., Guo, W.-Z., Zheng, W.-G., Zhao, Q., Yu, W.-Y., & Li, J.-S. (2024). Effects of irrigation scheduling on the yield and irrigation water productivity of cucumber in coconut coir culture. Scientific Reports, 14, 2944. https://doi.org/10.1038/s41598-024-52972-x

Liu, S., Li, J., Jia, S., Dai, Z., Du, F., Zhao, N., Fan, F., Liu, Z., & Zhao, S. (2024). Effects of irrigation approaches and mulching on greenhouse melon production and water use in Northern China. Water, 16(14), 2013. https://doi.org/10.3390/w16142013

Naounoulis, I., Faliagka, S., Levizou, E., & Katsoulas, N. (2024). Cascade hydroponics enhanced water and nutrients use efficiency in a greenhouse cucumber-melon crop combination. Scientia Horticulturae, 338, 113822. https://doi.org/10.1016/j.scienta.2024.113822

Oliveira, R. R. T., de Oliveira, F. de A., Góis, H. M. de M. N., de Menezes, P. V., dos Santos, S. T., Aroucha, E. M. M., & de Almeida, J. G. L. (2023). Salt stress and K/Ca ratios of the nutrient solution in the production and quality of the melon. Revista Ciência Agronômica, 54, 1–9. https://doi.org/10.5935/1806-6690.20230052

Prompukdee, N., Ueangsawat, K., Santasup, C., Kaweewong, J., Luesak, N., & Chaiwan, F. (2023). Study of water holding capacity of difference growing media with coconut coir as the main mixture. Khon Kaen Agriculture Journal, 51(5), 892–904. https://doi.org/10.14456/kaj.2023.67

Randhe, R. D., Hasan, M., Singh, D. K., Naresh Kumar, S., Kumar, P., Alam, W., Pandey, R., Kumar, M., & Waghaye, A. M. (2026). Effect of weight-based fertigation on physiology, gas exchange and yield of soilless cucumber and capsicum. Scientific Reports, 16, 4692. https://doi.org/10.1038/s41598-025-34858-8

Samba, N., Nunomura, O., Lu, N., Johkan, M., Nakano, A., & Tsukagoshi, S. (2024). Cucumber (Cucumis sativus L.) growth and productivity under solar radiation-based quantitative nutrient management in hydroponic system. Agronomy, 14(2), 296. https://doi.org/10.3390/agronomy14020296

Stroka, M. A., Reis, L., de Souza Los, K. K., Pinto, C. A., Gustani, F. M., Forney, C. F., Etto, R. M., Galvão, C. W., & Ayub, R. A. (2024). The maturation profile triggers differential expression of sugar metabolism genes in melon fruits. Plant Physiology and Biochemistry, 207, 108418. https://doi.org/10.1016/j.plaphy.2024.108418

Sun, T., Zhao, Y., Zhou, D., Gao, Z., & Hu, X. (2023). Effects of amount, electric conductivity, and frequency of a nutrient solution on melon yield and flavor quality. Scientia Horticulturae, 310, 111737. https://doi.org/10.1016/j.scienta.2022.111737

Takemura Electric Works. (n.d.). DM-13/DM-15 instruction manual [Manufacturer manual, in Japanese]. https://www.demetra.co.jp/uploads/DM1315.pdf

Xue, Q., Li, H., & Du, T. (2025). Mild water deficit during maturity reduces cracking rate of greenhouse muskmelon while improving fruit quality. Agricultural Water Management, 313, 109465. https://doi.org/10.1016/j.agwat.2025.109465

Yang, T., Altland, J. E., & Samarakoon, U. C. (2023). Evaluation of substrates for cucumber production in the Dutch bucket hydroponic system. Scientia Horticulturae, 308, 111578. https://doi.org/10.1016/j.scienta.2022.111578

Yang, Z., Kong, T., Xie, J., Yang, T., Jiang, Y., Feng, Z., & Zhang, Z. (2023). Appropriate water and fertilizer supply can increase yield by promoting growth while ensuring the soil ecological environment in melon production. Agricultural Water Management, 289, 108561. https://doi.org/10.1016/j.agwat.2023.108561

Yulidasari, E., Hermita, N., & Fatmawaty, A. A. (2026). Effects of growing media and variety on growth and fruit characteristics of melon (Cucumis melo L.) under drip irrigation. Jurnal Ilmiah Pertanian, 23(2), 107–122. https://doi.org/10.31849/jip.v23i2.33948

Zapata-García, S., Temnani, A., Berríos, P., Espinosa, P. J., Monllor, C., & Pérez-Pastor, A. (2025). Deficit irrigation and biostimulation preconditioning to improve drought resistance in melon. Agricultural Water Management, 309, 109311. https://doi.org/10.1016/j.agwat.2025.109311

Zhang, H., Muhammad Mohsin, K., Liang, Q., Du, Y., Maerhaba, P., Tian, B., Zhang, H., Zhang, W., Huang, Y., Wang, M., Zhu, J., & Fu, X. (2026). Rootstock selection shapes melon taste by divergent regulation of sugar and amino acid metabolism. Frontiers in Plant Science, 17, 1740115. https://doi.org/10.3389/fpls.2026.1740115

Zhou, Y., Li, K., Wen, S., Yang, D., Gao, J., Wang, Z., Zhu, P., Bie, Z., & Cheng, J. (2023). Phloem unloading in cultivated melon fruits follows an apoplasmic pathway during enlargement and ripening. Horticulture Research, 10(8), uhad123. https://doi.org/10.1093/hr/uhad123