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Production Planning for Spinach, Kale, and Hydroponic Pakchoi Using Linear Programming

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Abstract: Vegetable consumption has been on the rise in 2024, and projections suggest that by 2030, it will reach 17.48 million tons, equivalent to 62.4 kg per capita per year. This growing demand presents a valuable opportunity for 13,019 individual agricultural businesses engaged in urban farming. One of the key advantages of hydroponic vegetables is their freshness, as they are sold along with the hydroponic installation itself. However, producing hydroponic spinach, kale, and pakchoy comes with challenges, especially for companies looking to optimize production costs. This study aims to identify the best production combination to minimize expenses. Using linear programming analysis through the LINDO application, this study examines decision variables—hydroponic spinach (H1), kale (H2), and pakchoy (H3)—with constraints based on both internal factors (seeds, nutrients, growing media, planting holes, and labor) and external factors (customer demand). The results indicate a 2.14% cost reduction, amounting to Rp. 8,148,745, with an optimal production mix of 2,696 units of hydroponic spinach, 2,101 units of hydroponic kale, and 2,448 units of hydroponic pakchoy. To further improve cost efficiency, PT Sarindah Wicaksana is advised to carefully allocate resources based on optimal demand and implement a well-structured production plan.

Keywords: Agricultural optimization; Hydroponics; Linear programming; Production; Resource allocation

Introduction

Vegetables are a highly nutritious food source for the community. They are generally horticultural crops with a relatively short lifespan of less than a year (Muchtadi et al., 2016). In Indonesia, vegetable consumption is significant, with data from the Kementan (2021) showing an average consumption of 50.74 kg per capita per year from 2016 to 2020, with a 2% annual increase. However, during and after the pandemic (2021-2023), vegetable consumption decreased to 38.18 kg per capita per year, with a growth rate of 1.3% (BPS, 2024). 2024 marks the beginning of an economic recovery after the COVID-19 pandemic, leading to an increase in vegetable consumption. It is forecasted that by 2030, vegetable consumption will reach 17.48 million tons, equivalent to 62.4 kg per capita per year (Sonjaya et al., 2021).

Vegetable consumption at the household level is influenced by food management. According to Mulyo et al. (2022), household income and the number of family members are key factors closely correlated with household food consumption management. This creates a potential demand for vegetables and an opportunity for the 13,019 individual agricultural businesses engaged in urban farming (BPS, 2023).

Hydroponics is considered one of the agricultural solutions for the future, particularly in the production of

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leafy vegetables. The hydroponic system is a production method that significantly contributes to the environment, economy, and society, as well as offering flexibility (Susilawati, 2019). Hydroponics enables the modification of sustainable production growth media, conserving rapidly depleted land and available water resources (Qadeer et al., 2020). Additionally, hydroponics is beneficial for urban agriculture (Engelseth, 2023).

Various forms of hydroponics, both commercial and non-commercial, such as aquaponics and vertical production, have been researched (Gustavsen et al., 2022). Hydroponic systems based on the type of water are divided into several types, namely DWC (Deep Water Culture), NFT (Nutrient Film Technique), FHS (Floating Hydroponic System) or floating rafts, DFT (Deep Floating Technique), Ebb and flow (tides) including aeroponics (Aini & Azizah, 2018). This system needs to be continuously monitored for nutrient flow to ensure optimal product yield (Chabla et al., 2019; Nguyen et al., 2016).

Cultivation activities with hydroponic methods tend to be in demand by young people in farming, because it seems more classy, far from the impression of slums, and uses technology that young people are interested in. This answers the concerns about kindergartens in agriculture that are getting older so that the sustainability of agricultural production can be expected (Arvianti et al., 2019). The adoption of agricultural technology can improve production systems (Onuwa et al., 2023).

Rabbani et al. (2017) stated that the advantage of hydroponic vegetables is that vegetables remain fresh because they are marketed with hydroponic installations. But in terms of weakness, there are striking price differences between retailers. The opportunity is that raw materials are always available, while the threat of products is limited to vegetables that are in great demand by consumers.

Another advantage of hydroponic plants is that they consume nutrients more effectively and efficiently (Herwibowo & Budiana, 2014) and tend to avoid diseases and pests that attack the soil (Nurlaeny, 2014; Chabla et al., 2019), allowing the company to save on production costs.

Good production planning is essential for minimizing company losses related to unsold vegetable products and for producing goods according to market needs (Abidin et al., 2020). Linear programming models are commonly used to find optimal solutions within certain constraints by analyzing maximum or minimum objective functions for specific scenarios (Chanda et al., 2022). They offer the best results in mathematical models where the requirements are represented by linear relationships (Krynke & Mielczarek, 2018) and help to enhance performance (Goel et al., 2018). Linear programming is the most suitable method for fresh fruit and vegetable supply chains (Nguyen et al., 2016). Crude Palm Oil (Marimin & Zavira, 2020), water supply systems (Shah & Shah, 2008), and transportation (Prifti et al., 2020).

The formation of a linear programming model is based on three main elements: decision variables, goal functions, and constraint or restriction functions (Coronado-Hernández et al., 2021). The constraints are related to raw material resources, money/capital, time, and labor (Akbar & Mar'aini, 2022). To increase the competitiveness of vegetables, integrated management is necessary, starting from the supply of raw materials, production planning, and inventory control. A system of production planning and control is essential to achieve this (Handayani & Yuliarso, 2022).

PT Sarindah Wicaksana, also known as Kebun Wira, is a company that specializes in producing vegetables using the NFT hydroponic system method. The vegetables produced by Kebun Wira include spinach, kale, Pakchoi, curly lettuce, Dolorosa red lettuce, romaine lettuce, caisim, and kailan. Among these, spinach, kale, and pakchoi are the most in demand. These three vegetables are the focus of a study aimed at minimizing the cost of hydroponic vegetable production.

Based on the above background and problems, it was necessary to conduct research on "Production Planning of Hydroponic Spinach, Kale, and Pakchoi with Cost Minimization Approach." Therefore, the purpose of this study is to analyze production planning that can reduce the minimum production cost in the NFT hydroponic vegetable system.

Method

The research was conducted at PT. Sarindah Wicaksana, also known as Wira Garden, in Central Bogor District, Bogor City, West Java, from October to December 2022. The study utilized primary data from production managers and production garden management staff.

Data analysis involved *linear programming*, including primal analysis, dual analysis, and sensitivity analysis (Liang, 2023), with data calculations processed using *LINDO* software.

The initial stage of the analysis focused on determining decision variables for minimizing hydroponic vegetable production costs. The decision variables examined in this study were hydroponic vegetable spinach (H1), kale (H2), and pakchoi (H3). These three types of vegetables have the highest and most consistent demand.

The objective function aimed to minimize production costs.

$$\text{Min } C = \sum_{i=1}^{n} F_i H_i \quad (1)$$

Where
C = Production costs to be minimized (Rp)
F_i = Total production input cost per unit of type i vegetable product (Rp/unit)
H_i = i th number of hydroponic vegetable product outputs (units)
i = Types of hydroponic vegetable products (units)
n = Number of types of hydroponic vegetable products

The constraint function is examined from two perspectives: internal and external production. Internally, there are 5 inputs: vegetable seeds, A-B mix nutrient solution, planting media (rockwool), planting holes in NFT hydroponic system installations, and labor. Externally, there is a demand for hydroponic vegetables from customers and households. Under the model's assumption, fixed cost elements remain unchanged in the short term and are therefore disregarded.

The next step involves conducting a sensitivity analysis to determine the allowable limits in case there is a change to the previously obtained optimal solution.

Result and Discussion

Resource Capacity

In order to produce spinach, kale, and hydroponic pakchoi vegetables in Kebun Wira, a specific amount of resources is required. The availability of these resources is limited, as shown in Table 1, which outlines the respective capacities of each resource.

Table 1. Resource Capacity

Resources	Capacity/Month
Spinach Seeds	15,625 grains
Kale Seeds	4,800 grains
Pakcoy Seeds	5,400 grains
Nutrient Solution	150,000 ml
Rockwool	9,216 boxes
Planting Holes	8,400 holes
Labor Hours	400 hours
Spinach Demand	2,696 units
Kale Demand	2,101 units
Pakcoy Demand	2,448 units

Source: Primary Data Processed, 2023

Production Cost

The costs calculated in this study are limited to the variable costs needed for the hydroponic production of spinach, kale, and pakchoi. Costs that are not directly related to production purposes were not included in this study. For details on the production cost calculation for spinach, kale, and hydroponic pakchoi vegetables in Kebun Wira, please refer to Table 2.

Primal Analysis

Primal analysis is conducted to determine the most efficient combination of products that aligns with the goal of production optimization, specifically minimizing costs. This analysis leads to the lowest production costs incurred by Kebun Wira.

Table 2. Vegetable Production Cost per Unit

Cost Component	Production Cost (Rp/Unit)		
	Spinach	Kale	Pakchoi
Seeds	1.56	16.7	25
Rockwool	29	29	29
AB *Mix* Nutrition	153.46	153.46	153.46
Power	104.7	130.7	119.5
Workforce	368.3	368.3	368.3
Depreciation Cost	406.2	490.5	442.3
Total Production Cost	1063.22	1188.7	1137.6

Source: Primary Data Processed, 2023

The primal analysis is based on the company's objectives. The objective function in this study is a mathematical equation used to achieve the optimal production combination and minimize production costs. Referring to Table 2, the objective function for minimizing production costs can be formulated as follows:

$$C \text{ min} = 1063.22H_1+1188.7H_2+1137.6H_3$$

The results of the primal analysis obtained in Table 3 are based on the function of these objectives, which are then analyzed *using* LINDO software. The combination of producing three types of vegetables, as shown in Table 3, results in minimal production costs for spinach, kale, and pakchoi.

Table 3. Primal Analysis Results

Decision variables	Types of vegetables	Value	Reduce Cost
H_1	Spinach	2,696	0
H_2	Kale	2,101	0
H_3	Pakchoi	2,448	0
Total Cost			Rp 8,148,745

Source: Primary Data Processed, 2023

Dual Analysis

Dual analysis is a method used to assess resources. It is based on a constraint function that considers vegetable seed resources, A-B mix nutrient solution, growing medium (rockwool), planting pits, labor, and vegetable demand. Each of these constraints is described as follows:

Seed Constraints

The required number of seeds for each type of vegetable unit varies. Spinach vegetables require 5 seeds for one vegetable unit, while kale and pakchoi vegetables each require 2 seeds for one plant unit. Based on the resource constraints in Table 1, the constraint functions for spinach, kale, and pakchoi seeds are as follows:

Spinach $5h_1 \geq 15{,}625$
Kale $2h_2 \geq 4{,}800$
Pakchoi $2h_3 \geq 5{,}400$

Nutrient Solution Constraints

The nutrient solution used for hydroponic production in Kebun Wira is an AB mix nutrient solution with limited capacity (refer to Table 1). The nutritional requirement for all types of plants per unit is 15.35 ml. The constraints of the AB mix nutrient solution *are* as follows:

$$15.35h_1+15.35h_2+15.35h_3 \geq 150{,}000$$

Planting Media Constraints

The planting media utilized by Kebun Wira is rockwool (Table 1). Each plant requires one box of rock wool. The constraints of the planting media function are as follows:

$$h_1+h_2+h_3 \geq 9{,}216$$

Planting Hole Constraints

The planting hole required for the production of each type of vegetable is 1. The constraints for the planting hole are as follows:

$$h_1+h_2+h_3 \geq 8{,}400$$

Labor Hour Constraints

Labor required to produce hydroponic vegetables is 0.04 hours per unit for all types of vegetables. The labor hour constraint functions are as follows:

$$0.04h_1+0.04h_2+0.04h_3 \geq 400$$

Demand Constraints

On average, the demand for the three types of vegetables varies (Table 1). The demand constraints function for spinach, kale, and pakchoi vegetables is as follows:

Spinach $h_1 \geq 2{,}696$
Kale $h_2 \geq 2{,}101$
Pakchoi $h_3 \geq 2{,}448$

Based on the overall constraint function of each resource, the dual analysis results are presented in Table 4.

Table 4. Dual Analysis Results

Constraint	Slack or Surplus	Information	Dual Price	Information
Spinach Seeds (grains)	2,145	Excess	0	Inactive
Kale Seeds (grains)	598	Excess	0	Inactive
Pakcoy Seeds (grains	504	Excess	0	Inactive
AB Mix Nutrition (ml)	38,789.25	Excess	0	Inactive
Rockwool (boxes)	1,971	Excess	0	Inactive
Planting Holes	1,155	Excess	0	Inactive
Labor Hours	110.2	Excess	0	Inactive
Spinach Demand (units)	0	Fulfilled	1,066.63	Active
Kale Demand (units)	0	Fulfilled	1,192.1	Active
Pakchoi Demand (units)	0	Fulfilled	1,141	Active

Source: Primary Data Processed, 2023

Sensitivity Analysis

Sensitivity analysis is a method used to measure how changes in certain values or amounts can affect optimal conditions. This analysis is performed on both the goal function, which represents changes in production cost objectives, and the constraint function, which represents changes in available resources. The goal is to ensure that even with potential changes, the optimal conditions can still be maintained.

Production Cost Sensitivity

Sensitivity analysis of production costs depends on its purpose. Table 5 shows the results. The allowable decrease in the cost of spinach, kale, and pakchoi vegetables is limited to Rp. 1,063.22, Rp. 1,188.7, and Rp. 1,137.6, respectively. This means that the reduction in the production cost of these vegetables is capped at those values. On the other hand, the allowable increase value is unlimited. This indicates that the additional production costs of the three types of vegetables are not restricted in quantity, as the addition will not impact the minimum cost conditions that have been previously established.

Table 5. Cost Sensitivity Analysis of Hydroponic Vegetable Production

Decision Variables	Types of Vegetables	Current Coefficient Rp/Unit	Allowable Increase Rp/Unit	Allowable Decrease Rp/Unit
H_1	Spinach	1063.22	Infinity	1063.22
H_2	Kale	1188.70	Infinity	1188.70
H_3	Pakchoi	1137.60	Infinity	1137.60

Source: Primary Data Processed, 2023

Resource and Demand Sensitivity

The optimal conditions may result in limited changes in the supply of key resources and demand at increasing or decreasing capacity. The results of the sensitivity analysis on resources and demand are presented in Table 6.

The maximum allowable increase value for all resources is infinity, meaning there is no limit to the increase in the quantity of each resource. However, the allowable decrease value for each resource is finite and varies. In Table 6, the allowable decrease value for each resource is equal to the slack or surplus value in the dual analysis. This allowable decrease value indicates the limit of reduction in the quantity of resources resulting from the use of previously unused resources. If the reduction exceeds the allowable decrease value, the quantity of resources falls below the optimal resource capacity limit, affecting the optimal product combination

Table 6. Resource and Demand Sensitivity Results

Constraint	Current RHS	Allowable Increase	Allowable Decrease
Spinach Seeds (grains)	15,625	Infinity	2,145
Kale Seeds (grains)	4,800	Infinity	598
Pakcoy Seeds (grains	5,400	Infinity	504
AB Mix Nutrition (ml)	150,000	Infinity	38,789.25
Rockwool (boxes)	9,216	Infinity	1,971
Planting Holes	8,400	Infinity	1,155
Labor Hours	400	Infinity	110.2
Spinach Demand (units)	2,696	429	293
Kale Demand (units)	2,101	299	138
Pakchoi Demand (units)	2,448	252	120

Source: Primary Data Processed, 2023

The allowable increase in demand for spinach, kale, and hydroponic pakchoi vegetables is 429 units, 299 units, and 252 units, respectively. This also means that the allowable decrease in demand for each vegetable is limited to 293 units for spinach, 138 units for kale, and 120 units for pakchoi.

Based on the results of previous analyses, we can obtain production planning recommendations that will minimize production costs compared to current conditions. The recommendations for planning the production of spinach, kale, and hydroponic pakchoi vegetables in Kebun Wira are detailed in Table 7.

Table 7. Actual and LP Hydroponic Vegetable Production Planning Recommendations

Decision Variables	Types of Vegetables	Production (Unit)		Expenditure (Rp)	
		Actual	Minimum	Actual	Minimum
H_1	Spinach	2,693	2,696	2,863,251	2,866,441
H_2	Kale	2,230	2,101	2,650,801	2,497,459
H_3	Pakchoi	2,473	2,448	2,813,285	2,784,845
Total		7,396	7,245	8,327,337	8,148,745

Source: Primary Data Processed, 2023

Based on Table 7, it is known that the total production plan under minimum cost conditions is 7,245 units of planting pits, including 2,696 units of spinach, 2,101 units of kale, and 2,448 units of pakchoi. The actual total production exceeds the minimum cost conditions by 2.04%. This difference in production between the minimum cost and actual conditions results in varying expenses. The total expenditure under minimum cost conditions is slightly smaller than under the actual conditions. The expenditure in the minimum cost condition is Rp. 178,593 or 2.14% more efficient than the actual condition.

The recommended production cost savings are minimal due to the limitations of the cost minimization model. The cost calculation only considers variable costs while ignoring fixed costs, marketing expenses, and other factors. According to Arapostathis and Borkar (2021), certain costs cannot be controlled, necessitating a more sensitive formula.

Conclusion

The company's profit growth can be achieved by increasing internal resources to meet customer demand. This is evident from the production cost increase, which is considered infinite (unrestricted). The optimal product combination that minimizes costs consists of hydroponic spinach, water spinach, and pak choy, produced in the following quantities: 2,696 units of spinach, 2,101 units of water spinach, and 2,448 units of pak choy. This combination incurs a production cost of Rp. 8,148,745, resulting in a 2.14% cost reduction compared to the actual condition. Based on the study's findings, the following recommendations are proposed: Kebun Wira should consider resource allocation by optimizing demand, implementing production planning, and adjusting operational strategies, as the minimal cost achieved does not significantly differ from the actual production cost.Future research can be extended to other hydroponic crops by incorporating additional cost components related to production and marketing activities, leading to more comprehensive results.

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Author Contributions
L.I.I.: Developing ideas, analyzing, writing, reviewing, responding to reviewers' comments; R.A.R., T.I., R.A.P.S., A.M.: analyzing data, overseeing data collection, reviewing scripts, and writing; A.T.N.: reviewing and writing scripts.

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Conflicts of Interest
The authors declare no conflict of interest.

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