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The effect of some processing parameters on mechanical and image texture properties of fried carrot

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Abstract

In this study, potential application of image texture analysis as a non-destructive method for automation and prediction of mechanical properties of carrot chips was investigated. Samples were fried at different processing conditions and moisture content, colour parameters (i.e. L^*, a^*, b^* and ΔE) and mechanical properties (i.e. hardness and apparent modulus) were determined. Hardness and apparent modulus increased by increasing frying temperature and time. Four image texture features namely contrast, correlation, energy and homogeneity were calculated using gray level co-occurrence matrix. The results showed contrast and energy of gray level images were well correlated with hardness of fried samples in compression and puncture tests. Correlation coefficients of 0.97 and 0.98 between four image texture features and hardness were obtained in compression and puncture tests, respectively. Results indicate that image texture analysis can be successfully applied as a non-destructive method for estimation of mechanical properties of carrot.

Keywords: Carrot; frying; image texture analysis; mechanical texture properties

Introduction

Carrot (*Daucus carota*) is one of the most important sources of natural antioxidants such as β-carotene and flavoniods and vitamins A, C and E (Alasalvar, Grigor, Zhang, Quantick, Shahidi, 2001). This agriculture product has been linked to inhibit certain types of cancer and chronic diseases (Rao, Agarwal, 1999). However, the carrot's shelf-life is confined due to its high moisture content which lead to the loss and oxidation of nutritional compounds such as vitamins and carotenoids and consequently, intensification of the bitterness flavor (Rao *et al.*, 1999). Deep-fat frying can be applied as a preservation method to prolong shelf-life and enhance taste, appearance and texture of carrot. Immersion of food materials into hot oil causes partial evaporation of the water and increase porosity and crispness, which lead to improve their palatability (Mohebbi, Fathi, Shahidi, 2011). Dueik *et al.* (2010) reported vacuum frying of carrot can maintain approximately 90 and 86% of its trans α-carotene and β-carotene, respectively.

Mechanical texture features and colour are recognized as the most important quality aspects affecting sensory perception of fried products. Temperature and time of frying have been reported to possess a critical effect on these properties. Pedreschi *et al.* (2007) studied colour components changes during potato frying and showed the colour changes (ΔE) enhanced with increasing frying time. Kita *et al.* (2007) investigated the effect of temperature on texture of fried potato and showed that the hardness decreases by increasing the processing temperature. Pedreschi and Moyano (2005) reported the lower frying temperature the crisper potato chips is produced. In spite of importance of mechanical texture properties of fried product, their applications are limited for on-line quality control evaluation due to destructive and time consuming natures of their evaluation instruments.

Image textures are important image features and have been recently applied in food engineering for quality evaluation as a non-destructive, objective and rapid method (Borah, Hines, Bhuyan, 2007; Dan, Azuma,

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Kohyama, 2007; Fathi, Mohebbi, Razavi, 2009; Gonzales-Barron, Butler, 2008; Zheng, Sun, Zheng, 2006). Image texture is defined as the spatial organization of intensity variations of pixels in gray level image, which corresponded to both brightness value and pixel locations (Pietikanen, 2000). Published researches revealed that image texture features can be correlated with mechanical properties of food materials (Qiao, Wang, Ngadi, Kazemi, 2007; Thybo *et al.*, 2004). Image texture features are usually classified into four categories namely, statistical, structural, model-based and transform-based textures (Bharati, Liu, MacGregor, 2004). In the food industry, statistical texture is the most commonly used method for quality evaluations. This method includes grey level co-occurrence matrix (GLCM), grey level pixel-run length matrix, and neighboring grey level dependence matrix (Zheng *et al.*, 2006). The former that has been proposed by Haralick *et al*. (1973), is the widely applied statistical texture analysis method, in which texture features such as entropy, homogeneity, correlation and contrast are extracted by some statistical approaches from the co-occurrence matrix of gray scale image histogram. GLCM has been used for classification of cereal grain and dockage (Paliwal, Visen, Jayas, White, 2003), and apple (Kavdir, Guyer, 2002).

As mentioned above, determination of mechanical texture properties is both time consuming and destructive and development of a new replaced method is necessary. In spite of momentous application of image texture analysis, there is no published data in the literature on investigation of correlation between mechanical and image texture properties of food products. Therefore, the aims of this work were to determine mechanical and colour properties of fried carrot under different processing conditions and study the efficiency of image texture parameters (i.e. contrast, correlation, energy and homogeneity) to predict mechanical features of carrot chips.

Materials and methods

Sample Preparation

Fresh carrots (*Daucus carrota*) were purchased from local market and kept in refrigerator at 6-7 °C before frying. Carrots were cut into square dslices of 1mm in thickness and 30mm in length.

The frying process was accomplished in a thermostatically temperature controlled fryer (Black & Decker, USA). Sunflower oil was used for frying due to its high smoking point. The fryer was filled with 2.5L of sunflower oil. The fresh oil had been preheated at frying temperature for 30min before frying. Carrot samples were immersed in the frying oil at 140°C and 160°C. At the end of the frying times (3, 4, 5 and 6 min), the samples were removed from the fryer and were blotted with adsorbent paper to remove excess surface oil. Moisture content of fried carrots were measured by drying the samples in a convection oven at 105 °C until constant mass was achieved and reported as the wet basis.

Mechanical Measurements

Mechanical texture measurements of carrot chips were accomplished at room temperature (25 °C) by texture analyzer (QTS Texture analyzer, CNS Farnell, Essex, U.K.). In this study, puncture and compression tests were performed applying a crosshead speed of 70 $\mathrm{mm\,min^{-1}}$ and using two probes with dimensions of 2mm and 35mm, respectively. The instrument's software was applied to determine the mechanical textural parameters, namely hardness (g) and apparent modulus ($\mathrm{g.s^{-1}}$). The experiments were fulfilled in three replications.

Image Acquiring and Colour Changes

For each treatment, four fried samples were scanned with a Cannon (8800F) desktop flatbed scanner (at Optical Resolution of 4800 dpi × 9600 dpi) and the images were saved as BMP format. To study the effect of frying parameters (temperature and time) on colour changes (ΔE), the RGB colour space images were converted to L^*a^*b space and colour changes were calculated applying the following equation:

$$\Delta E = \left[(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2\right]^{\frac{1}{2}} \quad (1)$$

where L^* is lightness component, which ranges from 0 to 100 and parameter a^* (from green to red) and b^* (from blue to yellow) are two chromatic components, which range from -120 to 120. Subscripts *1* and *2* are referred to colour components before and after frying process, respectively (Fathi, Mohebbi, Razavi, 2011).

Grey Level Co-Occurrence Matrix and Image Texture Analysis

The first procedure for extracting image textural features was presented by Haralick *et al*. (1973). Each textural property is computed from a set of GLCM probability distribution matrices for a given image. The GLCM shows the probability that a pixel of a particular grey level occurs at a specified direction and distance from its neighboring pixels. Gray level co-occurrence matrix is represented by $P_{d,\theta}(i, j)$ where counts the neighboring pair pixels with gray values i and j at the distance of d and the direction of θ.

In this study, four image texture features namely, contrast, correlation, entropy and homogeneity were calculated based on equations 2-5 (Qiao *et al*., 2007). Contrast measures the local variation in an image (ranging from 0 to [size (GLCM, 1)-1]^2) and a high contrast value indicates a high degree of local variation. Correlation is an indicator of linear dependency of intensity values in an image (ranging from -1 to 1). For an image with large areas of similar intensities, a high value of correlation is measured. Energy (angular second moment) returns the sum of squared elements in the GLCM (ranging from 0 to 1) and homogeneity indicates the uniformity within an image (ranging from 0 to 1).

$$Contrast = \sum_{i=0}^{N-1}\sum_{j=0}^{N-1}(i-j)^2 P_{d,\theta}(i, j) \quad (2)$$

$$Correlation = \frac{\left[\sum_{i=0}^{N-1}\sum_{j=0}^{N-1}(ij)P_{d,\theta}(i, j)\right] - \mu_x \mu_y}{\sigma_x \sigma_y} \quad (3)$$

$$Energy = \sum_{i=0}^{N-1}\sum_{j=0}^{N-1}P_{d,\theta}(i, j)^2 \quad (4)$$

$$Homogeneity = \sum_{i=0}^{N-1}\sum_{j=0}^{N-1}\frac{P_{d,\theta}(i, j)}{1+|i-j|} \quad (5)$$

where μ_x, μ_y and σ_x, σ_y are the mean and standard deviation of the sums of rows and columns in the matrix, respectively, and N is the dimension of square matrix of GLCM. In this study, the four mentioned textural features were computed using the mean of the four values of different orientations (0°, 45°, 90° and 135°) at d = 1 applying a program developed in MATLAB 7.0.

Statistical Analysis

Analysis of variance (ANOVA) was performed using a computerized statistical program called “MSTAT” version C, and determination of significant differences of means was carried out by “Duncan” test at 95% confidence level using the above software program. Regression equations and coefficients of determination (R^2) between the mechanical and image texture features were obtained using SlideWrite software, version 2.

Result and discussion

The effect of frying conditions on moisture content of carrot was depicted in Fig. 1. The moisture content showed a classical drying profile and it was diminished by increasing frying time and temperature. The decrease of moisture content in result of increase of frying temperature is due to enhance of diffusion coefficient. Similar results were obtained by Moyano and Pedreschi (2006).

The results of analysis of variance for colour and mechanical properties of deep-fat fried carrot were summarized in Tables 1 and 2, respectively. Effect of frying temperature, time and their combination were significant (P<0.05) on colour components of L^* and b^* and colour changes.

The mean values of colour parameters as well as colour changes at different processing conditions were tabulated in Table 3. The lightness (L^*) decreased as the frying temperature increased from 140 to 160° C. The darkening of carrot chips at higher processing temperature can be attributed to the acceleration of chemical reactions, e.g. Maillard reactions. Krokida *et al* (2001) reported that increasing frying temperature led to decrease of potato lightness. The results revealed that *b** component decreased with increasing frying temperature and time, indicating yellow colour deterioration. On the other hand, the samples were fried at higher frying temperature and longer time underwent more severe colour changes.

The effect of frying temperature was significant (P<0.05) on hardness and apparent modulus for both compression and puncture tests (Table 2). However, hardness was not statistically affected by frying time. Figures 2 & 3 show the mechanical properties of carrot chips determined by compression and puncture tests as a function of processing conditions. In all cases, hardness and apparent modulus of carrot chips raised as the frying temperature and time increased, which is due to fast moisture loss from the surface of the samples and consequently, forming of hard crust. Heredia *et al* (2014) studied textural properties of fried potato and reported a first stage of initial softening related to starch gelatinization followed by a second stage where the maximum force increased due to the gradual formation of a crust.

The image texture features (i.e. contrast, correlation, energy and homogeneity) of carrot chips were calculated from GLCM in four orientations and their average values in different frying temperatures and times were presented in Table 4.

Table 1. Successive mean squares from analysis of variance of color parameters of fried carrot

Source	Degree of freedom	Mean square			
		L*	a*	b*	Δ*E*
Temperature	1	635.98^{Sig}	77.09^{NS}	600.13^{Sig}	215.04^{Sig}
Time	3	606.44^{Sig}	12.22^{NS}	214.20^{Sig}	182.68^{Sig}
Temperature*Time	3	566.87^{Sig}	11.81^{NS}	167.26^{Sig}	138.12^{Sig}
Error	24	676.41	17.29	10.85	10.85
Total	31				

^{Sig}, statistically significant at 5%; ^{NS}, not statistically significant.

Table 2. Successive mean squares from analysis of variance of hardness and apparent modulus for compression and puncture tests

Source	Degree of freedom	Mean square			
		Hardness (compression)	Apparent modulus (compression)	Hardness (puncture)	Apparent modulus (puncture)
Temperature	1	61509.37^{Sig}	1327784.41^{Sig}	11310.04^{Sig}	1821457^{Sig}
Time	3	32886.486^{Sig}	591673.47^{Sig}	40950.04^{Sig}	301986.6^{Sig}
Temperature*Time	3	452.49^{NS}	13671.0^{Sig}	2001.15^{NS}	43171.41^{Sig}
Error	16	10759.71	59972.49	3843.5	56816.02
Total	23				

^{Sig}, statistically significant at 5%; ^{NS}, not statistically significant.

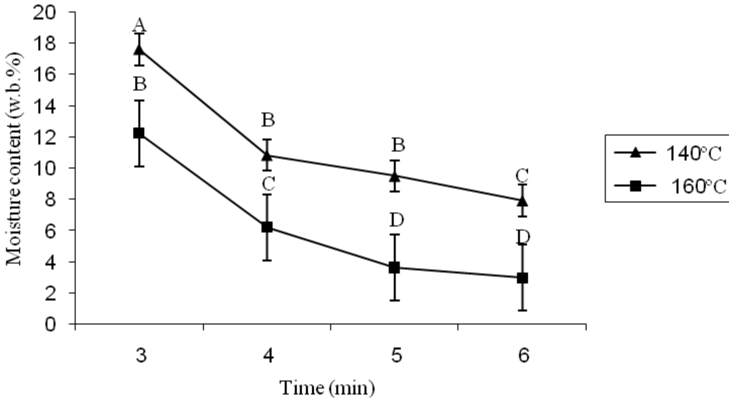

Fig. 1. Moisture content of carrot chips at different processing times and temperatures

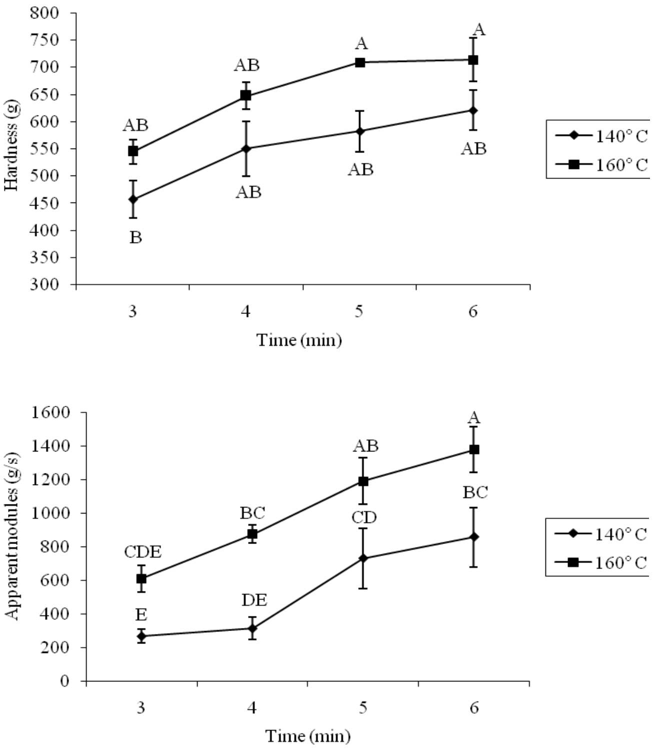

Fig. 2. Influence of frying temperature and time on the hardness and apparent modulus of carrot chips determined by compression test.

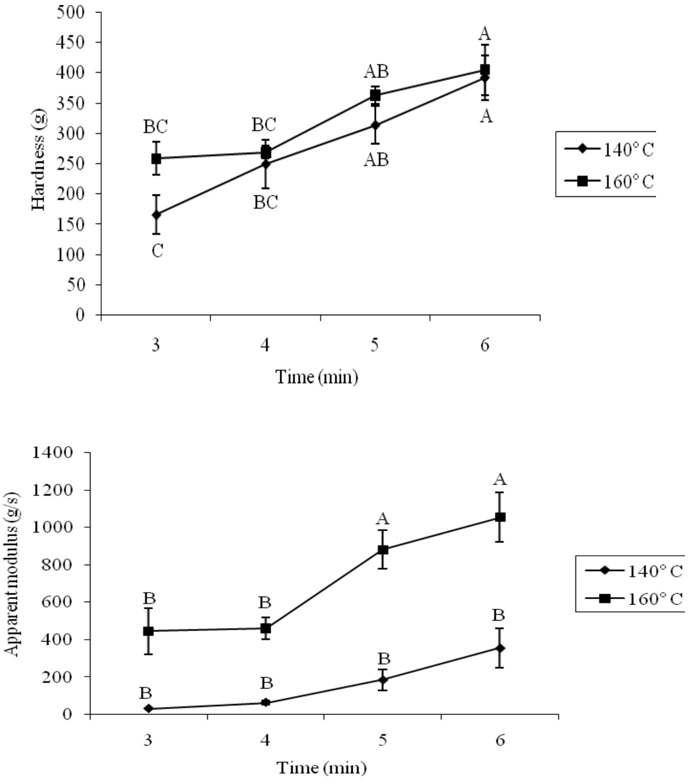

Fig. 3. Influence of frying temperature and time on the hardness and apparent modulus of carrot chips determined by puncture test.

The increase of the contrast as results of applying high frying temperature and long time indicates an enlargement of local variation of pixels in fried samples' images. However, the decrease trends of energy, correlation and homogeneity values reveal diminishing uniformity and smoothness of the images due to increase of black spot formation at higher frying temperature and time. As mentioned above, determination of mechanical properties of products is both destructive and time-consuming. Therefore, in this research an effort has been made to apply image texture analysis as a non-destructive and rapid method to predict mechanical properties of fried carrots. It was found that four image texture features were more correlated with hardness, rather than apparent modulus. Therefore, the obtained relationships between hardness values of compression and puncture tests and four image texture parameters including contrast, correlation, energy and homogeneity were presented in Figure 4.

It can be found that the hardness values of carrot chips in compression and puncture tests can be predicted using linear relationships of energy and contrast with superior correlation coefficients of -0.94 and +0.98, respectively. Qiao et al. (2007) studied the effect of frying condition on image texture properties of nugget. They stabilished multi-layer feed-forward networks to predict mechanical texture parameters based on image texture indices of samples. The results showed a strong potential for measuring mechanical and textural characteristics of fried nuggets using non-destructive image-based texture indices.

The results of multiple linear regression (MLR) between image texture features and hardness of fried carrots were also tabulated in Table 5. MLR relationships showed correlation coefficients of 0.97 and 0.98 for compression and puncture tests, respectively. These results reveal that image texture features can be potentially applied as a non-destructive method for quality control of mechanical properties of carrot chips.

Table 3. Average values of each color component and color changes of fried carrot at different frying conditions

Color parameter	140 °C				160 °C			
	3 min	4 min	5 min	6 min	3 min	4 min	5 min	6 min
L*	50.70^{AB}±0.70	59.11^{A}±4.22	54.70^{AB}±3.14	51.23^{AB}±1.31	55.66^{AB}±2.08	49.50^{B}±2.99	37.91^{C}±5.75	37.0^{C}±12.28
a*	21.84±0.71	19.50±2.28	20.04±1.46	19.77±1.43	23.79±2.86	23.06±0.41	20.68±1.36	20.56±10.97
b*	65.70^{A}±2.20	62.19^{A}±1.94	58.14^{AB}±2.16	55.12^{B}±1.74	59.18^{AB}±2.90	54.63^{B}±2.04	40.14^{C}±6.44	42.57^{C}±4.48
ΔE	33.23^{BC}±0.68	34.78^{BC}±1.57	35.93^{BC}±1.84	38.06^{B}±1.21	31.94^{C}±3.78	38.29^{BC}±1.57	49.98^{A}±6.58	49.15^{A}±4.50

The values in each row followed by different letters are statistically significant (P<0.05).

Table 4. Average values of image texture features of fried carrot at different frying conditions

Image texture feature	140 °C				160 °C			
	3 min	4 min	5 min	6 min	3 min	4 min	5 min	6 min
Contrast	0.173±0.024	0.199±0.023	0.225±0.031	0.254±0.010	0.191±0.030	0.208±0.056	0.255±0.038	0.277±0.036
Correlation	0.772±0.035	0.709±0.034	0.675±0.066	0.660±0.022	0.727±0.061	0.680±0.092	0.659±0.077	0.659±0.0120
Energy	0.350±0.012	0.348±0.009	0.291±0.024	0.250±0.018	0.30±0.051	0.250±0.012	0.227±0.012	0.210±0.012
Homogeneity	0.918±0.012	0.904±0.011	0.888±0.015	0.878±0.013	0.911±0.016	0.902±0.021	0.884±0.016	0.866±0.016

Table 5. Multiple linear regression (mlr) between image texture features and hardness of fried carrot in compression and puncture testes

Mechanical test	Relationship	Correlation coefficient	P value
Compression	Hardness= -3763.4 + (2809.2Contrast) - (944.4Correlation) - (655.7Energy) + (5119.6Homogeneity)	0.97	0.028
Puncture	Hardness = 335.8 + (1730.0Contrast) - (474.8Correlation) + (50.4Energy) - (116.5Homogeneity)	0.98	0.017

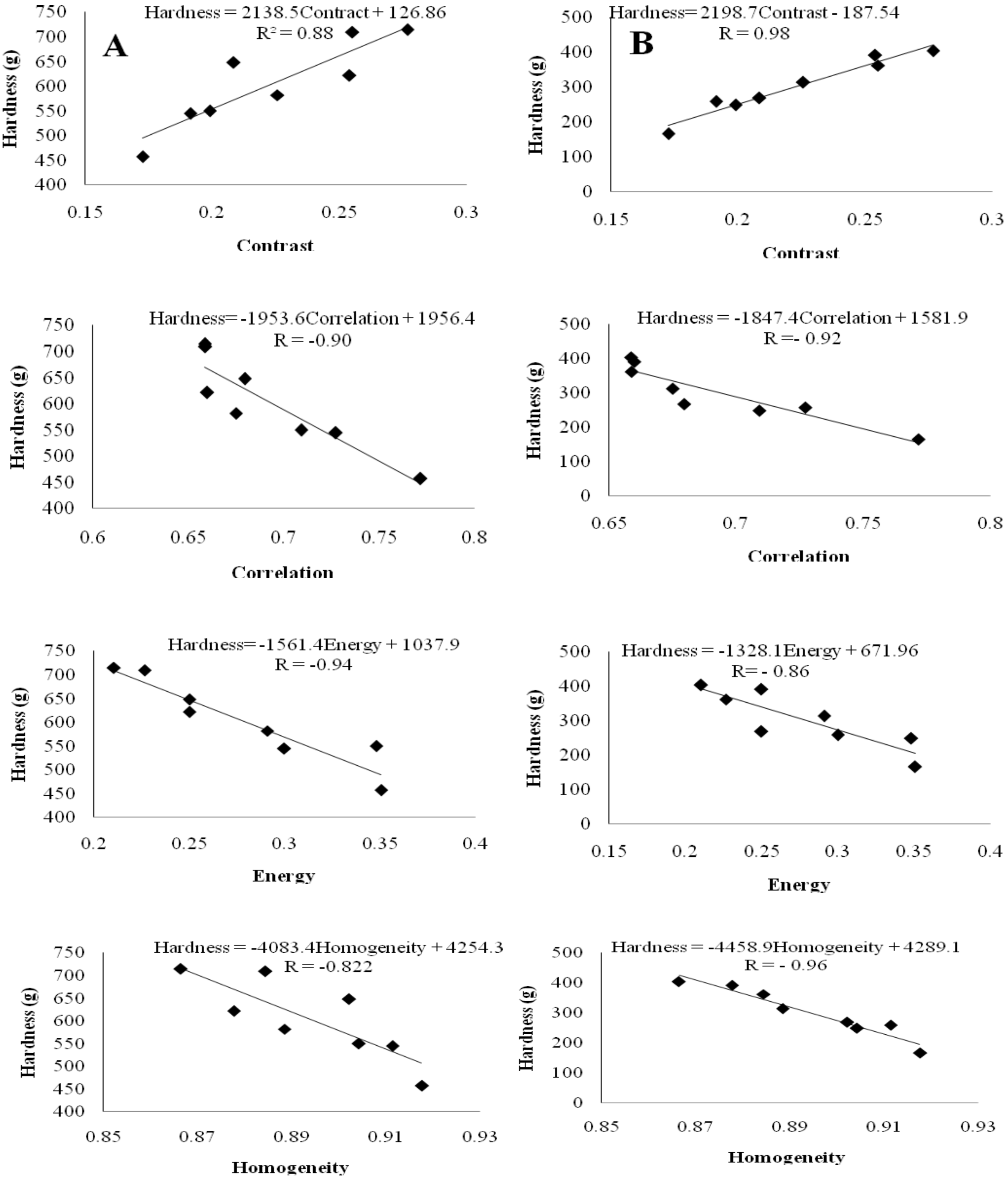

Fig. 4. Correlations of image texture features with hardness from compression (A) and puncture (B) tests

Conclusions

In this study, image texture analysis was applied to predict mechanical texture properties of carrot chips. Sliced samples were subjected to deep-fat frying at different processing conditions and moisture content, colour parameters (i.e. L^*, a^*, b^* and ΔE), mechanical properties (i.e. hardness and apparent modulus) and image texture features (i.e. contrast, correlation, energy and homogeneity) were determined. The results showed that moister content of fried samples (ranging from 2.97 to 17.60% w.b) decrease with increasing frying temperature and time. Nevertheless, the colour changes (ranging from 31.94 to 49.15) increased as the frying performed at the higher temperature for longer processing times. The results of mechanical texture analysis showed that hardness and apparent modulus significantly raised with increasing frying temperature and time. The image texture values, extracted from grey level co-occurrence matrix of fried carrots' images, showed that contrast and energy can be applied for estimation of hardness of samples for compression and puncture tests with high correlation coefficients of 0.94 and 0.98, respectively. The outcomes of this investigation suggest that image texture features can be successfully applied as a non-destructive and rapid method for mechanical texture prediction of carrot chips.

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جلد ۱۲، شماره ۳، مرداد - شهریور ۱۳۹۵، ص. ۳۴۹-۳۴۰

تاثیر برخی ویژگی‌های فرایند بر ویژگی‌های مکانیکی و بافت تصویر هویج سرخ شده

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چکیده

در این تحقیق کاربرد آنالیز بافت تصویر به‌عنوان یک روش غیرمخرب برای اتوماسیون و پیشگویی برخی ویژگی‌های مکانیکی چیپس هویج مورد بررسی قرار گرفت. نمونه‌ها در شرایط‌های مختلف سرخ شدندو رطوبت، پارامترهای رنگی (L^*، a^*، b^* و ΔE) و خواص مکانیکی (سختی و مدول ظاهری) تعیین شد. سختی و مدول ظاهری با افزایش دما و زمان سرخ کردن افزایش یافتند. چهار ویژگی بافت تصویر (کنتراست، همبستگی، انرژی و یکنواختی) با استفاده از ماتریس هم‌وقوعی سطح خاکستری محاسبه شد. نتایج نشان داد کنتراست و انرژی سطح خاکستری تصاویر همبستگی بهتری با سختی نمونه‌های سرخ شده حاصل از آزمون فشاری سوراخ کردن داشتند. بترتیب ضرایب همبستگی ۰/۹۷ و ۰/۹۸ بین چهار ویژگی‌های بافت تصویر و سختی در آزمون فشاری و سوراخ کردن بدست آمد. نتایج نشان داد که آنالیز بافت تصویر می‌تواند به‌عنوان یک روش غیرمخرب برای تخمین ویژگی‌های بافتی هویج استفاده شود.

واژه‌های کلیدی: هویج، سرخ کردن، آنالیز بافت تصویر، ویژگی‌های بافتی مکانیکی

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