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PREDICTION OF TOTAL SOLUBLE SOLIDS AND FIRMNESS OF CARROTS BASED ON CARROT WATER CONTENT

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ABSTRACT There are many cases in which it is desirable to determine relationships among fruit quality characteristics. For instance, total soluble solids (TSS) and firmness (FIR) are often determined using laborious and/or time consuming laboratory tests, but it may be more suitable and economical to develop a method which uses an easily available characteristics. In this study, two linear regression models for predicting TSS and FIR of Nantes carrot based on carrot water content (WC) were suggested. The statistical results of the study indicated that in order to predict TSS and FIR of carrot based on WC the linear regression models TSS = 34.9 - 0.30 WC with R^2 = 0.86 and FIR = - 1665 + 55.5 WC with R^2 = 0.84 can be strongly recommended.

Keywords: Carrot, Quality characteristics, Prediction, Modeling, Total soluble solids, Firmness, Water content

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 (Ahmad et al., 2005). It belongs to the family Umbelliferae. The carrot is believed to have originated in Asia and now under cultivation in many countries (Hassan et al., 2005). 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. It contains abundant amounts of nutrients such as protein, carbohydrate, fiber, vitamin A, potassium, sodium, thiamine and riboflavin (Ahmad et al., 2005; Hassan et al., 2005; Bahri & Rashidi, 2009; Rashidi et al., 2009a), and is also high in sugar (Suojala, 2000). 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 (Sharma et al., 2006). Its use increases resistance against the blood and eye diseases (Hassan et al., 2005).

Fruits and vegetables contain large quantities of water in proportion to their weight. Vegetables contain generally 90-96% water while for fruits normal water content is between 80 and 90% (Mohsenin, 1986). Water content has important effects on the storage period length of fruits and vegetables (Mostofi & Toivonen, 2006; Ullah et al., 2006; Rashidi et al., 2009b). It also exerts a profound influence on the quality characteristics of fruits and vegetables (Mohsenin, 1986; Hussain et al., 2005; Sharma et al., 2006). Therefore, the present investigation was undertaken to develop models for predicting two quality characteristics of carrot, i.e. total soluble solids and firmness based on carrot water content.

MATERIALS AND METHODS

Plant materials: Carrots (Daucus carota L., 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.

Experimental procedure: In order to obtain required data for determining linear regression models, some quality characteristics of carrot, i.e. water content, total soluble solids and firmness of seventy-five randomly selected carrots were measured using laboratory tests (Table 1). Also, in order to verify linear regression models by comparing their results with those of the laboratory tests, ten carrots were taken at random. Again, water content, total soluble solids and firmness of them were determined using laboratory tests (Table 2).

Water content: The water content (WC) of carrots was determined using the equation 1:

$$\text{Water content (\%)} = 100 \times (M_1 - M_2)/M_1 \qquad (1)$$

Where:

M_1 = Mass of sample before drying, g

M_2 = Mass of sample after drying, g

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 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. Based on the average firmness of carrots in 0-days (3200 N); the range of the cutting force was set to 2000-3400 N and the maximum cutting force measured during each test was considered as stiffness.

Regression models: Atypical linear regression model is shown in equation 2:

$$Y = k_0 + k_1X \qquad (2)$$

Where:

Y = Dependent variable, for example TSS or FIR of carrot

X = Independent variable, for example WC of carrot

k_0 and k_1 = Regression coefficients

In order to predict TSS and FIR of carrot based on carrot WC two linear regression models were suggested (Table 3).

Table 1. The mean values, Standard Deviation (S.D.) and Coefficient of Variation (C.V.) of water content (WC), total soluble solids (TSS) and firmness (FIR) of the seventy-five carrots used to determine liner regression models.

Parameter	**Minimum**	**Maximum**	**Mean**	**S.D.**	**C.V. (%)**
WC (%)	76.3	88.5	83.6	3.23	3.87
TSS (%)	8.60	12.3	9.83	1.05	10.6
FIR (N)	2543	3271	2975	195	6.57

Table 2. The mean values, Standard Deviation (S.D.) and Coefficient of Variation (C.V.) of water content (WC), total soluble solids (TSS) and firmness (FIR) of the ten carrots used to determine liner regression models.

Parameter	**Minimum**	**Maximum**	**Mean**	**S.D.**	**C.V. (%)**
WC (%)	75.6	88.5	83.3	3.84	4.61
TSS (%)	8.60	12.2	9.83	1.24	12.6
FIR (N)	2467	3271	2980	209	7.00

Table 3. Two linear regression models.

Model No.	**Model**
1	$TSS = k_0 + k_1\ WC$
2	$FIR = k_0 + k_1\ WC$

Statistical analysis: A paired sample t-test and the mean difference confidence interval approach were used to compare the TSS and FIR values predicted using models with the values measured by laboratory tests. The Bland-Altman approach (Bland & Altman, 1999) was also used to plot the agreement between the TSS and FIR values measured by laboratory tests with the TSS and FIR values predicted using models. The statistical analyses were performed using Microsoft Excel (Version 2003).

RESULTS AND DISCUSSION Two linear regression models, p-value of independent variable and coefficient of determination (R^2) of the two linear regression models are shown in Table 4.

Table 4. Two linear regression models, p-value of independent variable and coefficient of determination (R^2).

Model No.	Model	p-value of independent variable	R^2
1	TSS = 34.9 - 0.30 WC	5.04E-22	0.86
2	FIR = - 1665 + 55.5 WC	5.79E-21	0.84

TSS-WC model: In TSS-WC model TSS of carrot can be predicted as a function of WC of carrot. The p-value of independent variable and coefficient of determination (R^2) of the TSS-WC model were 5.04E-22 and 0.86, respectively. Based on the statistical result, the TSS-WC model was judged acceptable.

A paired samples t-test and the mean difference confidence interval approach were used to compare the TSS values predicted using the TSS-WC model and the TSS values measured by laboratory tests. The Bland-Altman approach (Bland & Altman, 1999) was also used to plot the agreement between the TSS values measured by laboratory tests with the TSS values predicted using the TSS-WC model.

The TSS values predicted by the TSS-WC model were compared with TSS values determined by laboratory tests and are shown in Table 5. A plot of the TSS values determined by TSS-WC model and laboratory tests with the line of equality (1.0: 1.0) is shown in Figure 1. The mean TSS difference between two methods was 0.070% (95% confidence interval: - 0.196% and 0.336%; P = 0.566). The standard deviation of the TSS differences was 0.371%. The paired samples t-test results showed that the TSS values predicted with the TSS-WC model were not significantly different than that measured with laboratory tests. The TSS differences between these two methods were normally distributed and 95% of these differences were expected to lie between $\mu+1.96\sigma$ and $\mu-1.96\sigma$, known as 95% limits of agreement (Bland & Altman, 1999; Koc, 2007; Rashidi & Gholami, 2008; Rashidi & Seilsepour, 2009). The 95% limits of agreement for comparison of TSS determined with laboratory test and the TSS-WC model were calculated at - 0.658 and 0.798% (Figure 2). Thus, TSS predicted by the TSS-WC model may be 0.658% lower or 0.798% higher than TSS measured by laboratory test. The average percentage differences for TSS prediction using the TSS-WC model and laboratory test was 2.9%.

Table 5. Water content (WC), total soluble solids (TSS) and firmness (FIR) of the ten carrots used in evaluating two linear regression models.

Sample No.	**WC (%)**	**TSS (%)**		**FIR (N)**	
		Laboratory test	TSS-WC model	Laboratory test	FIR-WC model
1	75.6	12.2	12.2	2467	2530
2	80.0	11.0	10.9	2972	2777
3	81.0	10.4	10.6	2938	2832
4	82.3	10.9	10.2	2896	2902
5	82.7	9.70	10.1	2999	2924
6	84.5	9.20	9.60	3020	3025
7	85.4	8.80	9.30	3024	3075
8	86.1	8.80	9.10	3112	3111
9	87.2	8.70	8.70	3271	3176
10	88.5	8.60	8.30	3097	3248

FIR-WC model: In FIR-WC model FIR of carrot can be predicted as a function of WC of carrot. The p-value of independent variable and coefficient of determination (R^2) of the FIR-WC model were 5.79E-21 and 0.84, respectively. Based on the statistical result, the FIR-WC model was also judged acceptable.

Again, a paired samples t-test and the mean difference confidence interval approach were used to compare the FIR values predicted using the FIR-WC model and the FIR values measured by laboratory tests. The Bland-Altman approach (Bland & Altman, 1999) was also used to plot the agreement between the FIR values measured by laboratory tests with the FIR values predicted using the FIR-WC model.

The FIR values predicted by the FIR-WC model were compared with FIR values determined by laboratory tests and are shown in Table 5. A plot of the FIR values determined by FIR-WC model and laboratory tests with the line of equality (1.0: 1.0) is shown in Figure 3. The mean FIR difference between two methods was - 19.5 N (95% confidence interval: - 90.9 N and 51.7 N; P = 0.550). The standard deviation of the FIR differences was 99.7 N. The paired samples t-test results showed that the FIR values predicted with the FIR-WC model were not significantly different than that measured with laboratory tests. Again, the FIR differences between these two methods were normally distributed and 95% of these differences were expected to lie between $\mu+1.96\sigma$ and $\mu-1.96\sigma$, known as 95% limits of agreement (Bland & Altman, 1999; Koc, 2007; Rashidi & Gholami, 2008; Rashidi & Seilsepour, 2009). The 95% limits of agreement for comparison of FIR determined with laboratory tests and the FIR-WC model were calculated at - 215 and 176 N (Figure 4). Thus, FIR predicted by the FIR-WC model may be 215 N lower or 176 N higher than FIR measured by laboratory test. The average percentage differences for FIR prediction using the FIR-WC model and laboratory test was 2.5%.

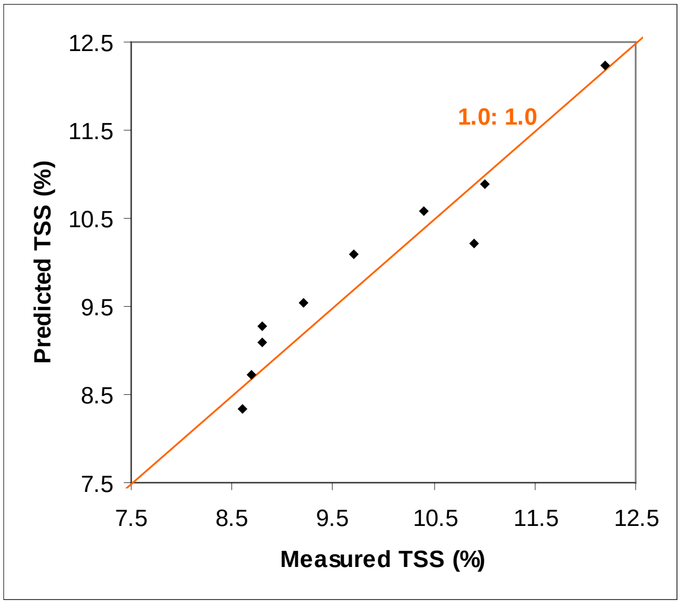

Figure 1. Measured TSS and predicted TSS using the TSS-WC model with the line of equality (1.0: 1.0).

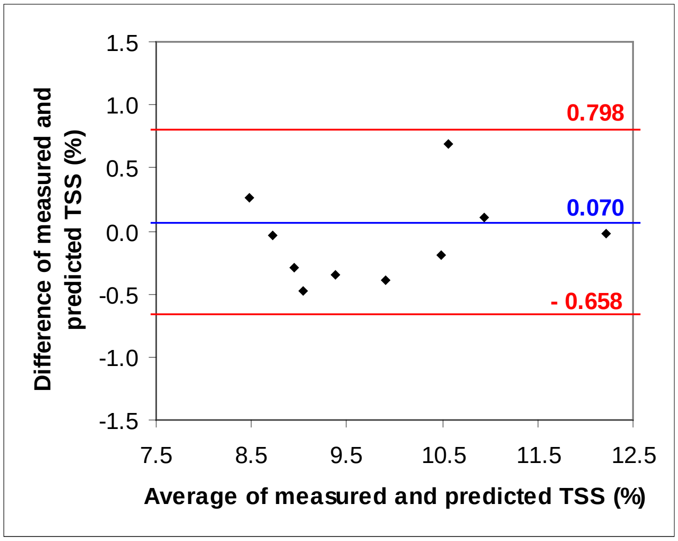

Figure 2. Bland-Altman plot for the comparison of measured TSS and predicted TSS using the TSS-WC model; the outer lines indicate the 95% limits of agreement (-0.658, 0.798) and the center line shows the average difference (0.070)

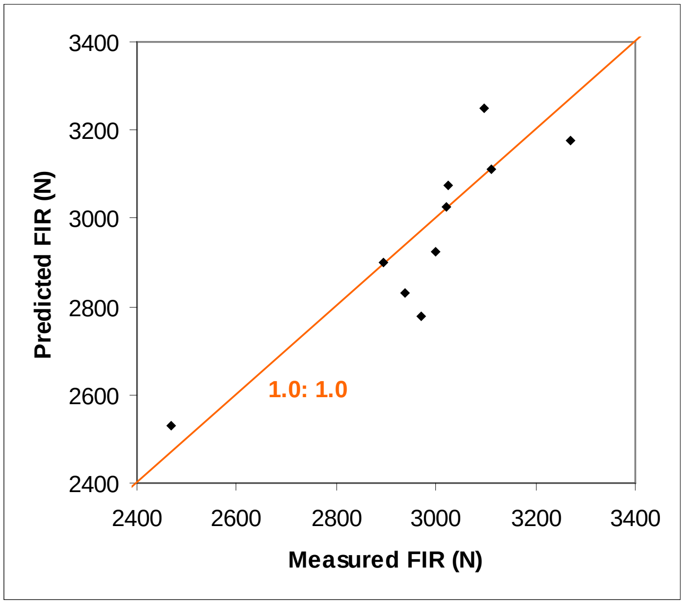

Figure 3. Measured FIR and predicted FIR using the FIR-WC model with the line of equality (1.0: 1.0).

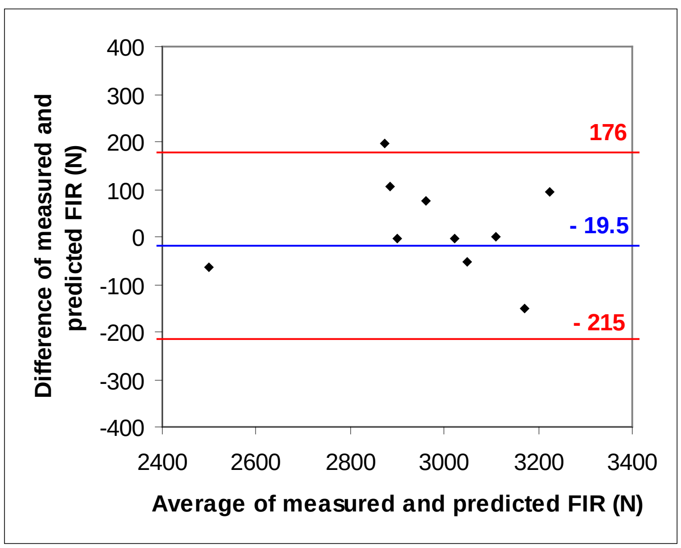

Figure 4. Bland-Altman plot for the comparison of measured FIR and predicted FIR using the FIR-WC model; the outer lines indicate the 95% limits of agreement (-215, 176) and the center line shows the average difference (-19.5)

CONCLUSION In conclusion paired samples t-test results indicated that the difference between the values predicted by the models and measured by laboratory tests were not statistically significant ($P > 0.05$). Therefore, two models provide a simple, rapid and economical method to predict total soluble solids and firmness of carrot based on carrot water content.

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