Computer vision based image analysis

Colour is an important feature of food products takes critical part in buying decision as it communicates with the consumers. Change of colour in biscuits during baking is a dynamic process in which certain colour transitions occur as the baking proceeds. Browning development in biscuits begins when sufficient amount of drying has occurred. Moreover it is associated with the recipe (reducing sugars, leavening agents, salt, amino acids, etc.) and baking conditions (temperature and time). For a fixed recipe, increasing the thermal load also increases the degree of browning on the surface of biscuits. Previous findings have revealed that colour can be correlated with the concentration of thermal processing contaminants such as acrylamide and 5-hydroxymethylfurfural (HMF) in bakery products.

Computer vision technology has been used for many years in food industry. In this project, **the objective was to develop a computer vision-based image analysis tool to monitor the development of surface browning in biscuits, and hence to predict the changes in the concentrations of acrylamide and hydroxymethylfurfural in biscuits during the baking process.** Being an objective, rapid and non-contact tool, computer vision-based image analysis is considered as a powerful technique for quality inspection and safety evaluation purposes for bakery products like biscuits.

A computer vision based image analysis system is composed of a camera to acquire digital images, daylight lamps to illuminate the object, and a personal computer to process the image data. With the camera, it is possible to register the colour of any pixel of the image of biscuits using three-colour sensors. The changes in the surface colour of biscuits can be determined by using two approaches;

1. Mean colour information (i.e. CIE a* value),
2. Featured colour information (i.e. browning ratio)

A typical image captured by a digital camera consists of an array of vectors called pixels. In the digital images of biscuits, pixels can be categorized into two or more groups based on the typical colour transitions occurred in biscuits during baking. These reference values are used for the segmentation of biscuit images. The pixels are classified into sub sets based on their Euclidian distances to the representative colour reference values. The segmented image is then used to calculate browning ratio as featured colour information to establish a correlation with other quality features of biscuits. Another approach is to extract mean colour information from the digital images of biscuits. In this application, it is possible to calculate average colour information in different colour space parameters (i.e. CIE Lab, RGB) for a selected region or entire image.

In order to test the capability of computer vision based image analysis, the biscuits prepared from a basic recipe (Table 1) by baking at different temperature (180-220^{o}C) and time (6-20 min) combinations were analyzed for surface colour.

Table 1 The basic recipe used to prepare model biscuits for computer vision based image analysis

Ingredient	Amount, g
WHEAT FLOUR (T55 / W150)	80
REFINED PALM OIL	20
SUCROSE	35
NaCl	1
WATER	17.6
SODIUM BICARBONATE	0.8
AMMONIUM BICARBONATE	0.4

The digital images of biscuits are shown in Figure 1. As an alternative tool, different computer vision based analysis algorithms were applied to biscuits in order to validate the potential of this technique for online monitoring.

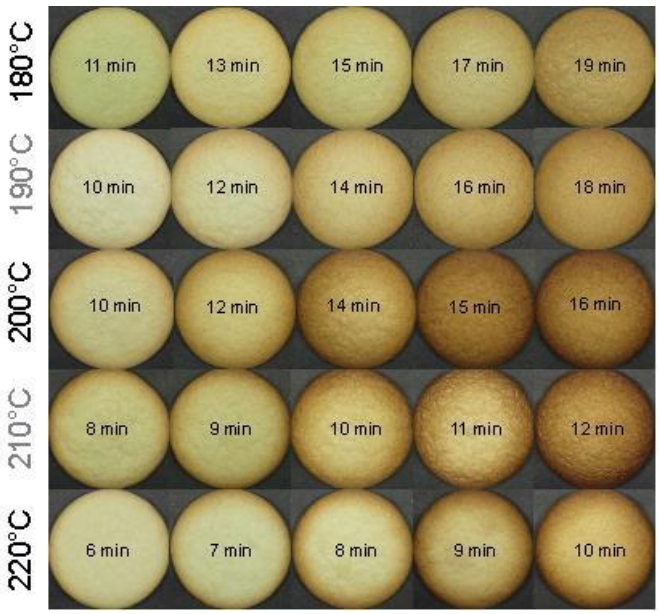


Figure 1. Digital images of biscuits baked at different temperature-time combinations used to build a calibration model for the prediction of acrylamide and HMF in biscuits

An algorithm for the determination of mean colour information was developed to measure surface colour of biscuits in CIE Lab colour space. Among the colour space coordinates, CIE a* value better indicated the development of browning on biscuit surface during baking. Since browning develops as a circle during baking, different colour regions occur on the biscuit surface. The image is first converted Lab from RGB, and mean L, a, and b values are calculated for the region of interest (centre, middle, edge). Mean colour (CIE a*) determinations were performed on biscuits to validate the computer vision-based image analysis tool for the prediction of acrylamide concentrations. The algorithm developed in the preliminary assays was used to correlate mean CIE a* value with acrylamide. As shown in Figure 2, change of CIE a* value with time was significantly different in centre, middle, and edge regions of biscuit. As expected, the edge of biscuit discs became darker more rapidly than the middle and centre regions.

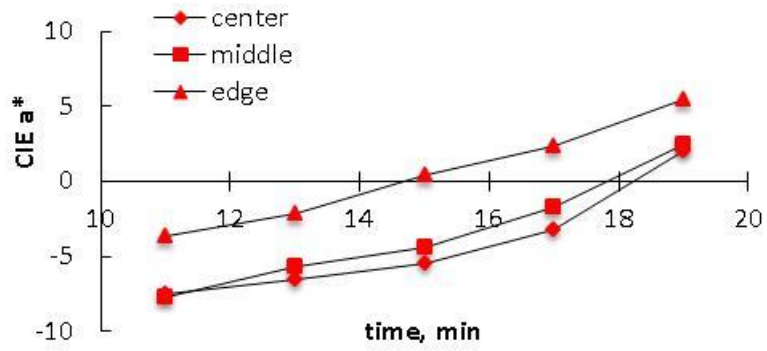


Figure 2. Change of CIE a* value in the center, middle and edge regions on biscuit surface during baking at 180 °C.

The CIE a* values measured in the edge correlated well with acrylamide concentrations of biscuits. As shown in Figure 3, there was a linear correlation between CIE a* value and acrylamide

concentration with a high correlation coefficient (r2=0.927). Based on this correlation, a CIE a* value of 4 indicates an approximate acrylamide concentration of 100 ng/g in biscuits prepared from the basic recipe. Similarly, CIE a* value of 11 indicates an approximate acrylamide concentration of 200 ng/g in biscuits. These results indicated that mean colour information taken from the digital image of biscuits could be used to predict acrylamide concentration in biscuits. However, this correlation is specific to the recipe given in Table 1. Any significant changes (removal or addition of ingredients, change in the ratio of certain ingredients) made on the recipe may require recalibration of the model as these changes may influence both the rates of browning and acrylamide or HMF formation. However, the calibration model exemplified here reflected very well the changes in baking temperature and time.

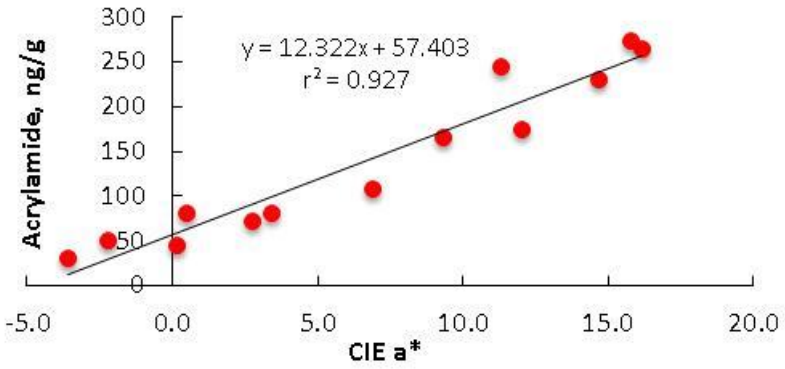
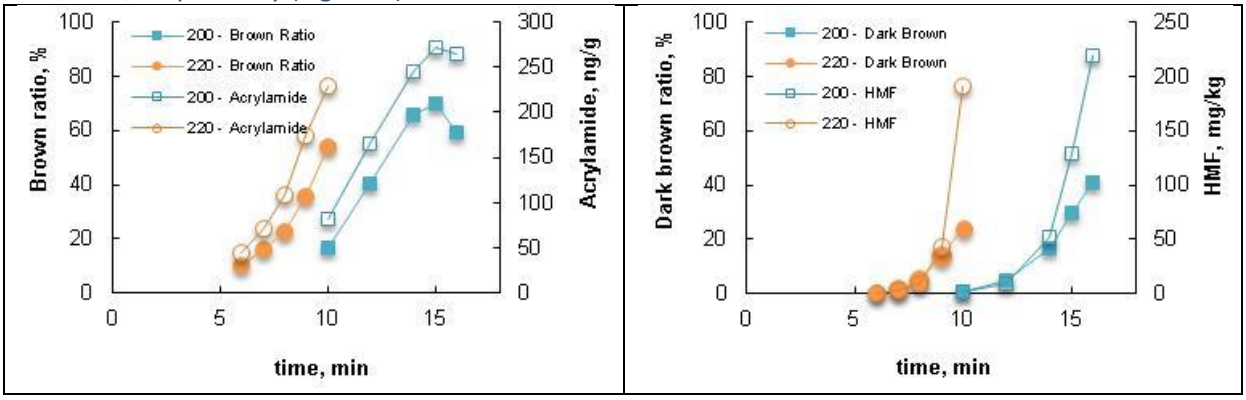


Figure 3. Correlation between the CIE a* value and acrylamide concentration of biscuits prepared from the basic recipe at different temperature-time combinations.

Another algorithm developed for the determination of brown ratio and dark brown ratio was based on the colour segmentation of digital biscuit images. The developments of brown and dark brown ratios, the new features defined in this study, have typical kinetic patterns resembling to acrylamide and HMF, respectively (Figure 4).



(a) (b)

Figure 4 (a) Change of brown ratio and acrylamide concentration with time in biscuits baked at 200 and 220°C. (b) Change of dark brown ratio and HMF with time in biscuits baked at 200 and 220°C

These kinetic pattern similarities allowed us to build a correlation between brown ratio and acrylamide concentration, and between dark brown ratio and HMF concentration for biscuits. There was a linear correlation between brown ratio and acrylamide concentration (r^2=0.963). A correlation between dark brown ratio and HMF concentration was also built for biscuits (r^2=0.964). The assays performed on the biscuits confirmed the potential of computer vision based image analysis algorithms for predictive monitoring of acrylamide and HMF during baking.

The following points were highlighted from the experimental results:

- Two computer vision based image analysis algorithms were developed for the extraction of mean colour and featured colour information from biscuits. These algorithms were successfully applied to the biscuits baked at different time-temperature combinations.
- Mean colour information as CIE a* value and featured colour information as brown ratio were found to correlate well with the change of acrylamide concentration in biscuits during baking. Dark brown ratio, another featured colour information was also defined and found to correlate with the change of HMF concentration in biscuits.
- **Surface colour of biscuits can be monitored online by means of computer vision based image analysis to predict PCs under real processing conditions.**
- The calibration models are specific to the recipe used. Any changes or modifications in the recipe would require validating the existing calibration model. If required, new calibration should be built for the modified recipe.

In conclusion, computer vision based image analysis offers rapid, accurate, non-contact, and non-destructive analysis of foods. Additionally, it provides a high level of flexibility and repeatability at relatively low cost and high throughput. Besides, it can be implemented online as an integral part of processing plants for real time monitoring of product quality.

Contact: Vural Gökmen, Hacettepe University (Turkey), vgokmen(at)hacettepe.edu.tr