Color quality variation of french fries during frying using image processing

Hassan Sabbaghi
M. Sc. Student of Food Technology
University of Agricultural Sciences & Natural Resources
Gorgan, Iran
hassansabbaghi@yahoo.com

Dr. Aman mohammad Ziaiifar
Assistant Professor of Food Process Engineering
University of Agricultural Sciences &Natural Resources
Gorgan, Iran
ziaiifar@gmail.com

Abstract—*The aim of this study was to evaluate the suitability of a computerized image analysis technique (with a flatbed scanner for image acquisition) in order to measure the amount of the important visual aspects of French fries such as color components in RGB system and characterization of intensity and luminance of product during process. The potato slices were fired at three temperatures (145, 160 and 175°C) during 4 min. Product temperature was measured, about 1mm below the surface of French fries, using T-type thermocouple and data logger. Product was removed from the fryer, then scanned with a flatbed Scanner. Color analyses were carried out using imageJ software. The applied image analysis technique was able to differentiate with high sensitivity the changes in French fries color during frying process. Result showed that main changes of color in process are during initial heating stage and process control in this stage is very important. This technique presents a high potential to develop a computer vision on-line system for frying process optimization.*

Keywords-image analysis; color; french fries; imageJ; computer vision

I. INTRODUCTION

Commercial deep-fat frying is an important part of the food industry and the French fries are among the major commercial fried foods and account for 44% of processed potatoes in the US [1]. Visual properties of fried foods such as color are important to consumers and they tend to associate these properties with the taste and crispiness, determining their acceptance or rejection [2]. Quality of fried foods is strongly defined in terms of color and texture [3].

In the French fry process, raw potatoes are washed, peeled, sorted, and cut into strips. Then, the strips are blanched in hot water, and then dehydrated with warm air to a moisture content of approximately 60% wet basis. After this, the potato strips are fried in hot oil, cooled in ambient air and finally frozen and packaged. The blanching step reduces the oil absorption by gelatinization of the surface starch. On the other hand, air dehydration leads to lower initial moisture content which also reduces the oil absorption. Thus, both the blanching and the air drying steps allow for a lower amount of oil in the final product. Another way to achieve that is by controlling the frying oil temperature, higher temperatures lead to lower absorbed oil [4].

French fries color is the result of Maillard reaction that depends on the superficial content of reducing sugars, and the temperature and frying period. The global impression of color on fried potatoes is based not only on the color itself but also on the quantity, distribution, shape and interlacing of the small elements distributed throughout the sample. Thus, the color appearance of French fries is also dependent on the amount and distribution of brown regions developed during frying as well as the remnant oil absorbed on the surface after frying, which produce oily areas with transparent appearance [1].

A product with good color quality and with no faults is very important and Vision technology has a crucial role in it. It is necessary to consider the variation during process to achieve optimal conditions. Therefore, vision technology by image processing techniques can be used to check for incomplete product. Computer vision applied to evaluate the internal texture of French fries. A set of 150 sample images were categorised into normal and hollow classes by three algorithms. The co-occurrence matrix gave the best results with 100% accuracy [5].

The color development is a surface phenomena, related to temperature and frying time. in several studies the acrylamide content in French fries has been related to color [6]. Therefore, an objective evaluation of the extension of the oily and brown areas in the surface of product could be useful in order to both provide an estimation of the final product quality, in terms of oil content and color intensity, and for the monitoring of the frying process. Usually, in industries and even in research laboratories, quality control and analyses are made by measurement of the color intensity of product after frying using visual inspection based on standard color charts, and in the best cases, using tristimulus colorimeters and spectrophotometers [7].

In the food industry the most common design is that of stationary camera and moving objects. The important factor, is to set the image acquisition rate fast enough to minimize image blur so that an analysis of image data can take place frame-by-frame and the goal of check out the photos can be divided into three categories According to Table 1. Recent developments in vision system include color image processing and three dimensional (3-D) image processing. Depending on the design of imaging system, different image processing techniques are required [8].

TABLE I. TYPES OF STUDIES IN COMPUTER VISION SYSTEM

Types of studies	input	output
Image Processing	Image	image
Image Analysis	Image	measurements
Image Understanding	Image	high-level description

A color space is a mathematical representation of a set of colors. The three most popular color models are RGB (used in computer graphics), YIQ, YUV, or YCbCr (used in video systems); and CMYK (used in color printing). All of the color spaces can be derived from the RGB information supplied by devices such as cameras and scanners. The red, green, and blue (RGB) color space is widely used throughout computer graphics. Red, green, and blue are three primary additive colors (individual components are added together to form a desired color) [9]. Table 2 contains the RGB values for colors with 100% amplitude and 100% saturated bars. Saturation refers to the relative purity or the amount of white light mixed with a hue. The pure spectrum colors are fully saturated and contain no white light. Colors such as pink (red and white) and lavender (violet and white) are less saturated, with the degree of saturation being inversely proportional to the amount of white light added. Every color in the RGB image mode has a unique identity consisting of the color intensity of each of the three basic colors (red, green and blue). The intensity scale is defined from 0 (darkest) to 255 (brightest) [10].

The color standard is used worldwide for the evaluation of French fries is the USDA French fry color (Fig. 1). The term fry color, as used in this standard refers to the color change which occurs in the potato units solely because of the frying process. According to this standard the products are divided into three categories based on color [11]:

- **Good color** means the bright, characteristic color of properly prepared frozen French fried potatoes. The fry color may be Extra light, Light, Medium light or Medium.
- **Reasonably good color** means a characteristic frozen French fry potato color which may be dull but not off color. In this case, the fry color may be variable, exceeding the uniformity criterion of Extra light, Medium light, Medium or Dark. After heating, however, the variation in the fry color of the units does not seriously affect the appearance of the product.

TABLE II. IN 100% RGB COLOR BARS.

Channels	Colors							
	White	*Yellow*	*Cyan*	*Green*	*Magenta*	*Red*	*Blue*	*Black*
R	255	255	0	0	255	255	0	0
G	255	255	255	255	0	0	0	0
B	255	0	255	0	255	0	255	0

- **Others,** French fries that fail to meet the requirements of previous paragraphs.

Many studies have been done on the color of fried products but color changes in different stage of frying less are cited. For example, Kinetics of crust color changes during deep-fat frying of impregnated French fries was studied [4]. Other Studies evaluated the suitability of color and textural features to characterize and classify commercial potato chips in four quality attributes, and to relate this to the preferences of a group of consumers. Results showed that features derived from the image texture contained better information than color features to discriminate both the quality categories of chips and consumer preferences [12, 13]. Researchers evaluated the suitability of a computerized image analysis technique (with a flatbed scanner for image acquisition) in order to measure the amount and distribution of the important visual aspects of potato chips. This technique presents a high potential to develop a computer vision on-line system for frying process optimization, as a function of the fat content of the final product [14, 15].

The objective of this work were (I) study the crust color changes during deep-fat frying for better control of process (II) define the appropriate conditions to achieve proper color in French fries using image analyzing (III) explain to how color of product has changed during different stages of process.

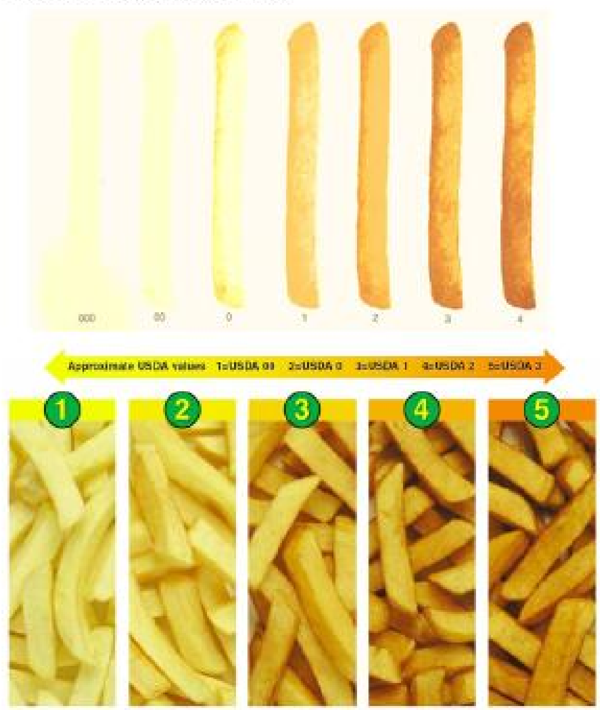

Figure 1. Examples of frying designed color chart and french fries. The fry color of a sample can this be done : Extra light (Lighter than USDA No. 1), Light (Similar to USDA No. 1 color), Medium light (Mostly similar to USDA No.2. Predominantly lighter than No.3 but may include No. 1.), Medium (Mostly similar to USDA No.3. May include units of No. 4 and/or No.2 fry color), Dark (Predominantly darker than USDA No. 3. May include color No. 4 or darker). Samples to be assessed in daylight or under artifitial daylight bulbs [11, 16].

II. Materials and Methods

A samples preparation

Agria variety is the most commonly used potato in French fries industry because of its regular shape and high dry matter content. Sample preparation was performed similar to the processing conditions for commercial French fries production. The tubers were washed, peeled and cut, by a manual cutter into strips of 8×8×60 mm. In order to minimize enzymatic browning and simulate the industrial practice before frying the potato slices were washed in tap cold water for 30 s and gently blotted with absorbing tissue paper in order to partially remove the excess starch.

B. Frying and surface temperature measurements

Experiments were carried out using temperature controlled frying unit (Deep fryer: Model BDZ-5A-1) at 145, 160 and 175°C respectively, using 2L sunflower oil as frying medium. For each oil temperature, frying time was 4min. Product temperature was measured, about 1mm below the Surface of French fries, using T-type thermocouple. Temperature variation is recorded in 2s time intervals in replicates of 3, using a data logger (Model TC-08 "RS-232" manufactured by Pico technology).

C. Image acquisition

Performing image acquisition in image processing is always the first step. For this purpose, French fries were removed from the frying unit at 30 s intervals (0, 30, 60, 90… 240s) and in replicates for each oil temperatures (145, 160, 175°C). Then, samples were allowed to drain for 20 min so that excessive oil could drain off. French fries were scanned with a Flatbed Scanner (HP ScanJet G2710, 2400-4800 dpi hardware resolution). After removing of Scanner lid, during image acquisition, the scanner was held in a black box, in order to exclude surrounding light and external reflections. All images were scanned at the same conditions, by positioning on the scanner the eight French fries coming from each repetitions and treatments (Fig. 2, "a"). The scanner was connected to the USB port of a PC provided with the Scanitto Pro Software (version 2.7.15.198) to visualize and acquire the digitalized images directly from the computer with high resolution. The scanned images were saved as TIFF-24 bit format in 300 dpi resolution and color mode. Finally, images were analyzed in the image J software (version 1.44p bundled with 32-bit Java) environment to investigate the RGB channels after color thresholding for ignore background (Fig. 2, "b").

D. Color image analysis and characterization

Image is made of pixels and each pixel has combination of colors like RGB. For color image analysis, at the first step R, G and B values mean is calculated individually for each channel using "RGB measurement" plugin of image J software. Thus, a mean is obtained for each channel and changes of these values were plotted against frying time.

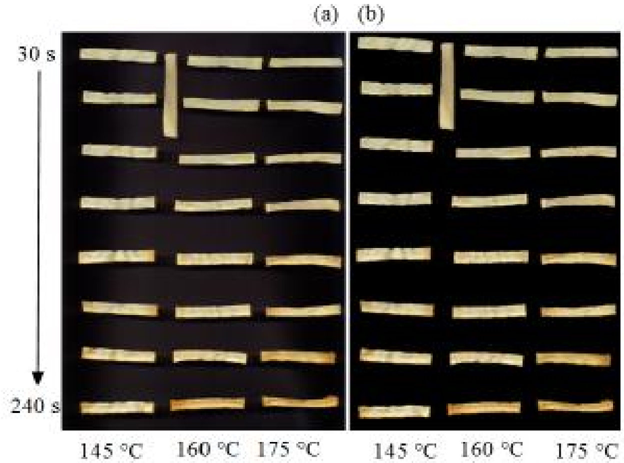

Figure 2. (a) Scanned image of samples at different conditions of temperature and time. A similar picture is also prepared for repeats. For each image, a blank sample for time 0 was placed vertically. (b) After color thresholding for ignore background in imageJ and selection of each sample for analysis.

Intensity in RGB color mode was measured for each image using RGB measurement plugin and variation of this parameter was interpreted. Relation of this parameter with RGB values is as follows:

$$I = \frac{R + G + B}{3} \quad (1)$$

In this case In this case, in fact image is converted to grayscale and intensity scale is defined from 0 (darkest) to 255 (brightest). When converting from RGB to grayscale, it is said that specific weights to channels R, G, and B ought to be applied. These weights are: 0.2989, 0.5870, and 0.1140. It is said that the reason for this is different human perception/sensibility towards these three colors. Furthermore luminance was obtained for each image by RGB measurement plugin that is follow as equation 2 [8]:

$$L= 0.299R+0.587G+0.114B \quad (2)$$

E. Statistical analysis

Statistical analysis was performed in completely randomized factorial design using SPSS software (version 19) and the test of mean comparison according to Fisher least significant difference (LSD) were applied at a level of significance of 0.01. Factors are oil temperatures (3 levels) and frying time with 60 seconds intervals (4 levels). The effect of each independent variable plus their interaction was interpreted.

III. Results and discussion

A. Surface tempreture of product

Temperatures inside potato strips are restricted to values slightly above the boiling point of water but, as frying proceeds and the surface becomes drier, the surface temperature T_s approaches the oil bath temperature.

Fig. 3 shows T_s (mean surface temperature of repeats for each sample), as a representative example for three frying temperature. At the beginning of the frying, the surface temperature rapidly increased to boiling temperature and then rose gradually as latent heat for moisture evaporation restrict temperature rise from the heat transfer from oil. During 4 min of frying, surface temperatures did not reach oil temperatures. Temperature profiles for each oil temperature was very similar although at 160 and 175 °C , surface temperature rising to boiling point of water with almost same rate, but less time will remain in the boiling water. So certainly expect that major changes in color of product are during surface boiling stage and occurs at failing rate stage into darker(, which is the longest, in which the internal moisture leaves the food, the core temperature rises to the boiling point, the crust layer increases in thickness and finally the vapor transfer at the surface decrease.

B. RGB channels

As shown in Fig. 4, the R parameter increases significantly during frying. Increasing of this parameter is not desired because that means a redder product, which is not acceptable for fried potatoes. As the temperature of frying increases, the R parameter increases for the same frying time, which is negative for color of fried products. n general, Fig. 3 and Fig. 4 show at constant surface temperature of the boiling range increasing of R is almost linear. Then, with developing of frying time, with rising of surface temperature above boiling point of water, less increasing rate of R channels was observed. Expected during the development process time, because of create a darker product R values will be reduced.

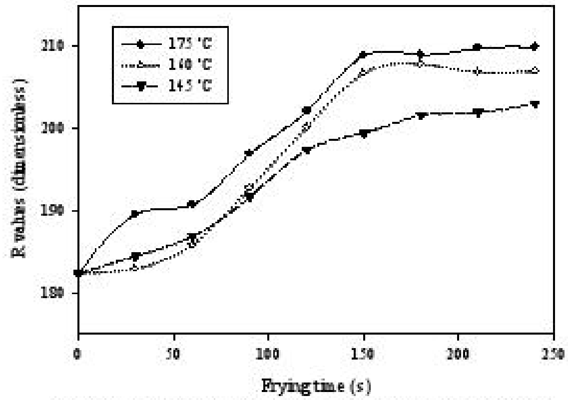

Figure 4. Effect of frying process on parameter R versus time.

R values changes in 145 °C was slowly and for 160°C and 175°C was very similar. Studies are shown the size of potato strips also affects the redness parameter of samples during frying. This parameter increases with sample thickness decrease, for the same frying time [17].

In Fig. 5 color changes to get brown can be explained in this way which use the same red and mix it with sap green (yellow-green) for brown obtained. The changes of G chnnels are similar to R channels. Reduction of B channels is just for more Blur and that is started Time of about 100 seconds and less more in 175 °C. reduction of oil uptake in high temperature also affect the small changes of G channels.

C. Relative Intensity and luminance charactrization

Grayscale images are often the result of measuring the intensity of light at each pixel. Fig. 6 shows that intensity of potato strips increases during the early stages of frying. While it remains almost constant afterwards and then it will reduced. . The comparison between Fig. 4 and Fig. 6 is shown that the rate of intensity approach to constant step more quickly. This can Because of production of brown pigment in process.

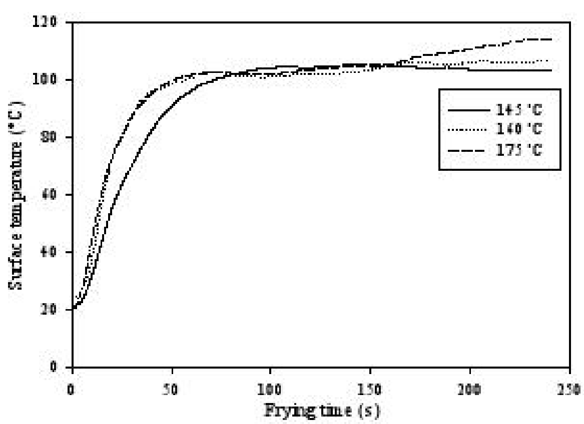

Figure 3. Surface temperature of French fries during frying at 145, 160 and 175 °C.

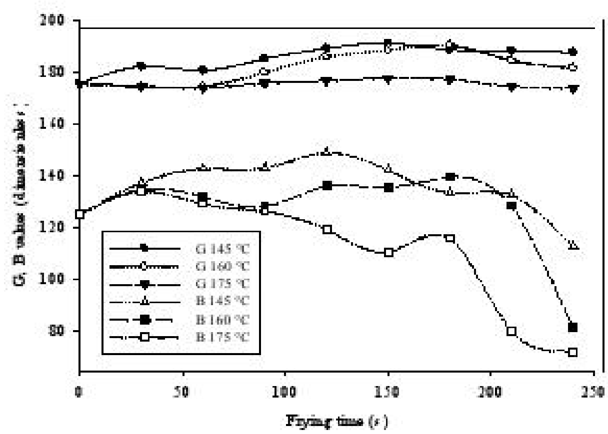

Figure 5. Effect of frying process on parameter G and B versus time.

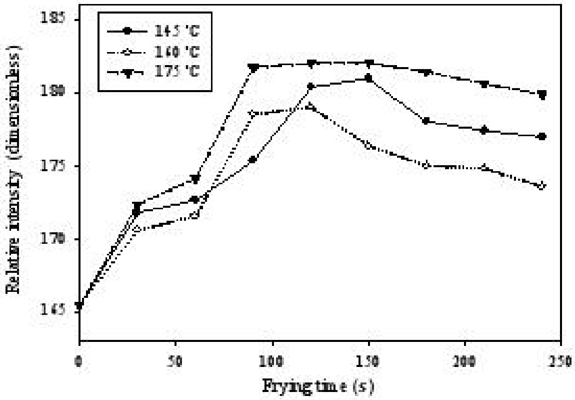

Figure 6. Changes of relative intensity levels of grayscale image during frying.

Brown is a color term, denoting a range of composite colors produced by a mixture of orange, red, rose, or yellow with black or gray in combination with low luminance or saturation. Thus, the increasing of maillard reaction rate is simultaneously with beginning of constant rate of intensity. With this interpretation, Increased Maillard reaction in 145 °C is later than other treatments. Brown background in image of product is required to be reduced of RGB channels, but R and G are reduced after more time. Fig. 5 shows this fact about 100 seconds after the beginning of the process.

Fig. 7 Shows changes of relative luminance levels during frying. Relative luminance follows the photometric definition of luminance for a reference white. Luminance is often used to characterize emission or reflection from flat, diffuse surfaces. Luminance is used in the video industry to characterize the brightness of displays. Thus, lightness of potato strips increases during the early stages of frying, while it remains almost constant afterwards. Oil temperature has a negative effect on the lightness of French fries. As the temperature of frying increases, luminance or lightness, for the same frying time, decreases. In addition reduction of lightness starts early at high temperatures oil.

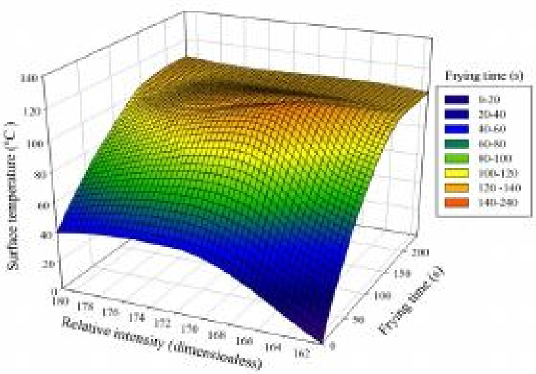

Figure 8. 3D curve of changes in RGB intensity and surface temperature in product during frying in 145 °C.

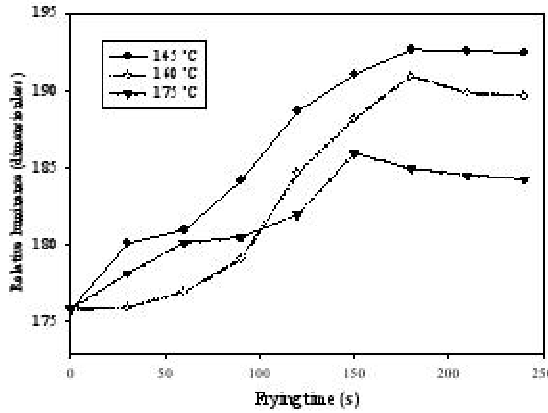

Figure 7. Changes of Relative luminance levels during frying.

Fig. 8 shows 3D curve of changes in RGB intensity and. Clearly, drastic changes in primary stage of frying in surface temperature and flowing intensity of grayscale.

D. Color changes in different parts of the product

Fig. 9 shows grayscale color changes in different parts of the product after 240 seconds at each temperature. Always in 3D color image analysis, edges of image have more blurry than flat surface. Because of main color changes in product edges and relative color stability of the intermediate part of product, observed with increasing temperature more strongly curved in 3D plot. Color uniformity of French fries is an important factor for quality of product. In low temperature color has more uniformity after 240s.

E. Statistical analysis

Statistical analysis was conducted to determine the effect of frying time (1, 2, 3 and 4 min) and temperatures factors on RGB channel. The results are shown in Table III. These results confirmed the sole and the interaction effect of the temperature and frying time on the color of chips. The test of mean comparison according to Fisher least significant difference (LSD) was applied at a level of significance of 0.01. Which was anticipated to result from the change of charts is much closer. For R channels changes, difference between the times have a high significant but for temperatures was no significant. Exactly least significant difference between 3 and 4 minutes was no significant. Thus, time is a critical point in color variation of French fries and Redness changes during the initial heating of frying is almost the same for all temperatures.

For G channels difference between 175 °C with other temperature was significant. Reduction of channel G in high temperature and stability of R is shown that high temperature caused more darkness and color uniformity even at short time (Fig. 9 "d"). Changes of B channels are significant versus of time and temperature that it shows drastic changes in this parameter during frying.

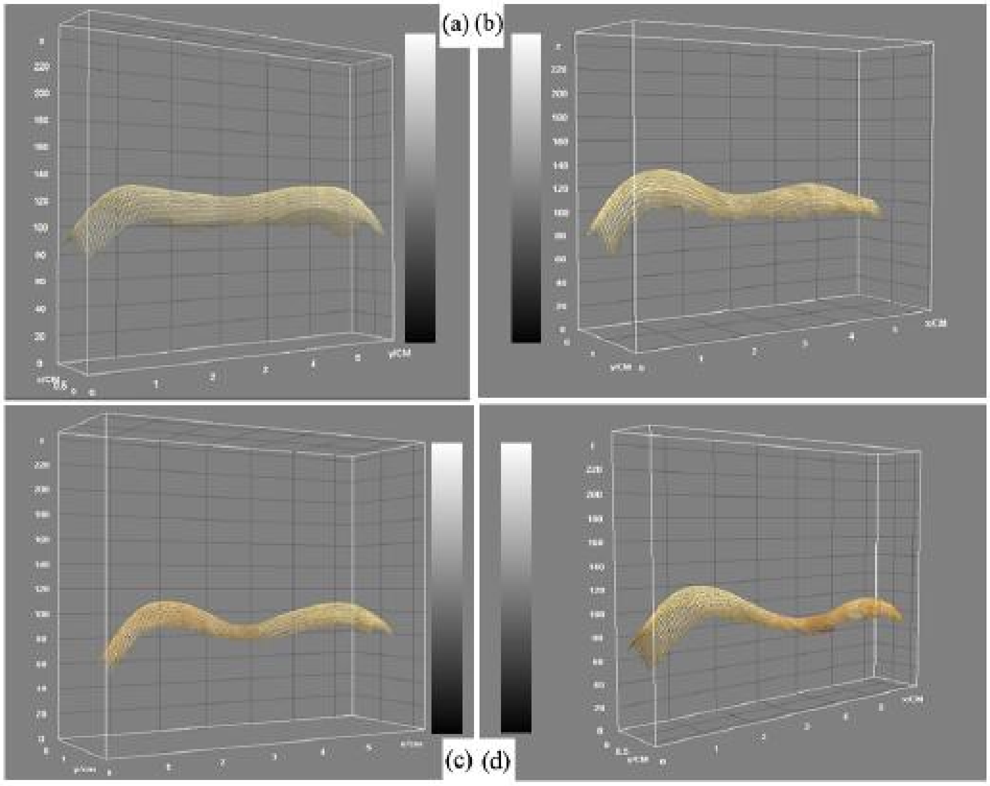

Figure9. 3D surface plot of grayscale inteisity change in different part of product. (a) blank sample at 0 frying time (b) sample is fried at 145°C for 240s (c) sample is fried at 160°C for 240s (d) sample is fried at 175°C for 240s.

TABLE III. EFFECT OF THE FRYING TEMPERATURE AND TIME ON COLOR PARAMETER OF FRENCH FRIES USING THE R G B CHANNELS.

Color parameter	Temperature (°C)	1min	2min	3min	4min
	145	$186.89^{a,\alpha}$	$197.41^{a,\alpha}$	$201.62^{a,\alpha,\beta}$	$200.12^{a,\alpha,\beta}$
R	160	$185.89^{a,\alpha}$	$200.16^{a,\alpha}$	$207.86^{a,\alpha,\beta}$	$205.06^{a,\alpha,\beta}$
	175	$190.74^{a,\alpha}$	$202.12^{a,\alpha}$	$208.95^{a,\alpha,\beta}$	$208.03^{a,\alpha,\beta}$
	145	$181.05^{b,\alpha,\beta}$	$189.51^{b,\alpha,\beta}$	$189.06^{b,\alpha,\beta}$	$187.94^{b,\alpha,\beta}$
G	160	$178.97^{b,\alpha,\beta}$	$186.49^{b,\alpha,\beta}$	$190.91^{b,\alpha,\beta}$	$182.03^{b,\alpha,\beta}$
	175	$174.35^{b,\beta}$	$177.11^{b,\beta}$	$177.57^{b,\beta}$	$172.21^{b,\beta}$
	145	$143.19^{c,\alpha,\beta}$	$149.38^{c,\alpha,\beta}$	$133.73^{c,\alpha,\beta,\gamma}$	$112.92^{c,\alpha,\gamma}$
B	160	$132.23^{c,\alpha,\beta}$	$136.35^{c,\alpha,\beta}$	$140.01^{c,\alpha,\beta,\gamma}$	$81.53^{c,\alpha,\gamma}$
	175	$129.45^{c,\beta}$	$119.65^{c,\beta}$	$116.18^{c,\beta,\gamma}$	$72.22^{c,\gamma}$

^{a}, ^{b} and ^{c} Indicate no significant difference at 0.01 level.
$^{\alpha}$ comparison in rows (oil temperatures), $^{\beta}$ and $^{\gamma}$ comparison in columns (frying times).

IV. Conclusions

The color changes of French fries during frying can be described using image analysis. Oil temperature and mostly process time showed significant influence on color parameter. The color change phenomenon gets more intense at higher oil temperatures. Three different periods were observed in color change during French fry process (rising, constant and falling). Grayscale intensity in different part of product shows that high temperatures create a color uniformity product. Temperatures about 175°C and short time give more intensity and lighter less red and more acceptable products. Production of maillard pigment in different temperatures can be explained using this image analysis. Drastic changes are in primary stage of frying in surface temperature and flowing intensity of grayscale. Thus, this stage is very important in control of process in order to approach acceptable product.

References

[1] G. Bingol, A. Zhang, Z. Pan and T. H. McHugh, "Producing lower-calorie deep fat fried French fries using infrared dry-blanching as pretreatment", Journal Food Chemistry, vol. 132 , 2012, pp. 686–692, doi:10.1016/j.foodchem.2011.10.055.

[2] S. Romani, P. Rocculi, F. Mendoza and M. D. Rosa, "Image characterization of potato chip appearance during frying", Journal of Food Engineering, vol. 93, 2009, pp. 487–494, doi:10.1016/j.jfoodeng.2009.02.017.

[3] F. Pedreschi, J. Leon, D. Mery and P. Moyano, "Development of a computer vision system to measure the color of potato chips", Food Research International, vol. 39, 2006, pp. 1092–1098, doi:10.1016/j.foodres.2006.03.009.

[4] P. C. Moyano, V. K. Rioseco and P. A. Gonzalez, "Kinetics of crust color changes during deep-fat frying of impregnated french fries", Journal of Food Engineering, vol. 54, 2001, pp. 249–255.

[5] H. Yin and S. Panigrahi, "Image processing techniques for internal texture evaluation of French fries", In 1997 ASAE Annual International Meeting, Paper No. 973127. St. Joseph, Michigan, USA.

[6] F. Pedreschi, P. Moyano, K. Kaack, K. Granby, "Color changes and acrylamide formation in fried potato slices", Food Research International, vol. 38, 2005, pp. 1–9, doi:10.1016/j.foodres.2004.07.002.

[7] Rodriguez-Saona, L.E., Wrolstad, L.E., "Influence of potato composition on chip color quality", American Potato Journal vol.74, 1997, pp. 87–106.

[8] I. T. Young , J. J. Gerbrands and L. J. v. Vliet, "Fundamentals of Image Processing, Delft University of Technology", 2007.

[9] K.N. Plataniotis and A.N. Venetsanopoulos, "Color Image Processing and Applications", Springer-Verlag , 2000.

[10] T. Vrekoussis, V. Chaniotis, I. Navrozoglou, V. Dousias, K. Pavlakis, E. N. Stathopoulos and O. Zoras, "Image Analysis of Breast Cancer Immunohistochemistrystained Sections Using ImageJ: An RGB-based Model", Anticancer Research, vol. 29. 2009, pp. 4995-4998.

[11] United States Standards for Grades of Frozen French Fried Potatoes, United States Department of Agriculture (USDA), 1969.

[12] F. Mendoza, P. Dejmek and J. M. Aguilera, "Color and image texture analysis in classification of commercial potato chips", Food Research International, vol. 40, 2007, pp.1146–1154, doi:10.1016/j.foodres.2007.06.014.

[13] F. Pedreschi, D. Mery, A. Bunger and V. Yanez, Computer vision classification of potato chips by color, Journal of Food Process Engineering , 2010, doi: 10.1111/j.1745-4530.2009.00540.x.

[14] S. Marty, K. W. Baker and A. G. Marangoni, "Optimization of a scanner imaging technique to accurately study oil migration kinetics", Food Research International, vol. 42, 2009, pp. 368–373, doi:10.1016/j.foodres.2008.12.017.

[15] T. Brosnan and D. W. Sun, "Improving quality inspection of food products by computer vision––a review", Journal of Food Engineering, vol. 61, 2004. pp. 3–16, doi:10.1016/S0260-8774(03)00183-3.

[16] British Potato Council, Sutton Bridge Experimental Unit, Guide to Chips, November 2011.

[17] M.K. Krokida, V. Oreopoulou, Z.B. Maroulis and D. Marinos-Kouris, "Color changes during deep fat frying", Journal of Food Engineering, vol. 48, 2001, pp. 219±225.