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*Full Length Research Paper*

# Prediction of carrot firmness based on water content and total soluble solids of carrot

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**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 water content (WC) and total soluble solids (TSS). In this study, typical two variables linear regression model for predicting FIR of Nantes carrot based on WC and TSS of carrot was suggested. The statistical results of the study indicated that in order to predict carrot FIR based on WC and TSS of carrot, the two variables linear regression model FIR = -2805.8 + 64.9 WC + 36.4 TSS with $R^2$ = 0.84 can be strongly recommended.**

**Key words:** Carrot, quality characteristics, prediction, modeling, firmness, water content, total soluble solids.

## 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; Rashidi and Bahri, 2009a). 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; Rashidi and Bahri, 2009b). 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 (Bahri and Rashidi, 2009). It contains abundant amounts of nutrients such as protein, carbohydrate, fiber, vitamin A, potassium, sodium, thiamine and riboflavin (Ahmad, 2005; Hassan et al., 2005; Rashidi et al., 2009a,b), 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 generally contain 90 to 96% water while for fruits, it is normally 80 to 90% water (Mohsenin, 1986). Carrot contains 75 to 88% water and 8.5 to 12.5% soluble solids (Rashidi and Khabbaz, 2010; Rashidi et al., 2010a, b). Water content and soluble solids exert a profound influence on the storage period length, mechanical properties and quality characteristics of fruits and vegetables (Mohsenin, 1986; Hussain et al., 2005; Mostofi and Toivonen, 2006; Sharma et al., 2006; Ullah et al., 2006; Rashidi et al., 2010a, b). Therefore, the present study was conducted to develop a regression model for predicting carrot firmness based on water content and 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, 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 regression model by comparing its

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**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 75 randomly selected carrots used to determine regression model.

| 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 randomly selected carrots used to verify regression model.

| 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 |

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:

$$WC = 100 \times (M_1-M_2)/M_1 \quad (1)$$

Where:
WC = Water content (%)
$M_1$ = 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 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 to 3400 N and the maximum cutting force measured during each test was considered as carrot FIR.

### Regression model

A typical two variables linear regression model is shown in Equation 2:

$$Y = k_0 + k_1X_1 + k_2X_2 \quad (2)$$

Where:
Y = Dependent variable, for example FIR of carrot
$X_1$, $X_2$ = Independent variables, for example WC and TSS of carrot $k_0$, $k_1$, $k_2$ = Regression coefficients
In order to predict carrot FIR based on WC and TSS of carrot, the two variables linear regression model FIR = $k_0 + k_1WC + k_2TSS$ 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 model with the FIR values measured by laboratory tests. The Bland-Altman approach (Bland and Altman, 1999) was also used to plot the agreement between the FIR values measured by laboratory tests with the FIR values predicted using the model. The statistical analyses were performed using Microsoft Excel 2007.

## RESULTS AND DISCUSSION

The two variables linear regression model, p-value of independent variables and coefficient of determination ($R^2$) of the model are shown in Table 3. In this model, carrot FIR can be predicted as a function of carrot WC and TSS. The p-value of independent variables (WC and TSS) and coefficient of determination ($R^2$) of the model were 8.01E-10, 0.188209 and 0.84, respectively. Based on the statistical result, the 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 model and the FIR values measured by laboratory tests. The Bland-Altman approach (Bland and Altman, 1999) was also used to plot the agreement between the FIR values

**Table 3.** The two variables linear regression model, p-value of independent variables and coefficient of determination ($R^2$) of the model.

| Model | p-value of independent variables | | $R^2$ |
|---|---|---|---|
| | WC | TSS | |
| FIR = -2805.8 + 64.9 WC + 36.4 TSS | 8.01E-10 | 0.188209 | 0.84 |

**Table 4.** Water content (WC), total soluble solids (TSS) and firmness (FIR) of the 10 randomly selected carrots used in evaluating the model.

| Sample No. | WC (%) | TSS (%) | FIR (N) | |
|---|---|---|---|---|
| | | | Laboratory tests | Model |
| 1 | 75.6 | 12.2 | 2467 | 2546 |
| 2 | 80.0 | 11.0 | 2972 | 2792 |
| 3 | 81.0 | 10.4 | 2938 | 2834 |
| 4 | 82.3 | 10.9 | 2896 | 2934 |
| 5 | 82.7 | 9.70 | 2999 | 2916 |
| 6 | 84.5 | 9.20 | 3020 | 3016 |
| 7 | 85.4 | 8.80 | 3024 | 3060 |
| 8 | 86.1 | 8.80 | 3112 | 3102 |
| 9 | 87.2 | 8.70 | 3271 | 3175 |
| 10 | 88.5 | 8.60 | 3097 | 3255 |

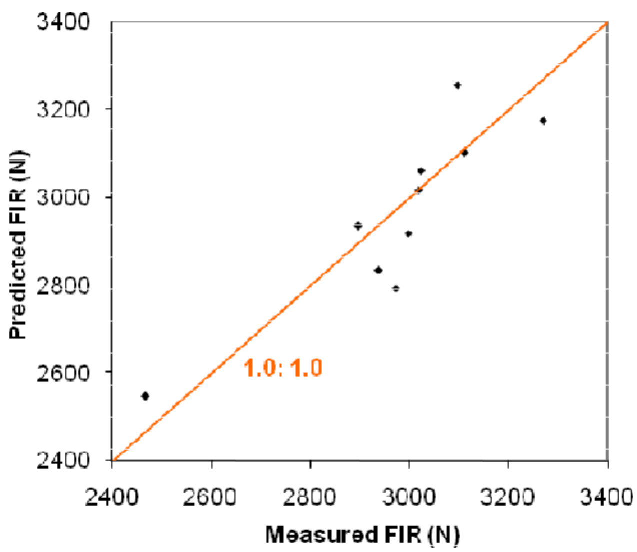


**Figure 1.** Measured FIR and predicted FIR using the model with the line of equality (1.0: 1.0).

measured by laboratory tests with the FIR values predicted using the model. The FIR values predicted by the 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 model and laboratory tests with the line of equality (1.0: 1.0) is shown in Figure 1.

The mean FIR difference between two methods was -16.6 N (95% confidence intervals for the difference in means: -88.4 N and 55.2 N; P = 0.6135). The standard deviation of the FIR differences was 100.3 N. The paired samples t-test results showed that the FIR values predicted with the 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 $\mu$-1.96$\sigma$ and $\mu$+1.96$\sigma$, known as 95% limits of agreement (Bland and Altman, 1999; Koc, 2007; Rashidi and Gholami, 2008; Rashidi and Seilsepour, 2009; Rashidi and Khabbaz, 2010; Rashidi et al., 2010a, b). The 95% limits of agreement for comparison of FIR determined with laboratory test and the model was calculated at -213.3 N and 180.1 N (Figure 2). Thus, FIR predicted by the model may be 213.3 N lower or 180.1 N higher than FIR measured by laboratory test. The average percentage differences for FIR prediction using the model and laboratory tests was 2.7%.

## Conclusions

A typical two variables linear regression model was used to predict carrot firmness (FIR) based on water content (WC) and total soluble solids (TSS) of carrot. The FIR values predicted using the model was compared to the FIR values measured by laboratory tests. The difference

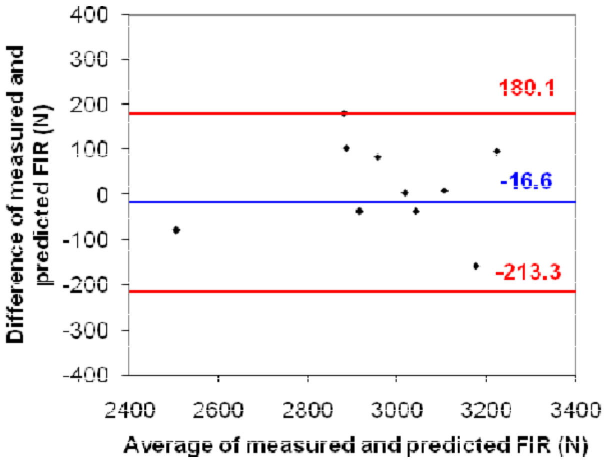


**Figure 2.** Bland-Altman plot for the comparison of measured FIR and predicted FIR using the model; the outer lines indicate the 95% limits of agreement (-213.3, 180.1) and the center line shows the average difference (-16.6).

between two methods was not statistically significant ($P > 0.05$). Therefore, the two variables linear regression model FIR = -2805.8 + 64.9 WC + 36.4 TSS with $R^2$ = 0.84 provides a simple, rapid and economical method to predict carrot firmness based on easily available and known quality characteristics of carrot, that is, total soluble solids and water content.

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