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Modeling of Carrot Total Soluble Solids Based on Carrot Firmness

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Abstract: Carrot total soluble solids (TSS) is frequently determined using laboratory tests, but it may be more appropriate and suitable to develop a model which uses a determined quality characteristic. In this study, a typical linear regression model for predicting carrot TSS based on carrot firmness (FIR) was suggested. Paired samples t-test results indicated that the difference between the TSS values predicted by model and measured by laboratory tests were not statistically significant and in order to predict carrot TSS based on carrot FIR the linear regression model TSS = 22.80 - 0.004 FIR with R^2 = 0.66 can be suggested.

Key words: Carrot · Total soluble solids · Firmness · 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 also 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].

The present study was conducted to develop a regression model for predicting carrot total soluble solids based on carrot firmness.

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 linear regression model, two quality characteristics of carrot, i.e. firmness and total soluble solids of seventy-five randomly selected carrots were measured using laboratory tests (Table 1). Also, in order to verify linear regression model by comparing its results

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

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

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

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

with those of the laboratory tests, ten carrots were taken at random. Once more, firmness and total soluble solids of them were determined using laboratory tests (Table 2).

Firmness (FIR): The 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 100 mm min^{-1} and post-test speed 600 mm min^{-1} were used. The "Trigger Type" was set to "Button" and distance to be traveled was set to 68 mm. The range of the cutting force was set to 2000-3400 N based on pre-tests and the maximum cutting force measured during each test was considered as FIR.

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

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

$$Y = k_0 + k_1X \quad (1)$$

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

In order to predict carrot TSS based on carrot FIR one linear regression model was suggested.

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

RESULTS AND DISCUSSION

The linear regression model (TSS-FIR model), p-value of independent variable and coefficient of determination (R^2) of the model are shown in Table 3. In this model carrot TSS can be predicted as a function of carrot FIR. The p-value of independent variable (FIR) and coefficient of determination (R^2) of the model were 6E-13 and 0.66, respectively. Based on the statistical result, the TSS-FIR model was judged acceptable.

Besides, a paired samples t-test and the mean difference confidence interval approach were used to compare the TSS values predicted using the TSS-FIR model and the TSS values measured by laboratory tests. The Bland-Altman approach [17] was also used to plot the agreement between the TSS values measured by laboratory tests with the TSS values predicted using the TSS-FIR model. The TSS values predicted by the TSS-FIR model were compared with TSS values determined by laboratory tests and are shown in Table 4. A plot of the TSS values determined by the TSS-FIR model and laboratory tests with the line of equality (1.0: 1.0) is shown in Fig. 1. The mean TSS difference between two methods was 0.04% (95% confidence intervals for the difference in

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
TSS = 22.80 - 0.004 FIR	6E-13	0.66

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

		TSS (%)	
Sample No.	FIR (N)	Laboratory tests	TSS-FIR model
1	2467	12.2	12.0
2	2972	11.0	9.80
3	2938	10.4	10.0
4	2896	10.9	10.2
5	2999	9.70	9.70
6	3020	9.20	9.60
7	3024	8.80	9.60
8	3112	8.80	9.20
9	3271	8.70	8.50
10	3097	8.60	9.30

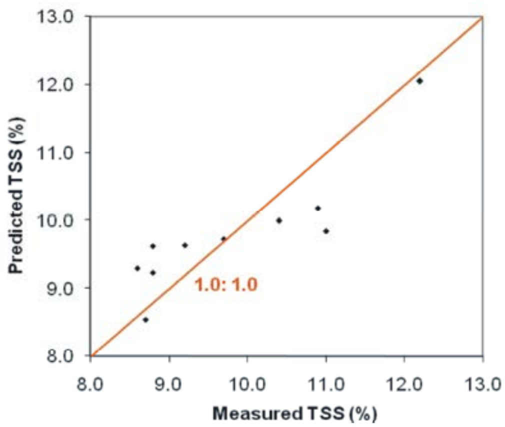

Fig. 1: Measured TSS and predicted TSS using the TSS-FIR model with the line of equality (1.0: 1.0)

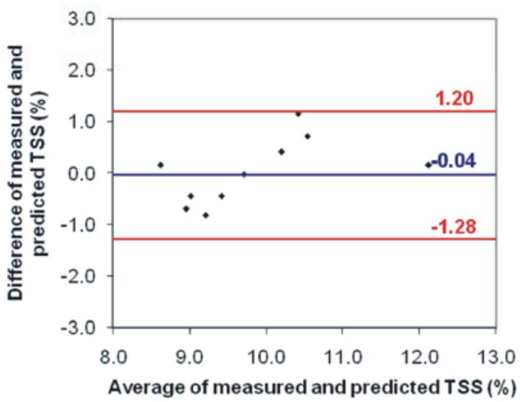

Fig. 2: Bland-Altman plot for the comparison of measured TSS and predicted TSS using the TSS-FIR model; the outer lines indicate the 95% limits of agreement (-1.28, 1.20) and the center line shows the average difference (-0.04)

means: -0.49% and 0.41%; P = 0.846). The standard deviation of the TSS differences was 0.63%. The paired samples t-test results showed that the TSS values predicted with the TSS-FIR model were not significantly different than that measured with laboratory tests. The TSS differences between two methods were normally distributed and 95% of these differences were expected to lie between ì-1.96ó and ì+1.96ó, known as 95% limits of agreement [10-12, 17-20]. The 95% limits of agreement for comparison of TSS determined with laboratory test and the TSS-FIR model was calculated at -1.28% and 1.20% (Fig. 2). Therefore, TSS predicted by the TSS-FIR model may be 1.24% lower or higher than TSS measured by laboratory test. The average percentage difference for TSS prediction using the TSS-FIR model and laboratory tests was 5.2%.

CONCLUSION

In order to predict carrot total soluble solids (TSS) based on carrot firmness (FIR) the linear regression model TSS = 22.80 - 0.004 FIR with R^2 = 0.66 can be suggested.

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