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Research article

Effects of Filter Cake from Sugar Mill Utilization as an Alternative Growing Medium on Growth Performance, Yield, and Economic Profitability of Melon in Soilless Culture

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Abstract

This study investigated the effects of filter cake as an alternative growing medium on the growth, yield, and economic profitability of melon in a soilless system. The greenhouse experiment followed a completely randomized design with three treatments: 100% coconut coir (control), 100% filter cake, and 50% filter cake + 50% coconut coir, each with three replications (90 plants in total). Growth was recorded weekly from 7 to 63 days after transplanting (DAS), and fruit quality was assessed at harvest. The 100% filter cake treatment significantly enhanced vegetative growth ($P<0.05$), producing the highest plant height (95.40 cm), number of nodes (13.30), number of leaves (13.30), and leaf width (19.30 cm) at 21 DAS. Although fruit quality parameters did not differ significantly ($P>0.05$), 100% filter cake tended to yield superior fruit weight (1.16 kg) and total soluble solids (16.69 °Brix). Economic analysis revealed that 100% filter cake provided the highest gross profit (82.70 THB plant^{-1}), return on growing media cost (55.68 times), yield per unit investment (0.464 kg THB^{-1}), and maximum investment efficiency (2.46 times per crop cycle). Its economic advantage resulted from the lowest growing-medium cost (2.50 THB plant^{-1}) while maintaining good yield and quality. Filter cake shows high potential as a cost-effective and sustainable alternative to coconut coir in soilless melon production. The results apply to the 'Khaitongkham Melon' variety during one growing season; further studies across varieties and seasons are recommended.

Keywords: filter cake; alternative growing medium; melon; soilless culture; coconut coir

1. Introduction

Currently, soilless culture systems have gained increasing popularity due to their ability to precisely control environmental factors affecting plant growth, enhance production efficiency, reduce risks from soil-borne diseases and pests, and optimize the utilization of water and nutrient resources (Savvas & Gruda, 2018). Such systems have become particularly favored for producing high-value economic crops, including melon (*Cucumis*

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melo L.), which is popular in both domestic and export markets. Melon is distinguished by its superior taste, aroma, and high economic value, and is well-suited for greenhouse production combined with modern management technologies such as drip irrigation systems, nutrient control, and soilless cultivation systems (Yavuz et al., 2021).

Although commonly used growing media in soilless culture systems such as coconut coir, peat moss, and perlite, possess suitable properties for plant growth, they face challenges of increasing costs, quality uncertainty, and sustainability limitations in procurement. Coconut coir, in particular, experiences high demand across multiple industries, significantly impacting farmer production costs (Apung et al., 2023).

Meanwhile, filter cake, a by-product from sugar production in the sugar industry, is an agricultural waste material produced in large quantities each production season. It is typically utilized as an organic fertilizer or a soil amendment due to its content of organic matter and beneficial plant nutrients such as phosphorus, potassium, and calcium (Ungureanu et al., 2022). However, the use of filter cake as a growing medium in soilless culture systems remains academically limited, despite its potential to improve growing medium properties such as water-holding capacity, porosity, and aeration, which are crucial factors for plant growth (Suwanree et al., 2024).

Previous studies have confirmed the use of filter cake as an organic amendment or conditioner (Soares et al., 2024). However, research on its direct application as a substrate in soilless cultivation remains scarce (Gruda, 2019). Furthermore, empirical evidence is limited regarding how changes in substrate physical properties influence plant growth, fruit quality, and economic profitability in melon production (Saediman et al., 2020). This represents a key knowledge gap in developing sustainable and cost-effective alternatives to coconut coir in soilless melon-culture systems.

Accordingly, this study aims to determine whether filter cake can be used as an alternative growing medium to coconut coir in soilless melon production, and how its use influences plant growth, fruit yield, and economic profitability. We hypothesized that filter cake could be used to improve the physical properties of the growing medium, particularly its water-holding capacity and aeration, thereby enhancing melon growth and yield while reducing production costs. To verify this hypothesis, both agronomic performance and economic return were evaluated, as the practical adoption of alternative growing media requires consideration of both biological efficiency and economic feasibility.

From a theoretical perspective, the use of filter cake as a growing medium can be supported by the concepts of the circular economy and agro-industrial by-product valorization, which emphasize maximizing the value of locally available agricultural residues within an agro-ecological-economic system (Soares et al., 2024).

Given this significance, this study aimed to investigate the potential of filter cake as an alternative growing medium to coconut coir in soilless culture systems by comparing its effects on growth performance, yield, and economic profitability of melon. The results of this study are expected to provide guidance for adding value and sustainably utilizing agricultural waste materials, as well as helping reduce production costs and enhance farmers' economic security.

2. Materials and Methods

2.1 Experimental design

The experiment was conducted in the greenhouse of the Plant Production Technology Program, Valaya Alongkorn Rajabhat University under the Royal Patronage, Sa Kaeo

Province, Thailand. A completely randomized design (CRD) was employed consisting of three treatments: (1) 100% coconut coir (control treatment), (2) 100% filter cake, and (3) 50% filter cake mixed with 50% coconut coir. Each treatment had three replications with 10 growing bags per replication, totaling 90 experimental units.

2.2 Experimental procedures

2.2.1 Collection and characterization of filter cake

The filter cake was obtained from Eastern Sugar and Cane Public Company Limited, located in Huai Jod Subdistrict, Watthana Nakhon District, Sa Kaeo Province, Thailand. The material was collected immediately after the clarification and filtration stage of the sugar production process and then air-dried under shaded conditions to stabilize its moisture content. Visible impurities such as leaf residues, stones, and fiber clumps were manually removed, and the material was passed through 0.5 mm and 2.0 mm sieves to ensure uniform particle size for analysis and experimental use. The pH of the filter cake was determined using a 1:1 ratio of soil to deionized water (10 g soil:10 mL water) in triplicate, measured with a pH meter (ExStik pH100). The total nitrogen (N) content was analyzed by the Kjeldahl method, while the sample was digested using a $HClO_4$:HNO_3 (6:1 v/v) wet oxidation method and filtered through Whatman No. 1 filter paper. The total phosphorus (P) concentration was determined colorimetrically using the vanadomolybdate reagent method and measured at 420 nm with a spectrophotometer. Concentrations of K, Ca, and Mg were quantified using an atomic absorption spectrophotometer (AAS) (Perkin Elmer, PinAACle 900F) following the method of Motsara and Roy (2008).

2.2.2 Growing medium preparation and seedling production

The filter cake was air-dried under shaded conditions to stabilize its moisture content, and visible impurities such as leaf residues, stones, and fiber clumps were removed manually. The dried filter cake was then passed through a 5-mm mesh sieve to ensure uniform particle size suitable for use as a substrate. Only material exhibiting a uniform texture, an absence of foul odor, and no signs of mold contamination were selected for the experiment, following recommended preparation practices for substrate utilization (Soares et al., 2024; Saediman et al., 2020). The filter cake was composted for 6 months before application in the growing medium.

All growing media were soaked in water for at least 24 h before being packed into growing bags measuring 30×25 cm that contained approximately 5 kg of growing medium (dry weight basis). Commercial melon seeds 'Khaitongkham Melon' (*Cucumis melo* L.) variety underwent germination enhancement by soaking in warm water at 40-45°C for 4-6 h, then wrapped in moist cloth for 24 h. Once germinated, the seeds were sown in seedling trays filled with peat moss. Seedlings with two true leaves (10 days old) were transplanted into the growing bags during the evening hours. The selection of the 50:50 mixture ratio of coconut coir and filter cake was based on a volume basis. This ratio was chosen to balance the physical properties of the growing medium. Preliminary observations indicated that using filter cake alone could lead to higher moisture retention and reduced aeration, while coconut coir provided better porosity and structural stability. Therefore, combining the two materials at equal volume was expected to improve water-holding capacity and aeration equilibrium, which are critical for root growth and melon development. Similar approaches

of substrate blending to optimize physical properties were reported in previous studies on organic substrate mixtures (Gruda, 2019).

Seed sowing was carried out on 3 August 2024, and the stepwise process of melon cultivation under greenhouse conditions, from seed germination to harvesting, is illustrated in Figure 1. Seedlings were transplanted into the growing bags on 13 August 2024 when they reached the two-true-leaf stage. Pollination was conducted between 2-4 September 2024 during the early morning (06:00-10:00). A single melon variety ('Khaitongkham Melon') was used in order to minimize genetic variation and ensure that differences observed among treatments were attributed primarily to the growing media rather than varietal characteristics. The experiment was conducted in one growing season from August to October 2024. After transplanting, plants were spaced at 50 cm between plants within rows and 1.2 m between rows to ensure adequate light interception, air circulation, and canopy development.

2.2.3 Water and nutrient management

Irrigation was conducted using a drip irrigation system combined with nutrient solutions of stock A and B types. Each stock solution was prepared as follows:

Stock A: Calcium nitrate ($Ca(NO_3)_2$) and iron chelate (Fe-EDTA)

Stock B: Potassium nitrate (KNO_3), magnesium sulfate ($MgSO_4$), monopotassium phosphate (KH_2PO_4), and micronutrients. The fertilizers used for preparing both stock solutions were sourced from Pro Agritech Co., Ltd. (Bangkok, Thailand), a licensed fertilizer manufacturer certified by the Department of Agriculture, Ministry of Agriculture and Cooperatives. The combined stock A and B solutions supplied all the essential macronutrients (N, P, K, Ca, Mg, and S) and micronutrients (Fe, Mn, Zn, Cu, B, and Mo) required for optimal melon growth (Sonneveld & Voogt, 2009).

The nutrient solution concentration was maintained at EC 2.0 mS/cm with pH adjusted to 5.9-6.5. Irrigation was divided into three phases: (1) vegetative growth stage - 4 times daily, 5 min each; (2) flowering and fruit development stage - increased to 8 times daily, every hour from 9:00 AM to 4:00 PM, 3 min each; and (3) pre-harvest stage - reduced water quantity and frequency during the final 5 days, with no irrigation on the last day, supplemented with foliar spray of calcium-boron solution. The irrigation and nutrient supply schedule were adjusted according to the crop growth stages as shown in Table 1

2.2.4 Plant management and pollination

Staking began 14 days after transplanting using vertical strings ≥200 cm high. When melon plants developed, pruning was performed to retain nodes 9-12 for pollination. The bottom 3-5 leaves were removed to improve air circulation. When plants reached 25 nodes, the growing tips were removed to promote fruit development. Hand pollination was performed between 6:00-10:00 AM. In this study, the term 'most perfect fruit' refers to a fruit that exhibits a uniform round to oblong shape, normal ovary development, absence of visible defects (e.g., cracking, scarring, insect damage), and firm peduncle attachment. Only one fruit per plant meeting these criteria was retained, and other fruits were removed when selected fruits reached the size of a chicken egg. This uniform fruit selection approach helps minimize variation among experimental units, ensuring that differences in growth and yield were attributable to the growing media treatments rather than variability in fruit set (Wu et al., 2025).

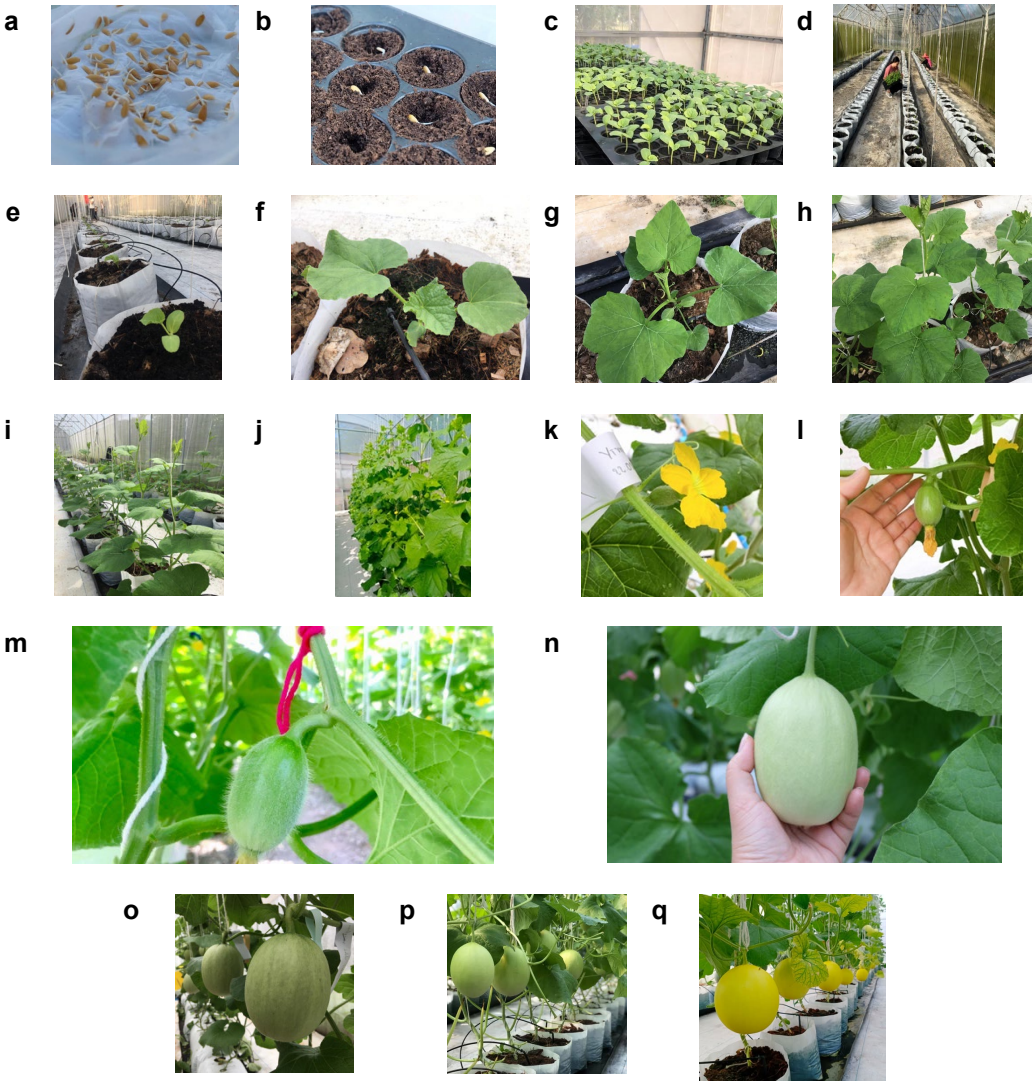


Figure 1. Melon cultivation in the greenhouse (6 × 24 m) a) Germination of seeds in moist tissue paper for 7 days; b) Transfer of germinated seeds into 50-cell seedling trays; c) Melon seedlings at 14 days old; d) Arrangement of growing bags in the greenhouse with 1.2 m spacing between rows; e) Transplanting seedlings into 30 × 25 cm growing bags; f) Melon plants at 7 days after transplanting; g) 14 days; h) 21 days; i) 28 days; j) 35 days; k) Hand pollination; l-m) Fruit set observed at 35-42 days; n) Fruit thinning at 47 days, retaining one fruit per plant; o) Fruit enlargement at 49 days; p) Fruit turning light green to yellowish at 56 days; q) Harvesting at 63-65 days after pollination.

Table 1. Drip-fertigation regime (EC, stock injection rate, frequency, duration, and daily volume) across melon growth stages

Growth Stage	EC ($mS \cdot cm^{-1}$)	Stock A/B Injection Rate	Irrigation Frequency	Time Schedule	Duration per Cycle	Approx. Volume per Plant per Day
Vegetative growth	2	7.5 mL Stock A + 7.5 mL Stock B per 1,000 L water	4 times/day	09:00, 11:00, 13:00, 15:00	5 min/cycle	1.2-1.5 L/plant/day
Pollination	2	7.5 mL Stock A + 7.5 mL Stock B per 1,000 L water	8 times/day	Hourly from 09:00-16:00	3 min/cycle	1.5-2.0 L/plant/day
Fruit development	2	7.5 mL Stock A + 7.5 mL Stock B per 1,000 L water	8 times/day	Hourly from 09:00-16:00	3 min/cycle	2.0-2.5 L/plant/day
Pre-harvest	1.8-2.4 (reduced gradually)	Calcium-boron foliar spray applied instead of AB solution	4-5 times/day, gradually reduced	As above	3 min/cycle, then withheld last 1-2 days	Reduced to 0.8-1.2 L/plant/day; final 1-2 days no irrigation

2.2.5 Harvesting

Melon fruits were harvested 30-35 days after pollination, determined by skin color, clear netting pattern, and raised fruit apex. A clear netting pattern refers to a well-developed, uniform, and corky network on the surface of the melon fruit, formed by suberization of the epidermal layer during the maturation stage. The raised fruit apex refers to a slight protrusion at the blossom end of the melon fruit, indicating full physiological maturity and sugar accumulation. These external characteristics are recognized as reliable indicators for determining the appropriate harvest maturity of melon fruits (Wu et al., 2025; Yavuz et al., 2021; Vanoli et al., 2023). After harvest, the melon fruits were stored under shaded conditions at a low temperature of 10-12°C to slow down postharvest respiration and metabolic activities, thereby extending shelf life and preserving fruit quality in accordance with standard postharvest management practices recommended for muskmelon (Saltveit,

2019). Harvesting was performed between 14-18 October 2024, corresponding to 40-45 days after pollination. Fruit maturity was determined based on skin color change, clarity of netting pattern, and elevation of the fruit apex. Only fruits that met these maturity indicators were selected for evaluation.

2.3 Data collection

Growth parameters were recorded from week 1 after transplanting until the pollination period at 7-day intervals, including plant height, stem diameter, number of nodes, leaf width and length, and number of leaves. Growth measurements were recorded weekly from 7 to 63 days after transplanting (DAS), corresponding to the vegetative, flowering, fruiting, and pre-harvest stages of melon development. Stem diameter was measured at 2 cm above the growing medium surface using a digital Vernier caliper (JEDTO Model 101-2201, Bangkok, Thailand) with a precision of 0.01 mm. Fruit quality parameters measured after harvest included fruit diameter, fruit length, fruit weight, flesh thickness, and total soluble solids (TSS) using a refractometer (°Brix). Economic profitability was assessed based on growing medium costs, sales revenue, return on growing medium investment, gross profit, and yield per unit investment in growing media to compare the cost-effectiveness of each growing medium type.

2.3.1 Nitrogen use efficiency (NUE)

NUE was calculated using the equation described by Moll et al. (1982), which is shown in equation 1:

$$NUE = \frac{\text{Fruit yield (kg/plant)}}{\text{Total nitrogen applied (g/plant)}} \quad (1)$$

where Fruit yield represents the total fresh fruit weight per plant at harvest, and Total nitrogen applied refers to the cumulative amount of nitrogen supplied through the nutrient solution during the cultivation period.

2.3.2 Economic profitability analysis

Economic profitability was evaluated on a per-plant, per-crop-cycle basis. The variable costs included:

(i) growing medium cost,

(ii) nutrient stock solutions A and B (materials × dose × volume applied),

(iii) water and electricity for fertigation,

(iv) labor (nursery, transplanting, pruning, hand pollination, fertigation monitoring, harvesting, grading), and

(v) crop cultural practices (trellis strings and clips, pruning tool depreciation, disinfectants, and miscellaneous supplies).

The economic parameters were calculated using the following equations 2-6:

$$\text{Gross Return}\left(\frac{\text{THB}}{\text{plant}}\right) = \text{Selling price (THB/kg)} \times \text{Marketable fruit weight (kg/plant)} \quad (2)$$

$$\text{Total Variable Cost}\left(\frac{\text{THB}}{\text{plant}}\right) = \text{Growing medium} + \text{Stock A} + \text{B} + \text{Water \& electricity}$$

$$+\text{Labor} + \text{Cultural practices} \quad (3)$$

$$\text{Gross Profit (THB/plant)} = \text{Gross Return} - \text{Total Variable Cost} \quad (4)$$

$$\text{Return on Growing Media Cost (times per crop cycle)} = \frac{\text{Gross Return}}{\text{Growing medium cost}} \quad (5)$$

$$Yield\ per\ Unit\ Investment\ \left(\frac{\text{kg}}{\text{Baht}}\right) = \frac{\text{Fruit weight}}{\text{Growing medium cost}} \quad (6)$$

These parameters were used to evaluate the cost–benefit efficiency of each growing medium (adapted from Suwanree et al., 2024).

2.3.3 Maximum investment efficiency (MIE)

The maximum investment efficiency (MIE) was calculated to evaluate the economic performance of each growing medium using the following equation 7:

$$MIE = \frac{\text{Gross Return (THB)}}{Total\ Cost\ of\ Growing\ Medium\ ZTHB)} \quad (7)$$

where gross return represents the total revenue obtained from melon sales per treatment, and total cost of growing medium includes the expenses of substrate materials, nutrient solution, and labor associated with their management.

This parameter indicates the profitability per unit investment in the growing medium, with higher values reflecting greater economic efficiency (Călugăr et al., 2020; Majdalawi et al., 2023).

2.4 Statistical analysis

Data were analyzed using analysis of variance (ANOVA) for completely randomized design (CRD), and mean differences were compared using Duncan's New Multiple Range Test (DMRT) at 95% confidence level. All statistical analyses were performed using IBM SPSS Statistics, Version 29.0.1.1 (IBM Corp., Armonk, NY, USA).

3. Results and Discussion

3.1 Growth performance

The chemical properties and nutrient concentrations of the filter cake used in this study are presented in Table 2. The filter cake exhibited a pH of 7.8, which was consistent with the findings of Suwanree et al. (2024), who analyzed filter cake and vinasse from the Mitr Phol Sugar Factory (Chaiyaphum Province, Thailand). The nutrient composition was N = 18.5 g kg^{-1}, P = 12.3 g kg^{-1}, K = 19.4 g kg^{-1}, Ca = 48.7 g kg^{-1}, and Mg = 7.7 g kg^{-1}. The high Ca content is likely attributed to both the quality of the sugarcane and the juice clarification process (da Silva et al., 2018), which agrees with Inthasan et al. (2022).

Growth analysis revealed that 100% filter cake promoted melon growth performance better than other growing media, particularly in plant height at 7, 14, and 21 days after planting (12.00, 34.20, and 95.40 cm, respectively), which were significantly higher than 100% coconut coir and 50% filter cake mixed with 50% coconut coir ($P<0.05$).

For stem diameter, 100% filter cake showed the highest value at 14 days after planting (5.71 mm), followed by 50% filter cake mixed with 50% coconut coir (5.21 mm) and 100% coconut coir (4.66 mm), with significant differences among treatments. However, no significant differences were observed at 7 and 21 days after planting. Regarding node number and leaf count, both 100% filter cake and 50% filter cake mixed with 50% coconut coir showed significantly higher values than 100% coconut coir. Notably, at 21 days after planting, 100% filter cake produced the highest leaf number (13.30 leaves), followed by 100% coconut coir (11.80 leaves) and 50% filter cake mixed with 50% coconut coir (11.00 leaves). Similar trends were observed for leaf width and length (Table 3).

Table 2. Chemical properties of sugarcane filter cake

Characteristics	pH	N ($g \cdot kg^{-1}$)	P ($g \cdot kg^{-1}$)	K ($g \cdot kg^{-1}$)	Ca ($g \cdot kg^{-1}$)	Mg ($g \cdot kg^{-1}$)
Filter cake	7.8±0.2	18.5±0.4	12.3±0.6	19.4±1.3	48.7±2.8	7.7±1.1

Table 3. Effects of growing media on growth parameters of melon from 7 to 63 days after transplanting (DAS)

Growth Parameters	Growing Media			P-value	C.V.%
	Coconut Coir Dust 100% (Control)	Filter Cake 100%	Filter Cake 50% + Coconut Coir Dust 50%		
Stem height (cm)					
7 Day	9.50^{b}	12.00^{a}	10.12^{b}	<0.01	4.05
14 Day	24.00^{c}	34.20^{a}	27.20^{b}	<0.01	3.24
21 Day	71.60^{c}	95.40^{a}	81.90^{b}	<0.01	2.78
28 Day	98.52^{c}	129.53^{a}	111.52^{b}	<0.01	4.27
35 Day	115.65^{b}	170.83^{a}	126.96^{b}	<0.01	5.27
42 Day	124.86^{c}	185.43^{a}	147.41^{b}	<0.01	1.87
49 Day	145.86^{c}	203.11^{a}	168.04^{b}	<0.01	4.24
56 Day	160.54^{c}	212.09^{a}	184.08^{b}	<0.01	1.92
63 Day	170.85^{c}	220.61^{a}	190.43^{b}	<0.01	3.27
Stem diameter (mm)					
7 Day	1.01^{c}	1.16^{a}	1.09^{b}	<0.01	2.14
14 Day	4.66^{b}	5.71^{a}	5.21^{a}	<0.01	3.13
21 Day	5.88^{b}	6.76^{a}	6.34^{a}	0.017	4.11
28 Day	8.20^{c}	10.19^{a}	9.44^{b}	<0.01	2.81
35 Day	8.99^{c}	11.02^{a}	10.11^{b}	<0.01	0.99
42 Day	10.54^{c}	13.86^{a}	12.07^{b}	<0.01	2.66
49 Day	11.54^{c}	15.11^{a}	13.14^{b}	<0.01	1.62
56 Day	12.88^{b}	15.84^{a}	14.69^{a}	<0.01	2.57
63 Day	12.95^{c}	15.90^{a}	14.77^{b}	<0.01	1.77

Table 3. Effects of growing media on growth parameters of melon from 7 to 63 days after transplanting (DAS) (continued)

Growth Parameters	Growing Media			P-value	C.V.%
	Coconut Coir Dust 100% (Control)	Filter Cake 100%	Filter Cake 50% + Coconut Coir Dust 50%		
Node number (nodes)					
7 Day	2.00	2.00	2.10	0.118	2.54
14 Day	5.90[b]	7.20[a]	6.80[a]	<0.01	2.25
21 Day	11.80[b]	13.30[a]	11.00[c]	<0.01	1.96
28 Day	13.87[c]	18.80[a]	15.53[b]	<0.01	2.67
35 Day	14.55[b]	18.98[a]	17.56[a]	<0.01	3.90
42 Day	17.82$_c$	20.69[a]	19.98[b]	<0.01	2.93
49 Day	18.04[c]	22.83[a]	20.43[b]	<0.01	1.91
56 Day	21.77[b]	24.45[a]	22.75[b]	<0.01	1.00
63 Day	24.03	24.45	24.43	0.81	2.64
Leaf width (cm)					
7 Day	5.85[b]	6.50[a]	6.60[a]	0.016	3.39
14 Day	11.95[b]	14.65[a]	14.05[a]	<0.01	2.80
21 Day	17.35[b]	19.30[a]	18.15[b]	<0.01	2.11
28 Day	18.43[b]	26.28[a]	19.54[b]	<0.01	1.59
35 Day	19.05[c]	28.53[a]	24.49[b]	<0.01	3.07
42 Day	23.36[c]	28.95[a]	24.87[b]	<0.01	2.43
49 Day	23.95[c]	30.55[a]	26.93[b]	<0.01	1.45
56 Day	29.04[b]	32.68[a]	30.27[a]	<0.01	2.61
63 Day	33.04[b]	39.08[a]	33.42[b]	<0.01	2.37
Leaf length (cm)					
7 Day	5.69[b]	6.75[a]	6.09[b]	<0.01	1.85
14 Day	8.35[b]	10.25[a]	10.05[a]	<0.01	3.00
21 Day	12.05[c]	13.25[a]	13.05[b]	<0.01	2.19
28 Day	15.48[b]	16.58[a]	16.56[a]	0.010	2.39
35 Day	16.17[c]	19.83[a]	18.33[b]	<0.01	2.89
42 Day	17.06[b]	19.88[a]	18.68[a]	<0.01	3.14
49 Day	19.67[a]	20.64[a]	19.65[b]	0.024	2.12
56 Day	21.04[b]	22.94[a]	22.33[a]	0.012	2.30
63 Day	23.17	23.96	23.12	0.276	2.40
Leaf number (leaf)					
7 Day	2.00[b]	2.00[b]	2.10[a]	<0.01	1.90
14 Day	5.90[c]	7.20[a]	6.80[b]	<0.01	2.05
21 Day	11.80[b]	13.30[a]	11.00[b]	<0.01	2.48
28 Day	12.67[c]	18.47[a]	14.33[b]	<0.01	1.89
35 Day	13.73[b]	19.53[a]	14.87[b]	<0.01	4.17
42 Day	15.04[b]	21.05[a]	16.65[b]	<0.01	4.23
49 Day	17.60[c]	23.87[a]	19.53[b]	<0.01	2.11
56 Day	19.04[c]	23.87[a]	21.31[b]	<0.01	2.37
63 Day	22.01[b]	24.86[a]	23.84[a]	<0.01	2.76

Note: Means followed by different letters in the same row are significantly different according to DMRT at P<0.05; ns = not significant (P>0.05).

Filter cake (100%) demonstrated statistical significance (P<0.05) in promoting melon growth performance in terms of plant height at 7, 14, and 21 days after planting compared to other growing media, yielding height values of 12.00, 34.20, and 95.40 cm,

respectively. This superior growth-promoting efficiency resulted from its richer composition of essential nutrients compared to coconut coir. Filter cake contained nitrogen (N) 1.6%, phosphorus (P) 2.17%, and potassium (K) 0.84%, while coconut coir contained only nitrogen (N) 0.38%, phosphorus (P) 0.06%, and potassium (K) 0.97% (Wongkoon et al., 2014; Prathima et al., 2024). The growth performance results for melon plant height during 7, 14, and 21 days demonstrated that the filter cake growing medium produced the best plant growth outcomes (Bachtiar et al., 2023), which aligns with plant physiological principles where nitrogen plays a crucial role in enzyme and chlorophyll synthesis, resulting in enhanced root system development, leaf development, stem growth, and other plant parts (Marlina et al., 2021).

The higher nitrogen content in filter cake (1.6%) compared to coconut coir (0.38%) resulted in improved nitrogen use efficiency (NUE) and enhanced photosynthetic capacity, as evidenced by the clear increase in leaf number (13.30 leaves at day 21). After 21 days, this growth advantage continued through later stages of development, with 100% filter cake producing consistently higher plant height, stem diameter, and leaf width and length up to 63 days after transplanting (DAS). At harvest, melon plants grown in 100% filter cake reached an average height of 220.61 cm, stem diameter of 15.90 mm, and leaf width and length of 39.08 cm and 23.96 cm, respectively, which were significantly higher than those grown in coconut coir (170.85 cm, 12.95 mm, 33.04 cm, and 23.17 cm, respectively). However, the difference in leaf length at 63 DAS was not statistically significant ($P>0.05$), despite a slightly higher mean value in the filter cake treatment. The number of nodes and leaves also increased continuously in plants grown in filter cake, reaching 24.45 nodes and 24.86 leaves per plant at 63 DAS, compared to 24.03 nodes and 22.01 leaves in the coconut coir treatment. Node numbers were not significantly different ($P>0.05$) at 63 DAS, whereas leaf numbers remained significantly higher in the filter cake treatment. These results indicate that filter cake not only enhanced early vegetative growth but also sustained vigorous growth through the reproductive and pre-harvest stages, particularly in plant height, stem thickness, and leaf development.

The increase in leaf width and length directly reflects the enhanced light interception and carbon assimilation capacity, which are primary factors controlling plant growth. This suggests that filter cake promotes a more developed canopy structure, enabling greater photosynthetic surface area and higher carbohydrate accumulation, which are important for subsequent fruit development.

These experimental results are consistent with research by Handajaningsih et al (2019), who used coconut coir mixed with coconut waste as growing medium and found that melon height and leaf number showed less growth compared to other treatments. They observed that the chlorophyll content in melon leaves was lower than that obtained when using filter cake mixed with rice husk charcoal, which corresponds to the report by Naenon et al. (2017), who found a positive correlation between chlorophyll content and nitrogen content in plant leaves. The positive relationship between leaf nitrogen content, chlorophyll accumulation, and enhanced vegetative growth observed in the present study is consistent with research by Seangngam et al (2021), who investigated Galia cantaloupe grown in sand mixed with bagasse (1:1 by volume). They reported that nitrogen content in cantaloupe leaves showed a statistically significant positive correlation with plant height ($r = 0.486$), indicating that increased leaf nitrogen content resulted in larger stem size and leaves that were thicker and darker green in color.

The higher phosphorus content in filter cake (2.17%) compared to coconut coir (0.06%) similarly resulted in increased chlorophyll a and b content. According to research by Pinpirom et al. (2020), who studied the effects of phosphorus content on growth and antioxidant compounds in sterile Phrommi plants, phosphorus affected plant growth by

influencing plant height, inflorescence height, and leaf chlorophyll content. The mechanism of phosphorus action occurs through its role as a component of coenzymes involved in energy transport processes, including adenosine triphosphate (ATP) and nicotinamide adenine dinucleotide phosphate (NADP), which provide energy for plant photosynthesis processes to fix carbon dioxide, synthesize lipids, and serve as essential components that assist in growth system development and transition from vegetative to reproductive phase, particularly during the critical first 21 days of melon growth when branch and leaf development occur. Overall, the results up to 63 DAS confirmed that 100% filter cake provided a balanced nutrient supply, maintained higher vegetative growth rates, and improved canopy structure, which together contributed to superior physiological performance and plant development throughout the cultivation period.

Similar findings were reported by Suwanree et al (2024), who investigated the nutrient retention and availability of biochars prepared from co-pyrolysis of vinasse and sugarcane filter cake. Their results demonstrated that filter cake-derived materials contained high levels of macronutrients such as K, Ca, and Mg and maintained strong nutrient retention capacity, highlighting their suitability for agricultural applications. Their results support the present findings that filter cake can serve as a nutrient-rich and sustainable substrate for melon production in soilless systems. From this study, it can be concluded that growing media with appropriate nitrogen content is the primary factor promoting photosynthetic efficiency and affecting overall melon growth performance, combined with adequate phosphorus content, which is an essential component in energy transport and metabolic processes. This reflects the importance of selecting growing media with appropriate essential nutrient content for melon cultivation in soilless culture systems.

3.2 Yield performance

The results indicated that different growing media had no statistically significant effect ($P>0.05$) on melon yield and fruit quality parameters, including fruit width, fruit length, flesh thickness, total soluble solids (TSS), and fruit weight (Table 4). However, fruits grown in 100% filter cake showed slightly higher values in all parameters compared to other treatments, with average fruit weight of 1.16 kg and TSS content of 16.69 °Brix, suggesting that the use of filter cake can produce melon fruit quality comparable to or slightly better than coconut coir alone.

The difference in total soluble solids content between growing media may be related to the potassium content in filter cake (0.84%) and coconut coir (0.97%), which are relatively similar, resulting in no statistically significant difference (Seangngam et al., 2021). Nevertheless, the slightly higher TSS value observed in the filter cake treatment is consistent with the findings of Seangngam et al. (2025), who reported that potassium plays a crucial role in sugar synthesis and carbohydrate translocation from leaves to fruits, thereby improving melon sweetness and flesh texture.

These findings imply that filter cake, containing balanced essential nutrients such as nitrogen, phosphorus, and potassium, can effectively support both vegetative and reproductive growth phases, leading to well-developed fruits with desirable quality. This agrees with Tangsuwan & Sangmanee (2018), who found that using bagasse mixed with soil (1:1 ratio) resulted in higher sweetness (15.10 °Brix) in the Kimoji cantaloupe variety, and Chikh-Rouhou et al (2021), who noted that melon fruit quality is largely influenced by nutrient balance within the growing medium, which affects fruit size, flesh thickness, and TSS accumulation.

Table 4. Effects of growing media on fruit quality parameters of melon

Fruit Quality Parameters	Growing Media			P-value	C.V.%
	Coconut Coir Dust 100% (Control)	Filter Cake 100%	Filter Cake 50% + Coconut Coir Dust 50%		
Fruit widths (cm)	13.89	14.02	13.80	0.23	2.93
fruit lengths (cm)	11.96	12.00	11.89	0.21	1.46
flesh thickness (cm)	2.92	3.28	3.10	0.52	1.43
TSS (ºBrix)	15.32	16.69	16.04	0.64	8.12
Weight (kg)	1.14	1.16	0.98	0.17	0.23

Note: Means followed by different letters in the same row are significantly different at $P<0.05$

3.3 Economic profitability

The economic profitability analysis of different growing media types revealed that 100% filter cake exhibited the highest economic profitability in all studied parameters. It achieved the highest sales revenue of 139.20 baht per plant, followed by 100% coconut coir at 136.80 baht per plant, and 50% filter cake mixed with 50% coconut coir with the lowest revenue of 117.60 baht per plant (Table 5).

When considering the return on growing media cost, 100% filter cake showed an outstanding return of 55.68 times, meaning that an investment in this type of growing medium would generate returns more than 55 times the initial investment. Filter cake (50%) mixed with 50% coconut coir provided a return of 27.67 times, and 100% coconut coir showed the lowest return of 22.80 times. Although the return from 100% coconut coir was the lowest, it is still considered a very high return in terms of investment. For gross profit from growing media, 100% filter cake generated the highest profit of 82.70 baht per plant, followed by 100% coconut coir with 76.80 baht per plant, and 50% filter cake mixed with 50% coconut coir with the lowest profit of 59.35 baht per plant. Furthermore, yield per unit investment in growing media demonstrated that 100% filter cake had the highest efficiency at 0.464 kg per baht, meaning that a 1-baht investment in this growing medium would yield 0.464 kg of produce. This was significantly higher than 50% filter cake mixed with 50% coconut coir (0.231 kg per baht) and 100% coconut coir (0.190 kg per baht). The maximum investment efficiency (MIE) calculated for 100% filter cake was 2.46 times per crop cycle, indicating the highest economic performance. In comparison, 50% filter cake mixed with 50% coconut coir yielded 2.02 times, and 100% coconut coir produced the lowest MIE at 2.28 times. These results highlight the superior economic efficiency of filter cake as a growing medium.

In the context of increasing agricultural production costs, particularly the growing medium costs for economically important crops like melon, the factors affecting these cost increases include the unavailability of quality growing media in the area, shortage of distribution sources, and higher growing medium prices. This situation has led farmers to consider using local agricultural waste materials, such as filter cake from sugar factories, which are abundant and can be efficiently utilized in the agricultural sector. Filter cake contains suitable properties for use as a soil amendment, including high organic matter content (up to 42%), improving soil structure, and increasing water and nutrient retention capacity. It has a pH value of 6.7, which is within the appropriate range for plant growth,

and an electrical conductivity (EC) of 1.25 dS/m, which is safe for plant health, along with essential nutrients. The study by Srisaikham and Rupitak (2022) reported that the use of filter cake significantly promoted plant growth, improving parameters such as shoot number, shoot weight, root length, and root weight. Using agricultural waste materials in this manner not only helps reduce production costs but also aligns with the circular economy concept, which emphasizes the maximum efficient use of resources, reduces waste creation, and promotes long-term environmental sustainability. Therefore, this study concludes that using 100% filter cake as an alternative growing medium offers the highest economic profitability due to its low cost (2.50 baht per plant) while providing the highest yield and quality, resulting in superior investment efficiency and returns compared to other growing media types.

Although the study provided valuable insights into the use of filter cake as a growing medium, it is important to note that this research is limited by the use of a single melon variety and a single growing season. Future studies should include multiple melon varieties and span several growing seasons to validate the findings.

Table 5. Effects of growing media on economic profitability of melon production (per plant per crop cycle)

Economic Profitability Parameters	Coconut Coir Dust 100% (Control)	Filter Cake 100%	Filter Cake 50% + Coconut Coir Dust 50%
Gross return (THB/plant)	136.80	139.20	117.60
Variable costs (THB/plant)			
Growing medium	6.00	2.50	4.25
Stock solution A + B	32.00	32.00	32.00
Water and electricity	2.00	2.00	2.00
Labor (nursery, transplanting, training, pollination, fertigation, harvest)	15.00	15.00	15.00
Crop cultural practices (trellis, clips, tool depreciation, sanitation)	5.00	5.00	5.00
Total variable cost	60.00	56.50	58.25
Gross profit (THB/plant)	76.80	82.70	59.35
Return on growing media cost (times/cycle)	22.80	55.68	27.67
Yield per unit investment (kg/Baht)	0.190	0.464	0.231
Maximum investment efficiency (MIE, times/cycle)	2.28	2.46	2.02

Note: Melon selling price = 120 Baht/kg; coconut coir dust price = 3 Baht/kg; filter cake price = 1.25 Baht/kg; stock solution A + B (Pro Agritech Co., Ltd. (Bangkok, Thailand) = 32 Baht/plant/cycle

4. Conclusions

From the research results, it can be concluded that using 100% filter cake as an alternative growing medium in soilless melon cultivation system demonstrated statistically significant efficiency ($P<0.05$) in promoting melon growth, particularly in plant height, node number, and leaf number when compared to 100% coconut coir and 50% filter cake mixed with 50% coconut coir. Regarding fruit quality, although no statistically significant differences were observed, 100% filter cake showed a tendency to produce higher quality yields, with total soluble solids content of 16.69 degrees Brix and average fruit weight of 1.16 kg. In terms of economic profitability, 100% filter cake provided the highest return of up to 55.68 times the growing media cost, meaning that investment in this growing medium would generate returns more than 55 times the initial investment. This high return is due to 100% filter cake having the lowest cost (2.50 Baht per plant) while still providing good yield and quality. Additionally, it provided the highest investment efficiency at 0.464 kg per Baht, meaning that a 1 Baht investment in this growing medium would yield 0.464 kg of melon, which is higher than the other growing media types. Therefore, filter cake represents a high-potential alternative growing medium for melon production in soilless culture systems, as it is cost-effective and can maintain good plant growth and fruit quality. However, it is important to note that the results of this study are limited to 'Khaitongkham Melon' and one growing season. Further research is needed to confirm these findings in other melon varieties and under different growing conditions to generalize the applicability of filter cake as a growing medium for melon cultivation. The results also indicate that the use of filter cake as the growing medium yielded the highest economic return relative to media cost and demonstrated superior investment efficiency. In conclusion, while filter cake showed promise as a growing medium, future research should explore the use of different melon varieties and longer-term studies across multiple seasons. This will help deepen scientific understanding of the practical applications of alternative growing media in sustainable agriculture.

5. Authors' Contributions

Janejira Namee and Panut Sooksoi designed research;
Janejira Namee and Natthakarn Pisutpiboonwong performed research;
Janejira Namee and Panut Sooksoi analyzed data;
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6. Conflicts of Interest

The authors declare no conflicts of interest.

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