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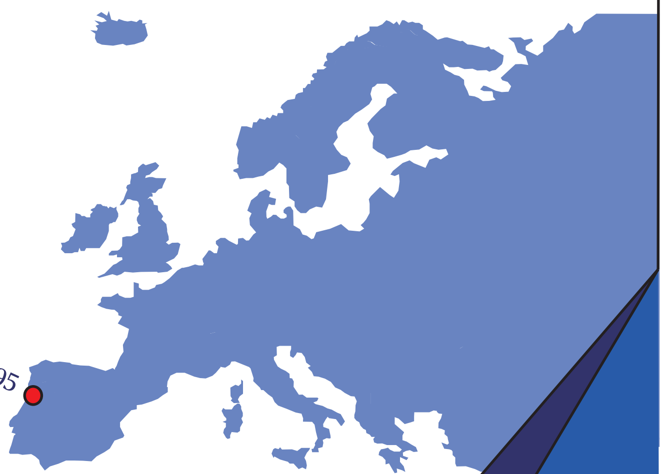

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Modelling Food Colour Degradation Kinetics - A Review

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Summary

A critical literature search was carried out on i) instrumental methods to measure objectively the colour of foods and ii) the determination of the degradation kinetics of food colour under thermal processing conditions. Although there is a significant number of publications dealing with colour measurement and the effect of thermal processing conditions on the colour change, the standardization of measuring methods and the kinetic models are included in only a few. In this communication, a critical review is presented and recommendations for further work are given.

1. Introduction

It is well known that the excessive heating of foods produces considerable losses in the organoleptic quality of the final products (Hayakawa and Timbers, 1977).

Kinetic models of the thermal degradation of quality attributes are essential to design new processes that maximize final quality retention with the required degree of safety.

Colour is an organoleptic property that greatly affects the consumer's acceptability of most food products. Therefore, the retention of colour may be used as an indicator of the damage to the quality of foods due to thermal processing (Banga *et al*, 1993).

The objective measurement of food colour can be used for on-line quality control of food processes. Although the sensory evaluation of food colour is more reliable, it is also a subjective and time consuming method (Ohlsson, 1980).

The objective of this work was to perform a critical literature search on: 1) Instrumental methods to measure objectively the colour of food products, 2) Mathematical modeling of food colour degradation kinetics under thermal processing conditions and 3) Research work applying colour degradation kinetic data to optimize process conditions in terms of final quality retention.

2. Colour measurements

Most colours are uniquely specified by a set of three imaginary red (X), green (Y), and blue (Z) primaries. These are CIE tristimulus values. To make colour data more intuitive and easier to interpret, these tristimulus values are usually converted to other colour scales (e.g. luminance factor Y% and the chromaticity coordinates x, y). The Hunter L, a and b colour scales are opponent-type systems. These measure the degree of lightness (L), the degree of redness or greenness (+/- a), and the degree of yellowness or blueness (+/- b) (Hutchings, 1994). The difference between two colors may be calculated as:

$$TCD = \sqrt{\Delta a^2 + \Delta b^2 + \Delta L^2} \quad (1)$$

where TCD is the total colour difference.

Some other more particular colour parameters have been used in the field of food science: e.g. browning index,

$$\text{Bronwning index} = \text{absorbance ratio } A520/\ 430 \text{ or } 420 \text{ nm} \quad (2)$$

Yellowness index

$$YI = 142.86\ b / L \quad (3)$$

and the parameter S.

$$S = R560 + R590 + R635 \quad (4)$$

3. Modelling colour changes

As can be observed in table 1, most of the work published in the field of modelling colour thermal degradation considered first order models:

$$C = C_o \exp(-\ k_T\ t) \quad (5)$$

or

$$C = C_o\ 10^{-\ t / D_T} \quad (6)$$

where C is the parameter of color, C_o the level of C at time zero, k_T the rate constant at constant temperature T, D_T the decimal reduction time at temperature T and t the time.

Zero order models have also been widely used (Table 1):

$$C = C_o - k_T\, t \tag{7}$$

The reaction order can be determined using the following equation:

$$\ln\left(-\frac{\partial C}{\partial t}\right) = \ln k_T + n \ln C \tag{8}$$

where n is the reaction order.

The effect of temperature on reaction rate constants was described by the Arrhenius equation:

$$k_T = k_o \exp\left(-\frac{Ea}{R\,T}\right) \tag{9}$$

where Ea is the activation energy, T the absolute temperature, R the universal gas constant and k_o the rate constant at infinite temperature.

For the thermal destruction time model described in equation 6, the temperature dependence follows the equation proposed by Bigelow:

$$D_T = D_{Tref}\, 10^{(T_{ref} - T)/z} \tag{10}$$

where z is the temperature sensitivity of the decimal reduction time D_T.

4. Results reported in literature

Table 1 presents a review of the research work published on modelling colour thermal degradation kinetics.

Several products were studied and several instruments and colour parameters were used to quantify the colour. For the same type of product there are no standardized methods.

In most cases a first order or a zero order model was able to model the reaction kinetics at constant temperature. The Arrhenius (9) or the Bigelow (10) equations were used to describe the effect of temperature.

The number of papers relating the objective measurement of food colour with sensory evaluation is still limited. Furthermore, very few authors use the kinetic data determined to validate and/or optimize processing conditions in terms of final quality retention.

Table I
Kinetics of color degradation

Reference	Product	Temperature Range (°C)	Equipment	Color Parameter	Kinetics	$D_{121°C}$ (min)	Z (°C)	$k_{121°C}$ (min^{-1})	k_o (sec^{-1})	Ea (kJ/mol)	Process Assessment
Hayakawa & Timbers (1977)	asparagus	79.5 - 149	Gardner AC-1	- a/b	1st order	17	41.7	—	—	—	
	green beans				1st order	21	38.9	—	—	—	No
	green peas				1st order	25	39.4	—	—	—	
Ohlsson (1980)	fish pudding	110 - 134	Hunterlab color	L	1st order	—	25	—	—	—	
	liver paste				1st order	—	21	—	—	—	
	strained beef				1st order	—	22	—	—	—	No
	strained veget.				1st order	—	21	—	—	—	
	tomato sauce				1st order	—	28	—	—	—	
	vanilla sauce				1st order	—	20	—	—	—	
Rao et.al. (1981)	peas	98.9 - 126.7	Hunter D25-3	a/b	1st order	13.2	38.3	—	—	73.15	No
Merin et.al. (1987)	prickly pear - fruit	50 - 90	Spectrophotometer	Absorvance at 535 nm	1st order	523.6	74.3	—	—	—	No
Rhim et.al. (1988)	skim milk	100 - 150	Spectrogard color system	L	1st order	—	—	—	1.95×10^{11}	114.8	
				a	order 0	—	—	—	3.75×10^{11}	104.9	
				b	order 0	—	—	—	2.75×10^{12}	110.3	No
				C	2nd order	—	—	—	3.17×10^{9}	103.6	
				browning index	order 0	—	—	—	2.65×10^{12}	123.5	
Rhim et.al. (1989)	grape juice	60 - 95	Spectrogard color system	L	1st order	—	—	—	1.30×10^{12}	114.75	
				a	1st order	—	—	—	8.95×10^{14}	131.80	No
				TCD	order 0	—	—	—	4.80×10^{10}	92.81	
Pagliarimi et.al. (1990)	milk	70 - 140	Colorimeter Minolta	TCD	order 0	—	—	—	2.50×10^{11}	101.8	No
				YI	order 0	—	—	—	9.58×10^{11}	117.5	
Sanchez et.al. (1991)	picked green olives	70 - 90	Spectrophoto-meter	S	1st order	523.6	74.3	—	—	___	Yes
Ghazala et.al. (1991)	model systems	110 - 150	Minolta CT-210								
				Y%	1st order	2455	30.2	0.000963	—	102.3	Yes
	color / DDW			x	1st order	3525	37.8	0.000668	—	81.4	
				y	1st order	4755	37.2	0.000494	—	83.1	
				Y%	1st order	2029	38.1	0.001160	—	81.0	
	color / MIX			x	1st order	4360	37.0	0.000540	—	83.4	
				y	1st order	4252	37.7	0.000552	—	82.1	

5. Conclusions

Several instruments and colour parameters are used to quantify the colour change during thermal processing. For the same type of product there are no standardized methods.

Few authors attempted to quantify the kinetics of colour degradation of foods under thermal processing conditions. In most cases where it is, first or zero order reaction kinetics are used.

The work relating the objective measurement of food colour with sensory evaluation is still limited. Furthermore, very few authors use the kinetic data determined to validate and/or optimize processing conditions in terms of final quality retention.

6. Recommendations for further work

There is a need to define adequate and standardized methods to measure objectively the colour of food products.

The kinetic data should be correlated with sensory evaluation.

The use of colour kinetic data to assess the final product quality retention and predict optimal processing conditions must be evaluated.

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