Virtual Plant Computational Model of Green-Leaf Vegetable Plant Bok Choy (Brassica chinensis L.) for Investment Decision

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Abstract. Plant computational modelling is a part of ecological informatics. It is a research domain that model the plant/s and is correlated to an environmental issue. A vegetable is one imperative plant. It has an important role in aspects of health, the environment, and also the economy. The study was performed to make a plant computational model of the green-leaf vegetable plant Bok Choy that can suggest the environment-oriented decision in agriculture investment. Two methods functional structural plant modelling (FSPM) and simple mathematics are operated respectively to model the Bok Choy plant morphologically and the decision recommendation. The study produced the morphological 3-dimension (3D) model of the forty-five-day-age plant Bok Choy and investment decision to plant Bok Choy in a hydroponic system.

1. Introduction
Vegetable plant is strongly correlating to aspects environment, health, and economy. In Indonesia, specifically it has imperative role to such aspects. The depth study regarding vegetable should be widely done, exceedingly the study interconnected with other research area, such as computer science domain.

Plant computational model (PCM) is a research domain possibly we are able to see plant growth and its correlation with other aspects in detail. PCM is a virtual laboratory presents how the plant grows morphologically. The studies in PCM domain were many. For examples, [1] developed the virtual rice plants model that proposed the best rice plant architecture in intercepting the sun light. The best one was hypothetically able to give the best yield. It was a part of [2] big work in developing the optimization model of 3-d structure of plant.

Furthermore, [3], who conducted a basic study of the graph that is implemented into basic virtual plant modeling. [4] conducted a study on modeling of young spruce plants. Where, the modeling results enabling the growth of the evergreen plant to be seen more realistically (rightly so with the original). And also [5] who modelled apple plants using GroIMP-FSPM. Then, the newest study, the virtual plant Green Amaranth was constructed well by [6]. It is still a preliminary study; however, it has good potential opportunity to deeply researched, as the study was talking about a unique Indonesian plant.

Here, we conducted the research in PCM domain, with Bok Choy that planted in hydroponic system as an object of the research, that associated with decision support model (DSM).
suggesting the objective decision based on environmental features. The introduction part of the paper is going to be continued by other parts respectively; related works, research methodology, result and discussion, and conclusion and further works.

2. Related Works

One promising approach to simulation in plant science is represented by FSPM. Indeed, the FSPM or virtual plant is a new generation model that can be used to assess the performance of plants in the virtual world by processing parameters structure and 3-D development. FSPM also explicitly reflects structural aspects plant architecture, internal functional aspects, and environmental impacts [7]. All it allows the growth of people and individuals and the level of the plant stand itself. One of the pioneering researchers was from de Reffye and colleagues in 1988. In the other study, [8] combined qualitative botanical analysis and quantitative statistical analysis to create a 3-D tree architectural simulation model with agroforestry applications, using data categorized into processes growth, branching processes, and geometric aspects. [9] designed a LIGNUM model that depicts a 3-D tree canopy (segments, branching points, and shoots) and defines deep growth it has to do with carbon metabolism that occurs in units corresponding to organs tree.

Lindenmayer and Prusinkiewicz use the L-system, which is a system of rewriting strings parallel, to represent the architectural development of plants [10]. This formal language theory approach is used to simulate ontogenesis in dependence on the light regime in plant crops such as maize [11,12] and wheat [13]. In the field of forest ecology, [14] developed the FSPM to calculate the annual photosynthetic gain in beech saplings (Fagus crenata). The calculation of the annual photosynthetic gain was used to find out the effect of leaf phenology and shoot slope on the carbon economy. With spirit Similarly, [15] used FSPM as a virtual laboratory for evaluating the effect of alternative local plant architectures on the performance of the entire canopy. He obtained results about the functional significance of foliage parameters for understanding the architectural development of plants and their foliage. Likewise, [16] used FSPM to investigate the effect of geometric properties (internode length, area leaves, angle of branching and shoot diameter) on the efficiency of tree light interception Apple.

3. Bok Choy

In this study, vegetable plant Bok Choy is taken as a research object. Bok Choy itself is a vegetable plant that has much vitamin ingredient; it consists of more than 50% vitamin C and is similar with Orange [17]. It is usually used to consume. It is categorized as short-age vegetable plant; it is habitually harvested when it has age 40 ± 5 days after seedling.

4. Research Methodology

Three main stages of the study are obviously mentioned in Figure 1; they are plant seeding and planting, data collecting, and model developing. Vegetable plant Bok Choy was seeded (see the seeds in Figure 2.A.) and planted in a hydroponic system. It was seeded in rock-wool with size 2.5 X 25 X 15 cm; where size 2.5 X 2.5 X 2.5 cm practically operated for one plant. Thus, there are 60 Bok Choy seeds in one rock-wool area (see Figure 2.B.), they started to appear in the second day after seeding (DAS). And, when they had approximately three or four real-leaves, they were ready to be moved in to each 7 cm height-size net-pot and putted in hydroponic system (see Figure 2.C.) with the type of water culture system. The composition of AB Mix nutrition in the water and water PH were designed with values 0.3% and 7.00 respectively; with uncontrolled natural sun light.

Furthermore, data collecting was performed. It was done day per day to observe above-ground-plant Bok Choy’s growth morphologically. The growth of Bok Choy’s main-stem, petioles, and leaves were precisely watched and examined. It was performed to 10%-20% of
planted plants (only the best plants selected). Moreover, the plant virtual model was developed. The data collected to be delivered in mathematical model and then coded in GroIMP modeling platform. FSPM and Fuzzy-logic methods were operated to construct it, respectively they functioned in making virtual plant model and decision support model.
5. Result and Discussion
The constructed virtual Bok Choy plant model is novel. Several researchers ever talked about virtual plat of apple, rice, pine, etc. the virtual Bok Choy plant has a unique characteristic. It has soft stem and it could be eaten. It has stack stem and continuously grow until 25 peaches of stem.

5.1. Plant’s Growth Model
Morphologically, the above-ground plant Bok Choy with 20 day-age is presented via toy picture without texture in Figure 3 and toy picture with texture in Figure 4. It consists of main-stem, petiole, preliminary leaves (red, blue, yellow, and grey), and preliminary leaves (the green ones). Abnormally, the second real leaf has worse performance than the first real leaf. However, for third real leaf until n-th real leaf indicate that the next leaf has better performance.

The mathematical model for illustrating the real leaf length ($RLL_{ln}$), real leaf width ($RLW_{ln}$), real leaf petiole length ($PL_{ln}$), and real leaf petiole diameter ($PW_{ln}$) are respectively presented in equations (1) – (4); where $ln$ is a leaf number (3 until n); $lpn$ symbolizes a leaf petiole number (3 until n), $A$ denotes a plant age, $SD$ represents a starting day for growing, and $ED$ signifies an ending day to grow. Each leaf and its petioles grows around 12 days maximally where it starts to grow in every 3 days (and all plant organs’ areas calculated by using basic mathematical conception).

The variable $dayAppear$ means the $i$–th day from stem, petiole, or leaf starting to grow. The specific condition is operated to model the increment of diameter or width of stem and petiole; where the increment value is 0.025 cm ± random(0.00 cm, 0.025 cm) in one particular condition. For example, the main-stem’s diameter increase 0.0063 cm in the 8-th day.

\[
RLL_{ln} = \sum_{i=SD}^{ED} ln\left(\left(-0.0014(A - i) + 0.1284\right) \pm rand\left(0, (-0.0013(A - i) + 0.0588)\right)\right) \tag{1}
\]

\[
RLW_{ln} = \sum_{i=SD}^{ED} ln\left(\left(-0.0013(A - i) + 0.0766\right) \pm rand\left(0, (-0.0008(A - i) + 0.0355)\right)\right) \tag{2}
\]
Figure 4. Toy with Texture Model of above-ground Plant Bok Choy.

\[ PL_{lpn} = \sum_{i=SD}^{ED} lpn[(0.006(A - i) + 0.0337) \pm rand((0, (0.0028(A - i) + 0.0194)))] \] (3)

\[ PW_{lpn} = \sum_{i=SD}^{ED} lpn[(0.002(A - i) + 0.0021) \pm rand((0, (0.0011(A - i) - 0.0002)))] \] (4)

The trend graph of \( RLL \) (the blue line) and \( RLW \) (the orange one) in 12 days (in average value from ten types of real leaf) could be presented in Figure 5. Both trends grow linearly. Furthermore, the trend-line of \( RLL \) and \( RLW \) respectively configured in equations (5) and (6), where \( x \) is a day. On the other hand, the trend graph of \( PL \) (the blue line) and \( PW \) (the orange one) are displayed clearly in Figure 6. Those trends expand slight-exponentially. They are formulated in equations (7) and (8) correspondingly.

Figure 5. Average RLL and RLW in Twelve Days.
\[ f(x) = 0.9159x + 0.035 \quad (5) \]

\[ f(x) = 0.4723x + 0.0411 \quad (6) \]

Figure 6. Average PL and PW in Twelve Days.

\[ f(x) = 0.4341e^{0.2493x} \quad (7) \]

\[ f(x) = 0.0434e^{0.322x} \quad (8) \]

Figure 7 shows horizontally (also vertical show in Figure 8) the artificial model of above-ground 25 Bok Choy plants planted in one hydroponic area with planting distance 4.0cm. The model constructed via real texture of stem, petiole, and leaf lamina of twenty-day-age Bok Choy plant. They mostly consist of two preliminary and five real leaves.

Figure 7. Artificial Plants of Above-Ground Twenty-Day-Age Bok Choy in Horizontal View.
Figure 8. Artificial Plants of Above-Ground Twenty-Day-Age Bok Choy in Vertical View.

5.2. Weight and Nutrition Simulation
Finally, the model is able to simulate the weight of each plant. For example, Figure 9 shows the plant weight for ten plants, with average 18.69 g ± 0.02 g. It is also able to reproduce nutrition ingredient data (weight on average) for each virtual plant. Table 1 represents such data (e.g. protein, carbohydrate, vitamin C, etc.). The nutrition value of weight is calculated via equation (9), where $N_{ij}$ signifies a value of $i$th nutrition type for $j$th plant, $c_i$ symbolizes coefficient of $i$th nutrition type, and $w_j$ is a $j$th plant weight up to current age.

$$N_{ij} = c_i w_j \tag{9}$$

5.3. Investment Decision
One decision could be proposed from the model is investing decision. For assumption for operational investment that presented in Table 2, the investors can start to get the profit when they harvest the plants in second period, when they planted around 15,280 plants. The simulation result of the profit in the second period of harvest is shown in Table 3. Then, the graph of cost (blue line), sale (orange line), and profit (grey line) for the second period of harvest is displayed in Figure 10; where type of plant planted number is taken from column of plant planted number in Table 3. In Figure 10 shows the type 7 indicating that the investment is going to give a profit. All model assumptions functioned are the normal condition.
Figure 9. The Plant Weight for Ten Plants (in gram).

Table 1. Nutrition Ingredient of One Plant (on Average).

| No | Nutrition   | Weight (on Average) |
|----|-------------|---------------------|
| 1  | Calorie     | 8.81 g              |
| 2  | Protein     | 1.03 g              |
| 3  | Carbohydrate| 1.50 g              |
| 4  | Fiber       | 0.69 g              |
| 5  | Calcium     | 72.45 mg            |
| 6  | Iron        | 0.57 mg             |
| 7  | Zinc        | 0.13 mg             |
| 8  | Vitamin C   | 30.84 mg            |
| 9  | Vitamin A   | 152.73 mcg          |
| 10 | Vitamin K   | 31.23 mcg           |

Table 2. Assumption of Operational Investment Percentage.

| No | Operational Investment | Point |
|----|------------------------|-------|
| 1  | Net pot                | 0.34  |
| 2  | Water place            | 0.27  |
| 3  | Styrofoam              | 0.27  |
| 4  | Rock-wool              | 0.08  |
| 5  | Seeds                  | 0.04  |
Table 3. Simulation Result of Investment.

| No. | Plant Planted Number | Sale (IDR)  | Profit (IDR)          |
|-----|----------------------|-------------|-----------------------|
| 1   | 1                    | 659.43      | -3,199,790.57         |
| 2   | 10                   | 6,594.28    | -3,197,905.72         |
| 3   | 100                  | 65,942.84   | -3,179,057.16         |
| 4   | 1000                 | 659,428.44  | -2,990,571.56         |
| 5   | 5000                 | 3,297,142.22| -2,152,857.78         |
| 6   | 10000                | 6,594,284.44| -1,105,715.56         |
| 7   | 15280                | 10,076,066.62| 66.62                |
| 8   | 30000                | 19,782,853.32| 3,082,853.32         |
| 9   | 50000                | 32,971,422.20| 7,271,422.20         |
| 10  | 70000                | 46,159,991.08| 11,459,991.08        |
| 11  | 90000                | 59,348,559.96| 15,648,559.96        |
| 12  | 100000               | 65,942,844.40| 17,742,844.40        |

Figure 10. Cost, Sale, and Profit Comparison.

5.4. Discussion
The model of virtual plant that combined with decision support model for making a strategical decision in hydroponic investment was successfully constructed. The model can show the simulation in 3D environment of plant growth in detail. Model can give any information insight concerning plant growth, vitamin ingredient per plant, and also can model the investment that can be taken by investment. The parameters considered in investment are cost, sale, and also profit. The model can show the break event point when the investor starts getting the profit.

It is a novel model. There is no researchers, in domain PCM, constructed the model combining PCM and DSM in one model. Here, the constructed PCM can supply the data and information to be operated by the developed DSM for suggesting the investment decision.
6. Conclusion and Further Work
The virtual plant model has been successfully constructed. It is able to be operated to see in detail various element mathematically and statistically in 3d agronomical based view. A plant growth was simulated well and it can also be functioned for any purposes in agronomy research domain. Other research fields have opportunities to benefit the constructed model to do other studies. The optimization field is open to do, particularly to optimize plant growth in several factors; weather, land condition, and also vitamin. Thus, the decision maker can take a right decision to select the best way in planting. Also, a field of decision support model is still open to study. The model should be developed to be benefited by a large number of stakeholders; government, agronomist, researchers, and also farmers.

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