IMAGE ANALYSIS OF THE BROWNING REACTION IN FOODS

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ABSTRACT

This study aimed to design an image system combined with surface temperature measurement for obtaining on-line browning data for food during cooking. The system was developed by adapting an oven with a thermal camera which was able to capture both the normal light image and infrared image for analysing the colour and temperature, respectively. The design of the lighting system was the most important factor for obtaining good quality images. The image was analyzed using the VIPS software to calculate the colour values. The result of this study showed that the imaging technique could be used for the Maillard browning study. It provided a greater speed, accuracy, cost effectiveness and consistency. The method was able to measure the distribution of colour on the surface in real time and does not destroy the sample. This makes it potentially useful for online monitoring of commercial baking processes.

INTRODUCTION

The Maillard browning reaction is one of the most important reactions occurring at the food surface. It results in a colour change into a golden colour which is considered a desirable characteristic by consumers in evaluating food quality [1]. Normally, the Maillard reaction is measured by chemical analysis or using colorimetry. These methods have some disadvantages in being time consuming, they average results over a large area or they destroy the sample. Image analysis or computer vision has often been applied in the agricultural and food industries for obtaining and analyzing colour and other properties. This technique was therefore used for evaluating the colour change due to the Maillard browning reaction on the food surface during processing. This study aimed to design an image system combined with surface temperature measurement for obtaining online data for the food during cooking.

METHODS

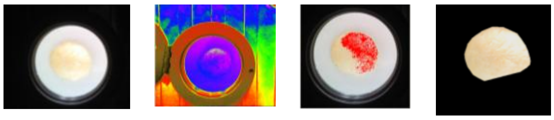
To study and compare the efficiency of the colour measurement method between the image and conventional colorimetry methods, the cooking systems were different. An oven was used for image method and a hot pan was used for colorimeter method.

The design of the oven cooking system

The system was developed by adapting an oven and combining it with a thermal camera (FLIR E60) which was able to capture both a normal light image for analyzing the colour and an infrared image for measuring the temperature as shown in Figure 1.

Figure 1 Oven cooking system setup showing lighting

The design of the lighting system was the most important factor for obtaining good quality images. To get high quality images of the pastry rising during the cooking process, providing light directly to the sample surface created a problem for the image analysis because specular reflection produced highlights as shown in Figure 2.



(a) (b) (c) (d)

Figure 2 Image of cooked pastry under direct lighting conditions: (a) pastry with direct lighting, (b) false colour image showing highlights, (c) check showing saturated pixels after calibration and (d) segmented image used for colour measurement

Therefore direct light on the pastry surface needed to be avoided. The solution was to place a wood sheet of 125 mm height in front of the oven to block the direct light (Figure 3). Consequently, the light passed over the wooden guard to the white painted wall and roof of the oven and then reflected to the pastry and the tile base.

Figure 3 A wooden guard placed at the front door of the oven

Figure 4 shows an image with a good even light and the same image after segmentation using VIPS program.

(a) (b) (c)

Figure 4 Good even light images: (a) normal image with a good even light (b) showing only a few pixels saturated pixels (coloured red) and (c) sample after segmenting sample from background

Due to the auto-exposure of the camera was found meant that when the sample darkened, the exposure increased to compensate. This caused the background to saturate. Since the tile background is used for colour calibration, saturation results in inaccurate calibration (Figure 5).

(a) (b)

Figure 5 Image series of pastry samples with self adjustment of the camera during the cooking process: (a) a light brown pastry sample with the reference white background and (b) a dark brown pastry sample with saturated background

This problem was solved by placing a sheet of white cardboard on top of the oven around the viewing port (Figure 6). Then the average light level was increased so that changes in the sample had less effect on the overall light level.

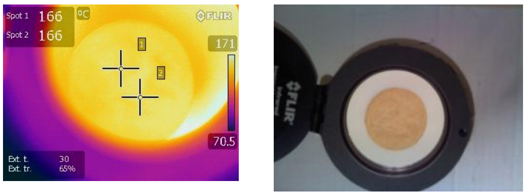
Figure 6 The light bulb above the oven and the white cardboard on the oven to overcome self adjustment issue

After the addition of the cardboard above the oven, good images were obtained as shown in Figure 7.

(a) (b)

Figure 7 Image series of pastry samples taken during the cooking process: (a) a light brown pastry sample with the reference white tile background and (b) a dark brown pastry sample with unsaturated reference white tile background

A system was therefore useful for providing good images, which were used for image analysis. The light image was analyzed to calculate the average colour and colour distribution of the sample in the *L*a*b** colour space. In addition, the infrared image gave the temperature history during baking. The infrared image is shown in Figure 8.



(a) (b)

Figure 8 Pictures captured by the FLIR infrared camera: (a) an infrared image and (b) a regular colour image

The pastry temperature was recorded during baking time. The time-temperature history and lightness data were used for fitting a kinetic model. The kinetic fitting result obtained from the thermal camera measurement was then compared with that derived from the conventional colorimetry method.

The design of pan baking system for colorimeter

The heating pan for pastry samples cooked in the study was developed by adapting a deep frying cooker (Figure

9). The pan system consists of the deep fryer (ANViL model FFA 3001-TEU), the non stick teflon pan sheet, the stirrer and the aluminium weight that was put on top of the pastry to ensure complete contact between the pastry samples and the pan sheet (Fig. 9). The dimensions of the deep fryer pot were 258 mm wide, 317 mm long and 145 mm deep and the dimensions of the pan sheet were 210 mm wide and long and 34 mm deep. The deep fryer pot contained oil which was used to heat the pan. Heat transfer oil (CALTEX Chevron: REGAL R&O 46) was selected for use in this study and it was heated by a 3 kW heating coil and the temperature controlled by a PID controller (model CAL 3200). A stirrer was applied to increase the heat transfer from the oil to the pan sheet and to make it uniform.

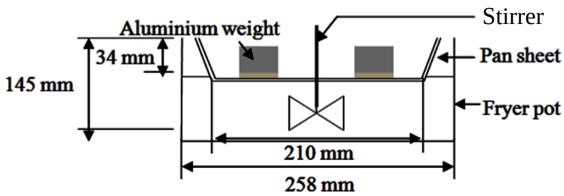


Figure 9 The prototype cooking system using a deep fryer

<u>**Experimental trials**</u>

Frozen pastry was purchased from the local supermarket and left at room temperature (20˚C) until thawed, then cut by a cookie cutter into circular sample with a diameter of 120 mm. The thickness of the pastry was 2 mm. The pastry was put into the oven at time 0 and then the oven was turned on. Therefore, the pastry temperature started from room temperature (20°C) and was heated to be close to the set point temperature. The experiments were carried out in a dark room and only the light from the lighting system was present.

For the conventional colorimetry method, the raw pastry was cut using a cookie cutter with a diameter of 50 mm. The experiments consisted of 5 replications at 10°C temperature intervals from 120°C-170°C bake on the deep fryer pan cooking system described above. Samples were randomly removed from four different baking positions after 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55 and 60 minutes. After removed the samples were suddenly cooled down indirectly with ice in a stainless steel tray to stop the cooking process. The brown colours on the pastry of all samples were measured using the spectrophotometer.

RESULTS

The temperature and lightness profiles of the pastry surface baking in the oven as measured by the thermal camera are shown in Figures 10 and 11, respectively. The temperature profile during cooking was achieved by varying the temperature to over the expected range of commercial cooking conditions and where Maillard reactions occur (120-180°C) [1, 2]. The temperature profile was a step-wise heating profile, with different times at each step. This was based on the hypothesis that the Maillard reaction needs a longer time for the reaction at lower temperatures to achieve the same colour change. Therefore at low temperature, the cooking process was run for a long time and the holding time was reduced at higher temperatures. The cooking time was prolonged for 60 minutes at the last stage of the process to observe the final lightness value at the end of the reaction.

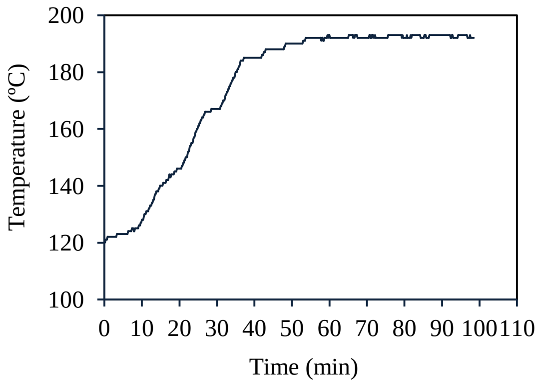


Figure 10 Temperature profiles of pastry baked for the thermal camera experiment

The lightness continuously decreased from the initial value of 93 to the final value at around 54 (Figure 11).

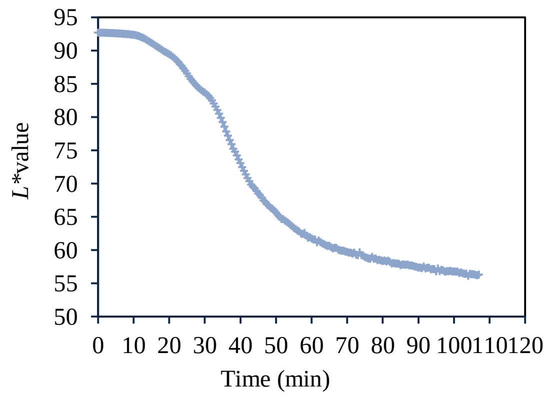


Figure 11 Lightness profiles of pastry baked for the thermal camera experiment

The lightness profiles of pastry baking on the hot pan for colorimeter study are shown in Figure 12. An isothermal kinetic model was to be used to fit the experimental data of lightness, therefore the experiment was designed to cook at constant temperature at six different levels (120, 130, 140, 150, 160, and 170°C). The experiment was run with five replicates, so the lightness profiles of the pastry surface at six levels of temperature are presented in Figure 12. It can be seen from Figure 12 that during the first ten minutes of the study at low temperatures (120 and 130°C), the lightness rapidly dropped and an increased again when the process reached approximately fifteen minutes. This was due to the slow evaporation of water in the samples. After that the lightness continuously decreased with time. This observation was found in other bakery products such as bread [2,3], buns [4], cookies [5, 6] and crackers [7].

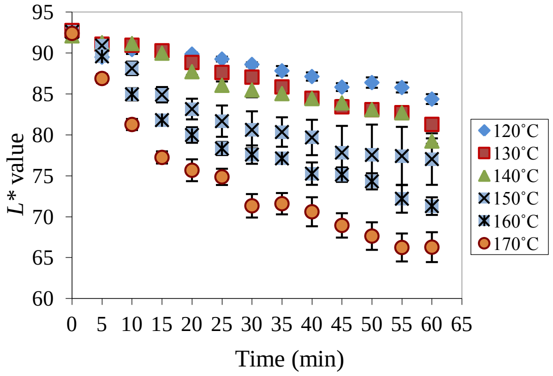


Figure 12 Lightness profiles of pastry baked on the pan for the colorimeter experiment

Online measurement of both colour and temperature were compared with conventional colorimetry of the final samples after baking. The experimental data obtained from these two methods were used for fitting a kinetic model and the results were compared.

Kinetic model fitting

Many other researchers found first order kinetics apply to browning reactions; for example bread baking [1,8], dough baking [9], cracker baking [7] and potato frying [10]. Therefore a first order kinetic model was used to fit the experimental data (Equation 1).

$$\frac{dL}{dt} = -k(l - L_{\infty}) \qquad (1)$$

All of the temperature and lightness data from the image method were recorded in Excel data sheet files. These data sheet files were used to fit the non-isothermal kinetic model using the *lsqnonlin* function in MATLAB®. The kinetic parameters (L^*_0, L^*_∞, E_a and k_{150}) were estimated as 93.37, 56.92, 67.79 kJ·mol^{-1} and 0.012 min^{-1} for the image study. For the spectrophotometer study, the non-linear regression with a Levenberg-Marquarat algorithm function *lsqcurvefit* in MATLAB was applied to fit the isothermal kinetic model to all the data simultaneously by minimizing the residual sum of squared errors. The kinetic parameters of L^*_0, L^*_∞, E_a and k_{150} were obtained from the kinetic fitting as 84.22, 46.09, 65.12 kJ·mol^{-1} and 0.015 min^{-1}. The activation energy values of these two experiments are in the range of the activation energy for non-enzymatic browning in foods (37.0 and 167 kJ·mol^{-1}) [11].

Having both temperature and colour data as a function of time from image analysis enabled the fitting of a non-isothermal kinetic model to the Maillard browning process. The conventional colorimetry method has to assume an isothermal kinetic model at the nominal oven temperature, with the colour only measured at the end of the baking process. The goodness of fit (R^2) for the kinetic fitting using the experimental data obtained from the image and colorimetery methods were 0.99 and 0.89 respectively. A comparison of the results from these two models showed that both of these two methods provide the useful experimental results for model fitting but the goodness of fit for experimental data using image method was higher. In addition using colorimetry has disadvantages in both the time required and cost of samples, because it needed many experimental runs to obtain enough data for model fitting. It also requires samples to be removed from the oven for measurement, preventing online analysis. The temperature data was roughly measured using a thermocouple probe. In contrast the imaging and thermal camera can measure the whole area of the sample, so this provided more accuracy in fitting the kinetic model.

CONCLUSION

It can be concluded that the imaging technique could be used for studying Maillard browning. It provided more accuracy in model fitting, took less time and cost. The method was able to measure the distribution of colour on the surface in real time and does not destroy the sample. This makes it potentially useful for online monitoring of commercial baking processes.

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