New Approach to Determine the Brownness of Bread Crust. Correlation between Crust Color and Protein Content

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ABSTRACT

The brownness of bread crust, and deviations of it towards gray, can be measured and characterized by a single figure by means of a novel application of tristimulus measurements.

The direct cause for this investigation was the observation of a deviating crust color occurring when flours of some lots of home-grown wheats were made into bread, in spite of a sufficient amount of sugars being available in the dough. The color, particularly of the top crust, may be grayish or dun instead of more-or-less dark brown. Such flour is referred to as gray-baking flour.

Bertram (1) demonstrated that the browning of bread crust is caused by Maillard, or carbonyl-amino, reactions (2) and that caramelization of sugars does not add essentially to the crust color. His tests also showed that the color was not determined exclusively by the protein content of the flour and the quantity of sugars.

Although several investigators (3–12) have studied the effects on the browning of the bread crust of adding sugars and amino acids, separately or combined, little knowledge is available regarding the formation of the normal crust color.

Initial quantitative measurements adopted as a measure of the crust color the total brightness of the light reflected by the crust (5,6,9,10). This total brightness gives no answer as to the shade of the color, which in those investigations may have been of little significance as the crusts of the loaves differed mainly in brightness, but little in shade.

For the purpose of a new study concerning the defective crust color of bread made of gray-baking flour we needed an objective measure for this deviation in shade. As the brightness of the light reflected by the crust provides no information about the shade, we used a modified tristimulus method for quantitative characterization of this grayish shade.

MATERIALS AND METHODS

Materials

For this study, pure-variety lots of home-grown wheats, grown on experimental fields, were used. The moisture content of the wheat was adjusted to 15%. Thirty minutes before milling, the moisture content was raised to 15.5%. On a Buhler laboratory mill, straight flours were made, with ash contents of 0.42 to 0.57% on dry basis, and an extraction rate of approximately 62%. For the rest, commercial ingredients were used.

Analytical Methods

Moisture contents were determined by drying for 1.5 hr. at 130°C. in an air-oven with free ventilation; ash contents, by incineration for 4 hr. at 600°C.; and protein contents (N X 5.7), according to Kjeldahl. The reported ash and protein contents are calculated on dry basis.

Breadmaking

Doughs were made with 2% yeast, 2% salt, 1% sugar, 20 p.p.m. potassium bromate (calculated on the flour "as-is") and a water addition corresponding with the quantity required to produce a dough consistency of 430 B.U. after 2 min. of mixing in the Brabender Farinograph (dough with yeast and salt). For each baking test, 1,100 g. of flour was taken. All doughs were mixed for 6 min. in Artofex laboratory mixers (F. Aeschbach A. G., Aarau, Switzerland) with dough temperature at 28°C. Sets of four tests were mixed simultaneously. After a 30-min. bulk fermentation at 30°C., the doughs were punched by hand; and after another 20-min. fermentation, were scaled by hand and rounded. The scaling weight was adjusted so as to get loaves containing 281 g. of flour ("as-is"); the resulting loaf weight was approximately 400 g.

After 15 min. of intermediate proof, the doughs were mechanically moulded and given a final proof of such a length that in each dough piece a standard amount of about 750 ml. carbon dioxide (CO_2) was generated [determined by means of an S.J.A. fermentation recorder (Aktiebolaget S.J.A., Stockholm, Sweden) at 30°C. in a proportional part of the same dough.]

The loaves were baked for 30 min. in a reel-type oven, without steam injection at the beginning of the baking process, at approximately 240°C. The oven capacity allowed four parallel tests of three loaves each to be baked in one charge. As doughs made of different flours may require different time intervals to generate a prefixed amount of CO_2, a slight concession had to be made to the exact amount of CO_2 in order to enable the four sets to be put simultaneously in the oven. This concession was made to avoid a temperature drop when a set of tins was put in while other sets were in the course of baking.

Measurement of Crust Color

The color measurements were made on the top crust of the loaf. A disc 6 cm. in diameter was cut from the center of the top crust. Colors were measured according to the tristimulus method by a photoelectric refleximeter (Photovolt Corp., Model 610, New York, N.Y.) in the apparatus for measuring the whiteness of bread crumb described by Croes (13). The rotary movement of the disc produces an average color reading.

The measurements were taken under conditions corresponding with lighting by C.I.E. (Commission International de l'Eclairage) standard light source C, that is, by average diffused daylight. Measurements were made on all of the loaves baked; thus sets of three readings were obtained, related to the three loaves from one dough. The results reported are averages of such sets of three measurements.

The principle of the color measurement according to the tristimulus method has recently been set out in an illustrative manner by Clydesdale (14). In addition to the specification of a color in the three tristimulus primaries X, Y, and Z, there are several other systems for color specification. The tristimulus primaries can be transformed into the parameters of these other systems.

One of these systems is the monochromatic color specification. This method assumes that any color of light can be obtained by mixing white light with monochromatic light. The wavelength of the required monochromatic light is referred to as the dominant wavelength. The color of a surface, i.e., that of the reflected light, is stated in three parameters, namely, total brightness, the dominant wavelength, and the degree of saturation of the reflected light with monochromatic light of the dominant wavelength. In measuring colors of a large number of bread crusts we found the dominant wavelength to be constant within fairly close limits, with an average at 581 nm. Light of this wavelength is yellow to orange-yellow. As in crust color the dominant wavelength may be considered constant, the differences in crust color between loaves can be characterized by two factors, total brightness and the degree of saturation.

Brown is not found as such among the spectrum colors; it is a color obtained by mixing a spectral color, yellow, and black. Dark brown is built up of yellow and much black; light brown, of yellow and little black. Addition of black corresponds with a lowering of the brightness. Yellow mixed with gray causes the eye to perceive the effect as a shift from yellow to brown, but the color produced is dun. Yellow mixed with very light gray, i.e., yellow plus a relatively large amount of white and little black, produces a chalky faded-yellow shade.

The dunness or grayness can be calculated from the total brightness and the degree of saturation. For the latter we use the symbol Y_w, representing the amount of white light reflected by the crust. Since brown = yellow + black, an ideally brown crust will have a $Y_w = 0$. The more the crust color deviates from the ideal brown, the more Y_w increases. The contribution of white light to the total brightness can be calculated as follows from the three reflection values obtained by a tristimulus measurement.

The three reflection values, calibrated against the reflection of magnesium oxide as ideal white, G(Green), A(Amber), and B(Blue), are transformed into the three tristimulus primaries X, Y, and Z with the formulas

$$X = 0.8\ A + 0.18\ B$$

$$Y = G$$

$$Z = 1.18\ B$$

in which Y is the total brightness. The degree of saturation and the dominant wavelength are calculated as follows: The tristimulus primaries are transformed into the two trichromatic coefficients x and y with the formulas

$$x = X/\ (X + Y + Z), \text{ and } y = Y/\ (X + Y + Z)$$

The x and y values enable the dominant wavelength, λ_d, and the degree of saturation, σ, to be read as percentages from chromaticity diagrams (15).

The contribution of the white light to the total brightness, which we refer to as Y_w, can be calculated with the formula

$$Y_w = Y\ (1 - \sigma/100)$$

in which Y_w = the contribution of the white light to the total brightness of the reflected light; Y = the total brightness of the light reflected by the bread crust as a percentage of the brightness of the light reflected by a magnesium oxide surface;

and σ = the degree of saturation of the reflected light with monochromatic light of the dominant wavelength as a percentage of the total brightness.

To improve the reproducibility by eliminating incidental differences between subsequent bakes (due for instance to slight variations in oven temperature), one standard flour was baked as a reference together with each bake. The values of σ and Y which were obtained in the first bake were fixed to the standard flour as reference values for the subsequent bakes. The correction factors that had to be applied to adjust σ and Y in subsequent bakes to obtain the values fixed by definition to the standard of the first bake were also applied to the σ and Y values of the other loaves forming part of the same oven charge. This way of correction was chosen because we did not find a clear relationship between the variations of σ and Y.

This procedure enabled the deviation from pure brown to be expressed in one objectively determined number, Y_W, varying from 0 for pure brown to approximately 40 for a crust with a chalky appearance. The value $(100 - Y_W)$ can be used as a measure of the "brownness" of the crust.

RESULTS

In color measurements of a large number of bread crusts we found that the dominant wavelength of the light reflected by the crust was constant within fairly close limits. The average found in 90 measurements on crusts with colors varying from chalky to dark brown was 581 nm., with a standard deviation of a single observation of 2 nm. This wavelength corresponds with yellow to orange-yellow light.

The average Y of all readings on loaves made of the standard flour was 21.3, with a standard deviation of 0.4; and the average σ was 44, with a standard deviation of 0.3. The author used the values Y = 23 and σ = 43 for the standard. As these values do not coincide with the average values for Y and σ, a systematic shift of all Y_W values occurs. This, however, does not affect the conclusions.

The method described was applied to the examination of flour samples of ten wheat varieties, to see if a relationship existed between the protein content of the flour and the crust color of the bread baked from it. Of each variety, eight samples with varying protein contents were examined. Table I summarizes the correlation

TABLE I. CORRELATION COEFFICIENTS (r) AND REGRESSION EQUATIONS FOR THE RELATIONSHIP BETWEEN PROTEIN CONTENT (x) OF THE FLOUR AND CRUST COLOR $(100 - Y_W)$ OF THE LOAVES, FOR THE VARIETIES EXAMINED

Wheat Variety	r	$(100 - Y_W)$ =
Carpo	0.95**	9.27 x − 11.10
Dippe's Triumph	0.92**	2.58 x + 61.08
Fasan	0.91**	4.55 x + 40.46
Cleo	0.88**	5.77 x + 30.24
Ibis	0.86**	3.33 x + 57.24
Felix	0.82*	6.17 x + 23.44
Flamingo	0.71*	4.45 x + 40.80
Orca	0.70	3.89 x + 48.31
Koga II	0.68	2.42 x + 66.12
Opal	0.53	1.23 x + 78.76

$P_{0.01} = 0.83$; $P_{0.05} = 0.71$.

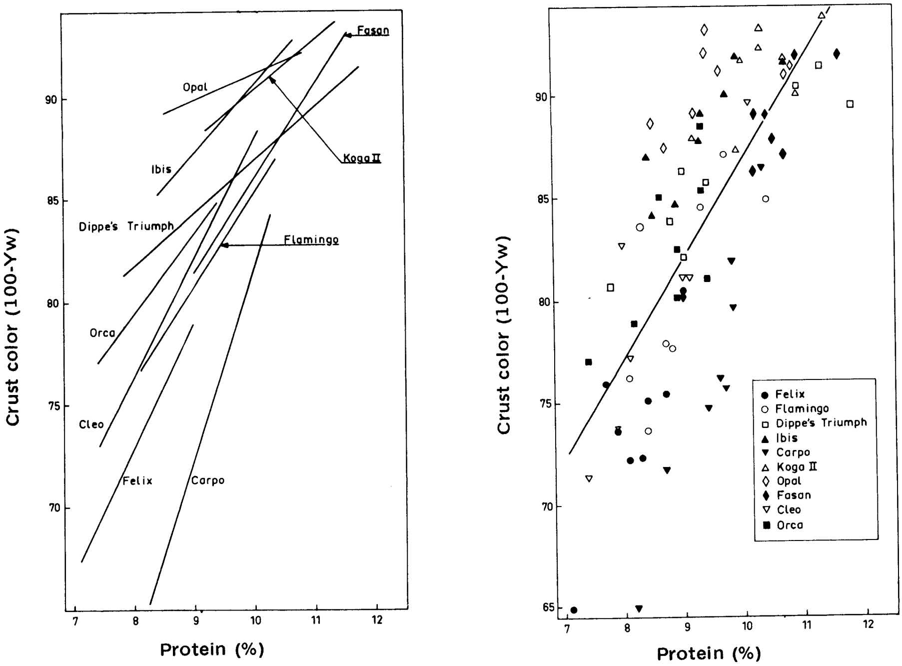

Fig. 1 (left). Regression lines representing the relationship between crust color of the loaves and protein content of the flour for a number of wheat varieties.

Fig. 2 (right). Overall relationship between crust color of the loaves and protein content.

and regression coefficients for the relationship between the protein content and the "brownness" ($100 - Y_W$) of the bread crust. Figure 1 and Table I show that the relationship between the crust color expressed as "brownness" and the protein content of the flour is not the same for all varieties.

Figure 2 contains all the protein contents associated with the color readings. The regression line shows the overall relationship between the protein content of the flour and the crust color of the bread, disregarding the differences between the wheat varieties.

A brownness ($100 - Y_W$) of 85 or over must be considered normal. It can be seen from Fig. 2 that this condition will be secured if the protein content of the flour is more than 10.5%. At a lower protein content some varieties still produced a good crust color, whereas others were deficient; flour with a protein content below 8.5% always produced bread with a deviating crust color. Though flours having a protein content as low as that are generally not used by themselves for breadmaking, the crust color may be adversely affected if a considerable percentage of home-grown wheat is incorporated in a mixed grist.

Sugar was added in the baking tests to eliminate any possible effects on the crust color by differences in sugar-forming power between the flour samples. The maltose figures of all samples were determined; no relationship between maltose figure and crust color could be demonstrated, so the addition of sugar in fact eliminated the influence of this factor on the crust color.

DISCUSSION

As the "brownness" can now be characterized in objective terms, the described method offers new scope for investigation concerning the color of bread crust.

The differences found between the examined varieties show that the protein content of the flour is not the only, or at least not the directly, determining factor for the crust color. This was not much to be expected, as the crust color is the result of Maillard reactions. Therefore some other factors which might provide an explanation were examined.

Free amino groups were determined by means of formol titration in flour suspensions in water or 4M urea and in suspensions of fermented and unfermented doughs. No relationship between free amino group content and crust color could be demonstrated.

Investigations to find a relationship between crust color and the amount of water-soluble nitrogen compounds in the flour showed the correlation to be no better than between protein content and crust color. Differences between varieties occurred also in this relation.

The varietal differences appeared to be smaller in the case of the relationship between wet gluten and crust color than between dry gluten and crust color. Possibly, the hydration of the protein plays some part in the Maillard reactions in the bread crust. Moisture content is known to be one of the factors affecting Maillard reactions. The relationship between protein content and crust color within one variety was retained, however, if the water addition was kept constant (16).

In our experiments we got some indications that the influence of starch on the water distribution in dough also affects the crust color. For a conclusive answer, further studies will be required.

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