Prediction of Carrot Water Content Based on Carrot Brix During Cold Storage

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Abstract: Water content of carrot during cold storage is frequently determined using laborious and time consuming laboratory tests. However, it is possible to develop a model which uses easily available quality characteristics of carrot. In this study, one linear regression model for predicting carrot water content (WC) based on carrot brix (BX) was suggested. Paired samples t-test results indicated that the difference between the WC values predicted by model and measured by laboratory tests was not statistically significant and in order to predict carrot WC based on carrot BX during cold storage the linear regression model WC = 115.6 - 3.362 BX with R^2 = 0.81 can be used.

Key words: Carrot · Cold storage · Water content · Brix · 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]. It belongs to the family Umbelliferae. The carrot is believed to have originated in Asia and now under cultivation in many countries [2]. 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 [1-4] and is also high in sugar [5]. 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 [6]. Its use increases resistance against the blood and eye diseases [2].

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% [7]. Water content has important effects on the storage period length of fruits and vegetables [8-10]. It also exerts a profound influence on the quality characteristics of fruits and vegetables

[6, 7, 11]. Therefore, the present study was carried out to develop a model for predicting carrot water content based on carrot brix during cold storage using a linear regression model.

MATERIALS AND METHODS

Plant Materials: Carrots (cv. Imperator 408) were purchased from a local market. They were visually inspected for freedom of defects and blemishes. Carrots were washed with tap water and then air dried for approximately one hour. Then, they were placed in the polyethylene boxes and stored at cold storage.

Experimental Procedure: The experiment comprised of nine storage periods, i.e. 0, 30, 45, 60, 75, 90, 100, 110 and 120 days at temperature of 2°C and 90% relative humidity. In order to obtain required data, water content and brix of 216 randomly selected carrots (24 samples for each storage period) was measured using laboratory tests. Quality characteristics of 200 randomly selected carrots were used to determine linear regression model. The mean values, standard deviation (S.D.) and coefficient of variation (C.V.) of brix and water content of the 200 randomly selected carrots are shown in Table 1.

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Table 1: The mean values, standard deviation (S.D.) and coefficient of variation (C.V.) of brix (BX) and water content (WC) of the 200 randomly selected carrots used to determine WC-BX model

Parameter	Minimum	Maximum	Mean	S.D.	C.V. (%)
BX (%)	8.60	12.1	9.63	0.88	9.18
WC (%)	74.4	88.5	83.2	3.30	3.96

Table 2: The mean values, standard deviation (S.D.) and coefficient of variation (C.V.) of brix (BX) and water content (WC) of the sixteen randomly selected carrots used to verify WC-BX model

Parameter	Minimum	Maximum	Mean	S.D.	C.V. (%)
BX (%)	9.00	12.2	10.7	1.13	10.6
WC (%)	73.4	84.8	79.8	3.30	4.14

Also, in order to verify linear regression model by comparing its results with those of the laboratory tests, quality characteristics of sixteen randomly selected carrots were utilized. The mean values, S.D. and C.V. of brix and water content of the sixteen randomly selected carrots are shown in Table 2.

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

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

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

where:

WC = Water content,%
M_1 = Mass of sample before drying, g
M_2 = Mass of sample after drying, g

Regression Model: In order to predict carrot WC based on carrot BX during cold storage, one linear regression model (WC-BX model) was suggested. A typical linear regression model is shown in equation 2:

$$Y = k_0 + k_1 X \qquad (2)$$

where:

Y = Dependent variable, for example WC of carrot during cold storage
X = Independent variable, for example BX of carrot during cold storage
k_0 and k_1 = Regression coefficients

Statistical Analysis: A paired sample t-test and the mean difference confidence interval approach were used to compare the WC values predicted using the WC-BX model with the WC values measured by laboratory tests. The Bland-Altman approach [12] was also used to plot the agreement between the WC values measured by laboratory tests with the WC values predicted using the WC-BX model. The statistical analyses were performed using Microsoft Excel 2007.

RESULTS AND DISCUSSION

Linear regression model, p-value of independent variable and coefficient of determination (R^2) of the model are shown in Table 3. In this model carrot WC can be predicted as a function of carrot BX. The p-value of independent variable and R^2 of the WC-BX model were 3.98E-74 and 0.81, respectively. Based on the statistical results, the WC-BX model was judged acceptable.

A paired samples t-test and the mean difference confidence interval approach were used to compare the WC values predicted using the WC-BX model and the WC values measured by laboratory tests. The Bland-Altman approach [12] was also used to plot the agreement between the WC values measured by laboratory tests with the WC values predicted using the WC-BX model. The WC values predicted by the WC-BX model were compared with WC values determined by laboratory tests and are shown in Table 4. A plot of the WC values determined by the WC-BX model and

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

Model	p-value of independent variable	R^2
WC = 115.6 - 3.362 BX	3.98E-74	0.81

Table 4: Brix (BX) and water content (WC) of the sixteen randomly selected carrots used in evaluating WC-BX model

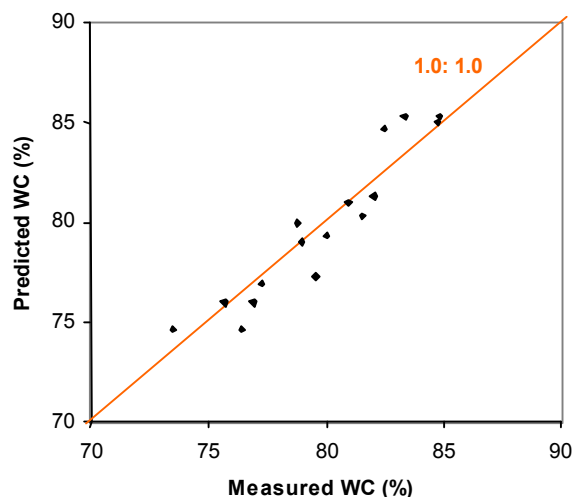| Sample No.	BX (%)	WC (%) Laboratory test	WC-BX model
1	9.10	84.7	85.0
2	11.4	79.6	77.2
3	10.5	81.5	80.3
4	12.2	76.5	74.6
5	9.00	84.8	85.3
6	10.8	80.0	79.3
7	10.2	82.0	81.3
8	11.8	76.9	75.9
9	9.20	82.4	84.6
10	11.5	77.3	76.9
11	10.6	78.8	79.9
12	12.2	73.4	74.6
13	9.00	83.4	85.3
14	10.9	79.0	78.9
15	10.3	80.9	80.9
16	11.8	75.7	75.9

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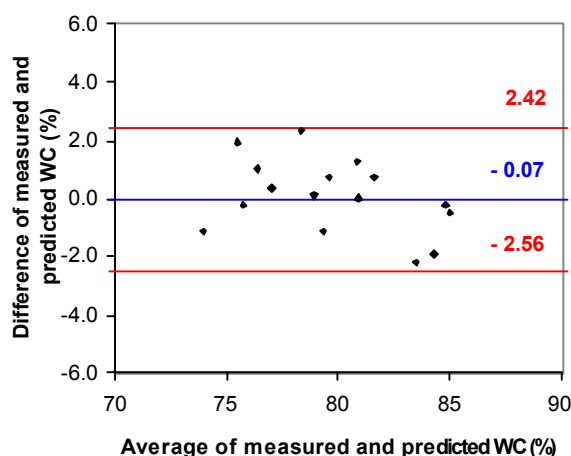

Fig. 2: Bland-Altman plot for the comparison of measured WC and predicted WC using WC-BX model; the outer lines indicate the 95% limits of agreement (-2.56, 2.42) and the center line shows the average difference (-0.07)

laboratory tests with the line of equality (1.0: 1.0) is shown in Fig. 1. The mean WC difference between two methods was -0.07% (95% confidence interval: - 0.75% and 0.60%; P = 0.8198). The standard deviation of the WC differences was 1.27%. The paired samples t-test results showed that the WC values predicted with the WC-BX model were not significantly different than that measured with laboratory tests. The WC 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 [12-15]. The 95% limits of agreement for comparison of WC determined with

laboratory tests and the WC-BX model was calculated at -2.56% and 2.42% (Fig. 2). Thus, WC predicted by the WC-BX model may be 2.49% lower or higher than WC measured by laboratory test. The average percentage difference for WC prediction using the WC-BX model and laboratory test was 1.22%.

CONCLUSION

In order to predict carrot water content (WC) based on carrot brix (BX) during cold storage the linear regression model WC = 115.6 - 3.362 BX with $R^2 = 0.81$ can be utilized.

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