World Journal of Fungal and Plant Biology 2 (3): 48-51, 2011
ISSN 2219-4312

Modeling of Carrot Firmness Based on Total Soluble Solids of Carrot

Fereydoun Keshavarzpour

Department of Agriculture, Shahr-e-Rey Branch,
Islamic Azad University, Tehran, Iran

Abstract: Carrot firmness (FIR) is often determined using difficult and time consuming laboratory tests, but it may be more appropriate and economical to develop a method which uses easily available and known quality characteristics of carrot such as total soluble solids (TSS). In this study, a typical linear regression model for predicting FIR of Nantes carrot based on TSS of carrot was suggested. The statistical results of the study indicated that in order to predict carrot FIR based on TSS of carrot the linear regression model FIR = 4472.5 - 152.3 TSS with $R^2 = 0.66$ can be recommended.

Key words: Carrot · Firmness · Total soluble solids · Prediction · Modeling

INTRODUCTION

Carrot (*Daucus carota* L.) is an important vegetable because of its large yield per unit area throughout the world and its increasing importance as human food [1, 2]. It belongs to the family Umbelliferae. The carrot is believed to have originated in Asia and now under cultivation in many countries [3, 4]. It is orange-yellow in color, which adds attractiveness to foods on a plate and makes it rich in carotene, a precursor of vitamin A [5]. It contains abundant amounts of nutrients such as protein, carbohydrate, fiber, vitamin A, potassium, sodium, thiamine and riboflavin [1, 3, 6, 7] and is also high in sugar [8]. It is consumed fresh or cooked, either alone or with other vegetables, in the preparation of soups, stews, curries and pies. Fresh grated roots are used in salads and tender roots are pickled [9]. Its use increases resistance against the blood and eye diseases [3].

Carrot contains 75-88% water and 8.5-12.5% soluble solids [10-12]. Water content and soluble solids exert a profound influence on the storage period length, mechanical properties and quality characteristics of fruits and vegetables [9, 11-16]. Therefore, the present study was carried out to develop a regression model for predicting carrot firmness based on total soluble solids of carrot.

MATERIALS AND METHODS

Plant Materials: Carrots (cv. Nantes) were purchased from a local market in Karaj, Iran. They were visually inspected for freedom of defects and blemishes. Carrots were then washed with tap water and treated for the prevention of development of decay by dipping for 20 min at 20°C in 0.5 g L^{-1} aqueous solution of iprodione and then air dried for approximately 1 h. After that, they were transferred to the laboratory and held at 5±1°C and 90±5% relative humidity until laboratory tests.

Experimental Procedure: In order to obtain required data for determining regression model, total soluble solids and firmness of seventy-five randomly selected carrots were measured using laboratory tests (Table 1). Also, in order to verify regression model by comparing its results with those of the laboratory tests, ten carrots were taken at random. Again, total soluble solids and firmness of them were determined using laboratory tests (Table 2).

Table 1: The mean values, standard deviation (S.D.) and coefficient of variation (C.V.) of total soluble solids (TSS) and firmness (FIR) of the seventy-five randomly selected carrots used to determine regression model

Parameter	Minimum	Maximum	Mean	S.D.	C.V. (%)
TSS (%)	8.60	12.3	9.83	1.05	10.6
FIR (N)	2543	3271	2975	195	6.57

Corresponding Author: Fereydoun Keshavarzpour, Department of Agriculture, Shahr-e-Rey Branch, Islamic Azad University, Tehran, Iran

Table 2: The mean values, standard deviation (S.D.) and coefficient of variation (C.V.) of total soluble solids (TSS) and firmness (FIR) of the ten randomly selected carrots used to verify regression model

Parameter	Minimum	Maximum	Mean	S.D.	C.V. (%)
TSS (%)	8.60	12.2	9.83	1.24	12.6
FIR (N)	2467	3271	2980	209	7.00

Total Soluble Solids: The total soluble solids (TSS) of carrots were measured using an ATC-1E hand-held refractometer (ATAGO, Japan) at temperature of 20°C.

Firmness: The firmness (FIR) of carrots was analyzed using a Hounsfield texture analyzer (Hounsfield Corp., UK). The test used was a shear or cut test on the 50 g carrot pieces closely placed into a 6×6×6 cm test box with 8 chisel knife blades. The variations in carrots size and geometry were minimized by testing the pieces of same thickness from the carrots. The test mode used for the texture analysis was "Force in Compression". A 5000 N load cell, test speed of 10 cm min^{-1} and post-test speed 60 cm min^{-1} were used. The "Trigger Type" was set to "Button" and distance to be traveled was set to 68 mm. The cutting force range was set to 2000-3400 N and the maximum cutting force measured during each test was considered as carrot FIR.

Regression Model: A typical linear regression model is shown in equation 1:

$$Y = k_0 + k_1X_1 \quad (1)$$

Where:
Y = Dependent variable, for example FIR of carrot
X = Independent variable, for example TSS of carrot
k_0, k_1 = Regression coefficients

In order to predict carrot FIR based on TSS of carrot the linear regression model FIR = k_0 + k_1TSS was suggested.

Statistical Analysis: A paired sample t-test and the mean difference confidence interval approach were used to compare the FIR values predicted using the FIR-TSS model with the FIR values measured by laboratory tests. The Bland-Altman approach [17] was also used to plot the agreement between the FIR values measured by laboratory tests with the FIR values predicted using the FIR-TSS model. The statistical analyses were performed using Microsoft Excel 2007.

RESULTS AND DISCUSSION

The linear regression model, p-value of independent variable and coefficient of determination (R^2) of the model are shown in Table 3.

Table 3: The linear regression model, p-value of independent variable and coefficient of determination (R^2) of the model

Model	p-value of independent variable	R^2
FIR = 4472.5 - 152.3 TSS	6E-13	066

Table 4: Total soluble solids (TSS) and firmness (FIR) of the ten randomly selected carrots used in evaluating the FIR-TSS model

		FIR (N)	
Sample No.	TSS (%)	Laboratory tests	FIR-TSS model
1	12.2	2467	2614
2	11.0	2972	2797
3	10.4	2938	2889
4	10.9	2896	2812
5	9.70	2999	2995
6	9.20	3020	3071
7	8.80	3024	3132
8	8.80	3112	3132
9	8.70	3271	3147
10	8.60	3097	3163

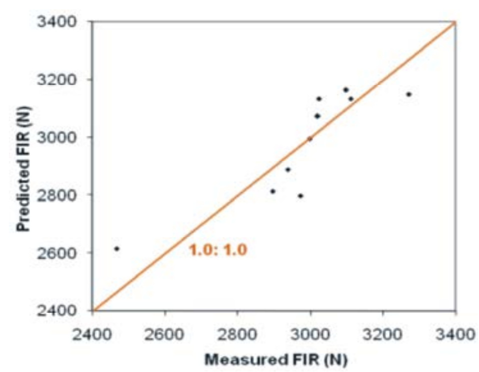

Fig. 1: Measured FIR and predicted FIR using the FIR-TSS model with the line of equality (1.0: 1.0)

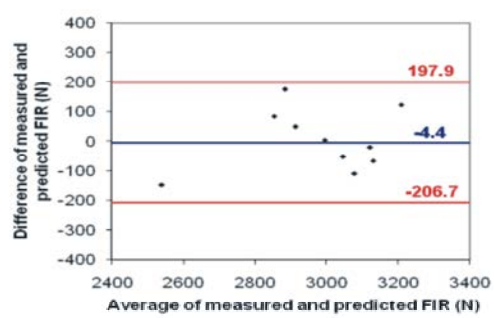

Fig. 2: Bland-Altman plot for the comparison of measured FIR and predicted FIR using the FIR- TSS model; the outer lines indicate the 95% limits of agreement (-206.7, 197.9) and the center line shows the average difference (-4.4)

In this model carrot FIR can be predicted as a function of carrot TSS. The p-value of independent variable (TSS) and coefficient of determination (R^2) of the model were 6E-13 and 0.66, respectively. Based on the statistical result, the FIR-TSS model was judged acceptable.

Moreover, a paired samples t-test and the mean difference confidence interval approach were used to compare the FIR values predicted using the FIR-TSS model and the FIR values measured by laboratory tests. The Bland-Altman approach [17] was also used to plot the agreement between the FIR values measured by laboratory tests with the FIR values predicted using the FIR-TSS model. The FIR values predicted by the FIR-TSS model were compared with FIR values determined by laboratory tests and are shown in Table 4. A plot of the FIR values determined by the FIR-TSS model and laboratory tests with the line of equality (1.0: 1.0) is shown in Fig. 1. The mean FIR difference between two methods was -4.4 N (95% confidence intervals for the difference in means: -78.2 N and 69.4 N; P = 0.8957). The standard deviation of the FIR differences was 103.2 N. The paired samples t-test results showed that the FIR values predicted with the FIR-TSS model were not significantly different than that measured with laboratory tests. The FIR differences between two methods were normally distributed and 95% of these differences were expected to lie between μ-1.96σ and μ+1.96σ, known as 95% limits of agreement [10-12, 17-20]. The 95% limits of agreement for comparison of FIR determined with laboratory test and the FIR-TSS model was calculated at -206.7 N and 197.9 N (Fig. 2). Thus, FIR predicted by the FIR-TSS model may be 206.7 N lower or 197.9 N higher than FIR measured by laboratory test. The average percentage differences for FIR prediction using the FIR-TSS model and laboratory tests was 2.8%.

CONCLUSIONS

A typical linear regression model was used to predict carrot firmness (FIR) based on total soluble solids (TSS) of carrot. The FIR values predicted using the FIR-TSS model was compared to the FIR values measured by laboratory tests. The difference between two methods was not statistically significant ($P > 0.05$). Therefore, the linear regression model FIR = 4472.5 - 152.3 TSS with $R^2 = 0.66$ provides a simple, rapid and economical method to predict carrot firmness based on easily available and known quality characteristic of carrot, i.e. total soluble solids.

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