Trends in Horticulture (2023) Volume 6 Issue 2
doi: 10.24294/th.v6i2.2809

ORIGINAL RESEARCH ARTICLE

Modeling in estimation of cucumber (*Cucumis sativus* L.) fruit weight based on fruit length and diameter in response to harvest option

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ABSTRACT

Cucumber (*Cucumis sativus* L.) is a tropical vegetable and a source of vitamins such as K, C, and B. It is commonly grown and sold for daily consumption, but picking the right fruit size is more profitable. Therefore, a method for estimating the fruit weight is highly recommended. This paper aimed to determine the dimensions of cucumber fruit based on its usual harvesting size and to establish a model to show the relationship between fruit weight, fruit length, and fruit diameter. Cucumber was planted in the experimental field belonging to the Faculty of Agricultural Biosystems Engineering, Royal University of Agriculture, Phnom Penh, Cambodia, from January to June 2022. In the study, 48 market-size fruits were randomly selected from the plots to measure their weight, length, and diameter. The result shows that fruit length and fruit diameter had a positive relationship ($P < 0.001$; $R = 0.70$). Fruit weight was 3.38 fruit length × fruit diameter ($P < 0.001$; $R = 0.95$). Nevertheless, *L/D* ratio negatively affected fruit weight, when it exceeded 3:1. Fruit weight was greater than 100 g when fruit diameter was over 4 cm and fruit length was over 10 cm. Therefore, when picking cucumber fruits, one must consider fruit length and diameter to be profitable. Further studies will focus on measuring cucumber fruit already available on the market to understand more about actual consumer preferences.

Keywords: cucumber; profitable; relationship; fruit size; linear regression

ARTICLE INFO

Received: 6 September 2023
Accepted: 25 September 2023
Available online: 8 October 2023

1. Introduction

Cucumber (*Cucumis sativus* L.) is known to be a popular commercial vegetable crop grown and eaten worldwide[1]. It also is a source of vitamin K (14%–19%), B and C, fiber, minerals, phosphorus, potassium, and magnesium, all of which are good for body growth and disease prevention[2]. The human body can be hydrated by the water content present in cucumber, while its fiber can boost digestive systems by preventing constipation[3]. It is native to Asia and Africa and has been consumed for 3000 years. Cucumber contains 96% water content, and they can expire very fast. So, they are normally consumed fresh, or in preserved form[4].

Cucumber fruit size and shape are considered to be primary factors and are the basic criteria for market classes at the commercial harvest stage because they determine yield and quality[5,6]. Some studies suggest that fruit length and fruit diameter are the main factors that determine cucumber fruit size and shape[7,8]. The standards for cucumber market type differ in fruit length and fruit diameter according to the demand by specific countries[9]. Cucumber fruit length should be picked when it is in the range of 16 cm–20 cm[10]. According to Bayer[11], marketable cucumber fruit size should have a length of 30 cm–35 cm and a diameter of 4.1 cm–4.7 cm. Some countries may need smaller fruit diameter (2

cm–2.5 cm) and smaller fruit length (13 cm–16 cm)[12]. However, not many studies have been conducted to find the relationship between cucumber fruit weight, fruit length, and fruit diameter. Thus, establishing any modeling to detect a relationship among cucumber fruit dimensions can contribute toward proper fruit size selection and easy estimation, which can be beneficial for similar fruit research work, or picking decisions by vegetable growers. The purpose of this study was to determine how the width and length of the cucumber affect its weight. The specific objectives were: (1) to determine the dimensions of cucumber fruit based on its usual harvesting size and (2) to establish relationships between fruit weight, fruit length, and fruit diameter.

2. Materials and methods

The cucumber used for this modeling was picked from the experimental plots located at the experimental field belonging to the Faculty of Agricultural Biosystems Engineering, Royal University of Agriculture, Phnom Penh, Cambodia (11.5117° or 11°30'42"; 104.9011° or 104°54'4"). The soil type was sandy loam (sand = 60%) and pH was 5.9 and 5 at soil depth of 0 cm–10 cm and 10 cm–20 cm, respectively. The experimental period started from January to June 2022, which was in the dry season.

Cucumber was planted in a nursery field for 14 days before being transplanted to four prepared plots, each 10 m^2. Some studies reported that a plot size of 5 m^2–8 m^2 is enough for cucumber planting[13–15]. Plant spacing and row spacing were 50 cm and 60 cm, respectively, which is in the range of recommended planting[16]. In each plot, an average of 20 seedlings were planted, watered, cared for, and applied with fertilizer in similar ways and amounts according to the recommended cucumber production. However, the study focused on fruit size only; therefore, at the harvest stage, 4 marketable fruits were randomly selected for measurement from 4 plants in each plot, and the picking was continued two more times with a time interval of 3 days. Thus, the total number of cucumber fruits used for this study was 48.

2.1. Sampling method and measurements

Cucumber fruit length was measured using a straight meter from one end to another, while fruit diameter was normally measured in three different locations on the fruit: $^1/_4$, $^2/_4$, and $^3/_4$[17]. However, in this study, there was some modification which measured fruit diameter in the middle of the fruit, and fruit weight was measured by placing it on an electronic scale and recording the weight (**Figure 1**).

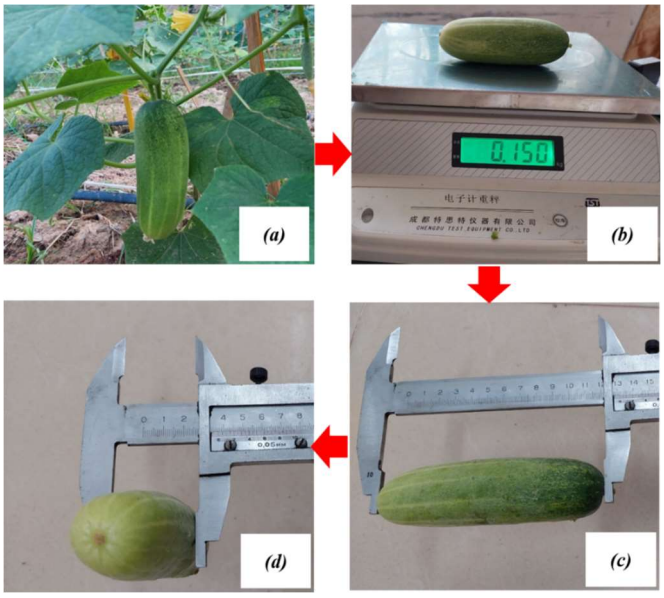

Figure 1. A diagram of the process for measuring cucumber fruit weight, length, and diameter after harvest.

2.2. Data analysis and interpretation

Linear regression and second-degree polynomial regression were applied to detect the relationship among cucumber fruit length, fruit diameter, fruit weight, and length/diameter (*L/D*) ratio. Equations and strength of relationship (*R*) were presented along with scatterplots to show the results at the error level of 5% (confidence level of 95%).

Fruit diameter (*D*) as function of fruit length (*L*):

$$D = f(L) \tag{1}$$

Fruit weight (*W*) as function of fruit length (*L*) and fruit diameter (*D*):

$$W = f(L, D) \tag{2}$$

Length/diameter (*L/D*) as function of fruit weight (W):

$$L{:}\,D\ ratio = f(W) \tag{3}$$

Simple linear regression equation[18]:

$$\mathrm{y} = \beta_0 + \beta_1 x + \varepsilon \tag{4}$$

where,

y is the dependent variable;

β_0 is the intercept constant;

β_1 is the slope of the line;

x is the explanatory variable;

ε is the residual.

Second-degree polynomial regression equation[19]:

$$\mathrm{y} = \beta_0 + \beta_1 x + \beta_2 x^2 + \varepsilon \tag{5}$$

where,

y is the dependent variable;

β_0 is the intercept constant;

β_1 is the linear effect parameter;

β_2 is the quadratic effect parameter;

x is the explanatory variable;

ε is the residual.

Strength of relation[20]:

$$R = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}} \tag{6}$$

where,

R is the strength of relation;

x_i is the individual value of the explanatory variable;

y_i is the individual value of the dependent variable;

$\bar{x}$ is the mean of x values;

$\bar{y}$ is the mean of y values.

R program (version 4.1.2) and RStudio (version: 2023.06.2 + 56) were used for the analysis[21]. The rstatix package was used to determine the correlation matrix for the cucumber fruit dimension[22], while the lattice package was used for plotting histograms[23], and the *R* base graph package for scatterplots with linear regression and second-degree polynomial regression; for a contour plot; and for a perspective plot.

3. Results and discussion

Histograms for cucumber fruit dimensions are shown in **Figure 2**. The data for fruit diameter, fruit length, *L/D* ratio, and fruit weight were normally distributed although the fruit weight was slightly skewed to the right. In **Table 1**, Fruit diameter, fruit length, *L/D* ratio, and fruit weight were 3.4 cm ± 0.08 cm, 10.1 cm ± 0.13 cm, 3:1, and 76.0 g ± 4.46 g, respectively. This study had larger fruit dimensions when compared to the study in Thailand by Buppaprasert and Yingjajaval[24], whose findings for fruit diameter, length, weight, and *L/D* ratio were 3.1 cm ± 0.4 cm, 7.0 cm ± 1.1 cm, 40.8 g ± 15.9 g, and 2.3:1, respectively. The marketable size for cucumber fruit is 30 cm–35 cm, 4.1 cm–4.7 cm for length and diameter, respectively[11].

When the correlations between the three fruit dimensions were studied, they were all positively related (**Table 2**). All the parameters had a strong relationship: fruit diameter and fruit length ($R = 0.70$); fruit diameter and fruit weight ($R = 0.89$); and fruit length and fruit weight ($R = 0.84$). This implies that when cucumber fruit length increases, so do fruit diameter and fruit weight. Similarly, when another parameter changes in size, others will be subject to a proportional trend.

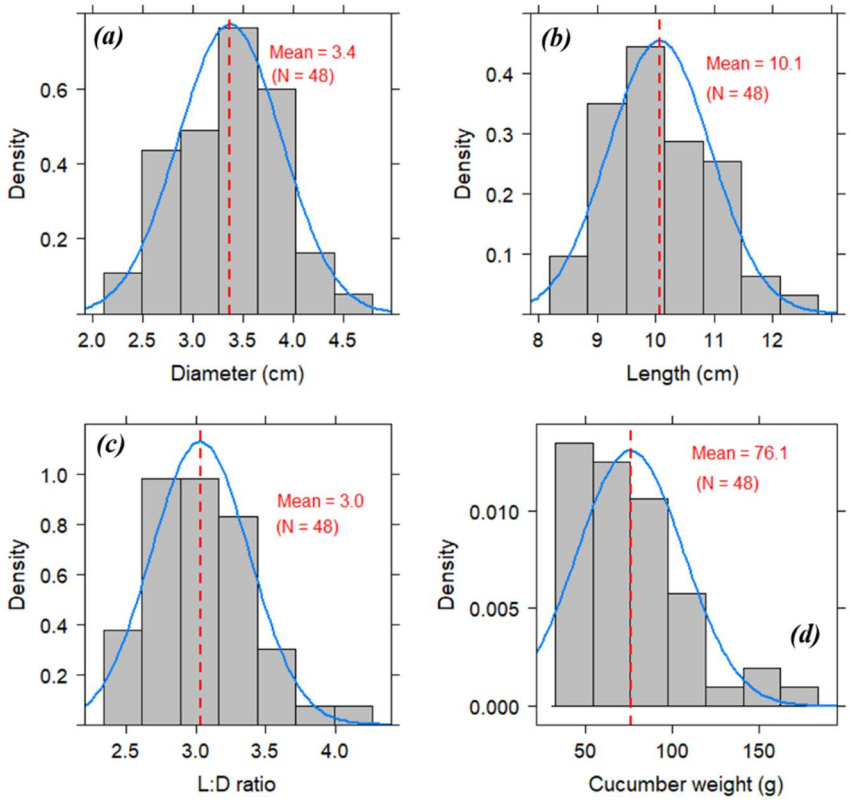

Figure 2. Histogram and normality curves for cucumber fruit diameter. **(a)** fruit length; **(b)** *L/D* ratio; **(c)** fruit weight; **(d)** based on a total sample number of 48 cucumber fruits picked from four plants for three times in a time interval of 3 days.

Table 1. Descriptive statistics for the fruit diameter, fruit length, and fruit weight of cucumber and *L/D* ratio.

Fruit dimension	N	Mean	SE	Min	Max
Diameter (cm)	48	3.4	0.08	2.4	4.7
Length (cm)	48	10.1	0.13	8.6	12.5
L/D ratio	48	3.0	0.05	2.4	4.0
Weight (g)	48	76.0	4.46	35.0	165.0

Table 2. Correlation matrix for the fruit diameter, fruit length, and fruit weight of cucumber.

Fruit dimension	N	Diameter (cm)	Length (cm)	Weight (g)
Diameter (cm)	48	–		
Length (cm)	48	0.70***	–	
Weight (g)	48	0.89***	0.84***	–

Note: "***" means the correlation is statistically significant at $\alpha = 0.001$.

3.1. Fruit length and fruit diameter

The relationship between cucumber fruit length and fruit diameter was detected, and it was seen to be strong and positive ($P < 0.001$; $R = 0.70$, **Figure 3(a)**). When fruit length increased by one unit, fruit diameter increased by 0.4 unit. Some studies also found that there was a strong relationship between cucumber fruit length and diameter[25], and also indicated that the strength of the relation was highly strong ($R > 0.90$).

3.2. Fruit weight and length × diameter

The Relationship between cucumber fruit weight and a product of fruit length and fruit diameter was detected (**Figure 3(b)**). They were positively related ($P < 0.001$), and the strength of the relationship was huge ($R = 0.95$). Therefore, predictions can be made for the fruit weight when fruit length and diameter are known. It was found that the real fruit weight measured in this study was about 3.8 times the product of fruit length and fruit diameter. Therefore, it can be used for the estimation of real fruit weight in future studies.

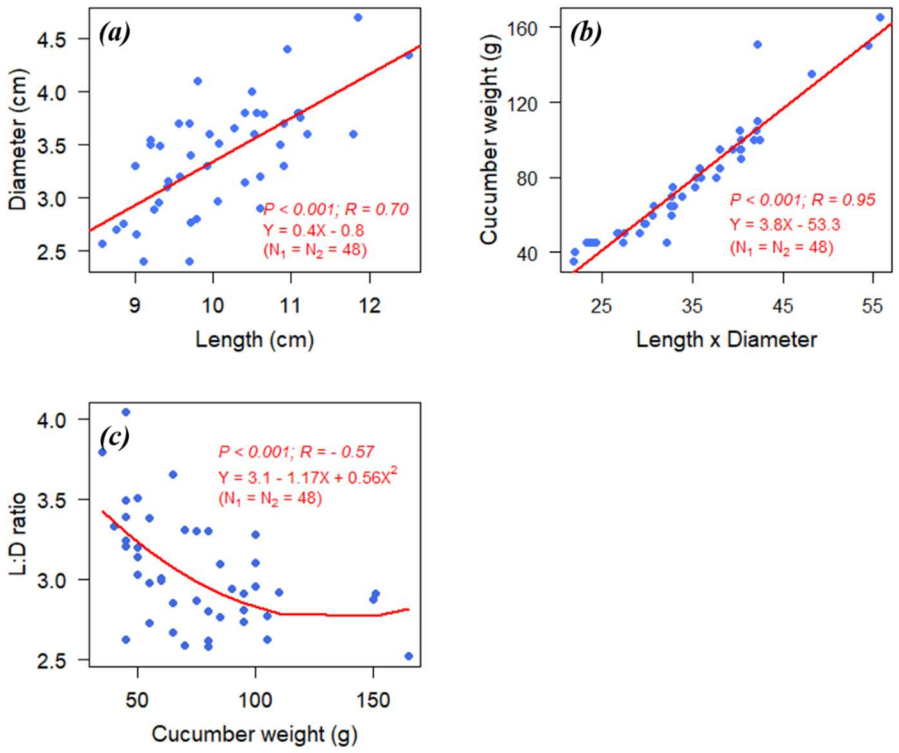

Figure 3. Scatterplots, regression lines and equations between **(a)** fruit length and fruit diameter; **(b)** fruit weight and length × diameter; **(c)** fruit weight and *L/D* ratio.

3.3. Fruit weight and *L/D* ratio

The relationship between cucumber fruit weight and *L/D* ratio was studied to determine whether it may affect the weight (**Figure 3(c)**). It can be seen that the relationship was negatively related ($P < 0.001$), and the strength of relationship was negatively strong ($R = -0.57$), which means that the greater the *L/D* ratio is, the smaller the fruit weight is. Therefore, the smaller the *L/D* ratio, the greater the fruit weight. According to the graph, when *L/D* ratio exceeds 3, the fruit weight tends to be smaller than 100 g. A study suggested that *L/D* in the range of 2.9:1–3.2:1 is acceptable, which means the fruit is large enough for picking[26]. *L/D* ratio of cucumber depends on the species, which can be in the range of 1.5:1–3:1 for Chinese cucumber, or in the range of 2.8:1–3.4:1 for American processing cucumber[27].

3.4. Fruit weight, fruit length and fruit diameter

Figure 4 shows the relationship of fruit weight as a function of fruit length and fruit diameter. It can be seen that cucumber fruit weight was affected by the length and diameter. When fruit diameter was smaller than 3.5 cm, the fruit weight was less than 100 g, regardless of fruit length. In contrast, when the fruit diameter was larger than 3.5 cm and fruit length was larger than 10 cm, the fruit weight exceeded 100 g. The weight continued to increase when fruit length and fruit diameter increased.

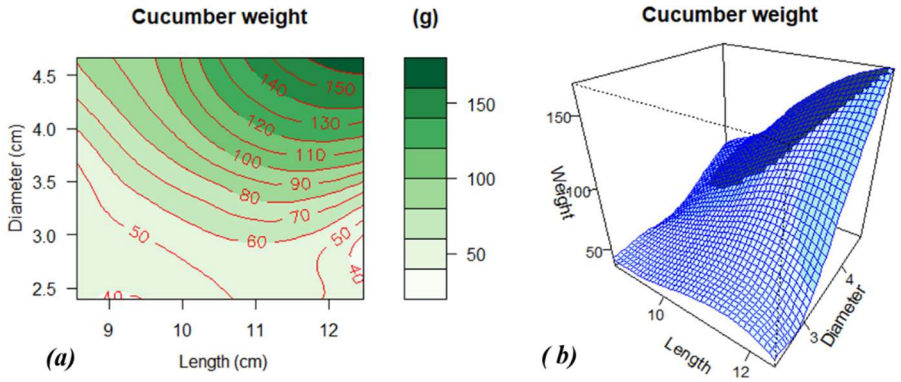

Figure 4. Contour plot for cucumber fruit weight as a function of **(a)** fruit length and fruit diameter; **(b)** a perspective plot for the relationship among the three parameters.

4. Conclusion

Fruit length and fruit diameter were positively related, and these two parameters could be used to estimate the fruit weight. In the study, the coefficient found for predicting the fruit weight was 3.38, which means that when fruit length and fruit diameter are known, they are just multiplied with this coefficient, and then the fruit weight can be estimated. However, *L/D* ratio affects fruit weight. If this ratio is too large, it tends to reduce the weight. Therefore, when cucumber fruits are picked for market sales, one must make sure that fruit with big enough diameter should be considered first to have more weight, which has higher economic value. Future studies should be made for cucumber size already available at the market to understand in depth customer's preferences in size and shape.

Author contributions

All authors made an equal contribution to the research presented in this paper, which covers the conceptualization, study design, data analysis, interpretation of the results, writing, and final revision of the paper.

Conflict of interest

The authors declare no conflict of interest.

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