Cross-Classification Technique Applied to the Evaluation of Cake Surface Characteristics[1]

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ABSTRACT

A cross-classification method was applied to the evaluation of top crust surface characteristics of cakes baked with various combinations of microwave and convection heating. The effects of order of application of heating mode and the time during baking at which the heating mode was changed were demonstrated. The cross-classification technique was sensitive in discerning differences in data of this type and should be useful and applicable in similar studies in which characteristics can be described by categories without assignment of scores to the categories.

Subjective, or sensory, evaluations of quality characteristics of baked products often utilize scaling methods such as those described by AACC methods (AACC 1976). Scaling methods are based on the assumption that a given attribute varies along a continuum that can be associated with scale points. The continuous data that result typically are analyzed by analysis of variance techniques. Limitations of scaling methods both as used by panels to assign scores and the subsequent deviations of such scores from the assumptions underlying analysis of variance techniques are well known.

In some cases, depending on the specific objectives of the experiment, it is sufficient to describe an attribute qualitatively by classification of that attribute (or variable) into discrete categories. For example, it might be sufficient to know whether the contour of a cake is sunken, flat, or peaked. The assessment of the degree of deviation from flatness, which is attempted in scaling procedures, is less important.

Detailed discussions of the analysis of categorical data are given by Fienberg (1980) and Bishop et al (1975). When several categorical variables are examined simultaneously, multidimensional contingency tables result in which each variable is a dimension of the table. For example, two-way contingency tables represent two dimensions with columns corresponding to the categories of one variable and rows corresponding to categories of the second variable. Depending on the experimental design, the variables can be either explanatory or response variables in the usual sense. Methods of analysis involve estimating the expected counts or probabilities for the cells of the table, and subsequent estimation of the goodness-of-fit between observed and expected values.

In this study, this technique was used to examine the effects on top crust characteristics of the order in which microwave and convection heating were used during baking of model cakes as well as the time within the baking period at which the baking mode was changed. In this case, the explanatory variables were order of heating mode and the time at which the heating mode was changed. The response variables were top crust surface appearance and cracking characteristics.

MATERIALS AND METHODS

The formula for the cakes, given by Gordon et al (1979), is based on the Kissell lean research formula (1959). Four hundred grams were weighed into glass baking pans (20.3 cm in diameter and 4.4 cm deep).

Cakes were baked in a convection/microwave oven (Sharp Carousel model R-8310). The output power for the convection component was 1,500 W. Microwave energy output was 650 W nominal at a frequency of 2,450 MHz. Baking temperature was 177° C during convection baking and 400 W effective at the pan region as determined by the method of Van Zante (1973) during microwave heating. Cakes were baked by the following combinations of minutes in the microwave mode (MW) and in the convection mode (CV): 0 MW, 35 CV; 1 MW, 30 CV; 2 MW, 25 CV; 3 MW, 20 CV; 4 MW, 15 CV; 5 MW, 10 CV; 6 MW, 5 CV; and 7 MW, 0 CV. These combinations were constructed by replacing 1 min of microwave heating with 5 min of convection heating. In one series, the microwave mode was used first; in the other series, the convection mode was used first. Three replications of each series were baked. Cakes were cooled for 30 min before evaluation. The top crust surface appearance was classified by the investigator according to whether it was shiny, dull, or a combination of shiny and dull areas. Crusts were also classified according to the size of cracks and pores as shown in Fig. 1.

The data for top crust surface appearance and characteristics were analyzed using cross-classification methods as described by Fienberg (1980). Two-way tables were prepared in which the row totals were fixed by the experimental design. In the examples in which order of heating mode was tested, seven treatments and their replications were used, giving row totals of 21. In the series with microwave heating first, only the data for cakes baked with microwave heating were analyzed. Similarly, in the series with convection heating, only the data for cakes baked with convection heating were included. The surface characteristic data were also analyzed for the effects of time in a given heating mode. For this analysis, time in a given heating mode was divided at 4 min for microwave mode first and between 15 and 20 min for the series with convection as first mode. Pearson's chi-square test was used to determine homogeneity of proportions.

RESULTS AND DISCUSSION

The use of the cross-classification technique to examine the effects of order of heating mode on top crust surface appearance is illustrated in Table I. Expected values under the assumption of independence are also shown to illustrate the method of analysis. The value of the chi-square test statistic, 24.89, exceeded the value of χ^2 for $\alpha = 0.05$ and 2 df, 5.99, indicating that the appearance of the crust differed according to whether the microwave or convection mode was used first. Dull crusts were characteristic of cakes baked with the microwave mode applied first. Shiny crusts were more characteristic of cakes when the convection mode was applied first.

Analysis of surface characteristics is shown in Table II. Cracking patterns were not related to the order of baking mode, as shown by the comparison value of the chi-square test statistic, 4.64, with that of χ^2 (7.81) for $\alpha = 0.05$ and 3 df.

Testing of the hypothesis that the time at which the heating mode was changed was associated with surface characteristics is shown in Tables III and IV. For this test, a division was made between cakes

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baked with less than 4 min of microwave heating and those baked with 4 min of microwave heating (Table III) and between 15 and 20 min of convection heating (Table IV). These points were chosen because at 4 min of microwave or 20 min of convection heating, the cakes were approaching temperatures (83° C at 4 min microwave heating and 81° C at 20 min during convection heating) at which the structure was being established through starch phase transitions (Cloke et al 1983). For both the series with microwave first and the series with convection first, the chi-square test statistics were significant, indicating that top surface characteristics were related to the time at which the heating mode was interrupted. Detailed interpretation as to why these cracking patterns occur is not attempted here, but the patterns represent the complex interplay of the mechanisms of heat and mass transfer in the two heating modes as shown by Wei et al (1983) in theoretical modeling studies.[2]

Although useful in the first interpretation of the experiment or in making general recommendations on the selection of combinations of heating modes, the conclusion that baking times of less than 4 min in the microwave mode result in cracking (regardless of whether the microwave mode precedes or follows the convection mode) does not establish that a minute in the first part of the heating period is equivalent to a minute in the later stages of baking after initial heating by convection. Heat and mass transfer are different when microwave energy is applied to the cold cake batter rather than to the hot batter. In modeling terms, the boundary conditions at the initiation of the heating mode are different. The modeling studies of Wei et al (1983a, 1983b) showed differences between convection and microwave modes in the development of temperature, air, and water-vapor pressure profiles within a sample during heating. These may relate to development of pressure points during baking and the need to maintain an elastic structure that can respond to the pressure and yet has enough strength to maintain the expanded structure after the cake cools. Because of differences in heat and mass transfer, the location and time of development of these pressure points will differ in the various combinations of heating modes.

The time in the convection mode might be more important than the time in the microwave mode. All cakes with 4 min or less in the microwave mode, either preceding or following the convection mode, had some degree of cracking, but only two of the cakes with more than 4 min in the microwave mode showed cracking. Concomitantly, each of the cracked cakes was exposed, either initially or finally, to longer convection times. Thus, it could also be concluded that cracking occurs as a result of longer convection times, either during the beginning of the baking process and encompassing the structure setting period (>20 min convection, convection initial mode), or if the cake is shifted to the convection mode before setting occurs in the microwave mode (>20 min convection, microwave initial mode).

Classifications of attributes were possible for this series of cakes because the differences were well defined and discrete, and separation into groups could be easily made. Such separations are more difficult when there is a more continuous change within attributes. In addition, as shown in the description of the top crust surface characteristics, there appeared to be four groups; three of these were related to extent of cracking, and one was related to the

[2]C. K. Wei, H. T. Davis, E. A. Davis, and J. Gordon. 1983. Unpublished data.

TABLE I
Classification of Top Crust Surface Appearance

Order of Heating Mode	**Surface Appearance**[a] Shiny	Dull	Both	Total
Observed values				
Microwave first	3	15	3	21
Convection first	19	1	1	21
Total	22	16	4	42
Expected values under independence[b]				
Microwave first	11	8	2	21
Convection first	11	8	2	21
Total	22	16	4	42

[a]Number in each cell represents number of cakes in that category.

[b]Expected values for shiny, microwave first $= \frac{21}{42}$ 22.

$$X^2 = \Sigma \frac{(\text{observed-expected})^2}{\text{expected}} = 24.89.$$

$\chi^2 = 5.99$, for 2 df, $\alpha = 0.05$.

TABLE II
Classification of Surface Characteristics by Order of Heating Mode

Order of Heating Mode	Cracks[a] Small	Medium	Large	Pores	Total
Observed values					
Microwave first	5	4	2	10	21
Convection first	1	9	2	9	21
Totals	6	13	4	19	42
Expected values under independence					
Microwave first	3	6.5	2	9.5	21
Convection first	3	6.5	2	9.5	21
Totals	6	13	4	19	42

[a]Number in each cell represents number of cakes in that category. $X^2 = 4.64$. $\chi^2 = 7.81$, for 3 df, $\alpha = 0.05$.

TABLE III
Surface Characteristics of Cakes Baked with Microwave Mode First, Classified by Time when Heating Mode Changed

Minutes of Microwave Heating, Microwave Mode First	Cracks[a] Small	Medium	Large	Pores	Total
Observed values					
<4 min of microwave[b]	3	6	3	0	12
≥4 min of microwave	2	0	0	10	12
Totals	5	6	3	10	24
Expected values under independence					
<4 min of microwave	2.5	3	1.5	5	12
≥4 min of microwave	2.5	3	1.5	5	12
Totals	5	6	3	10	24

[a]Number in each cell represents number of cakes in that category.

[b]<4 Min microwave includes: 0 microwave oven (MW), 35 convection oven (CV); 1 MW, 30 CV; 2 MW, 25 CV; and 3 MW, 20 CV. ≥4 Min microwave includes: 4 MW, 15 CV; 5 MW, 10 CV; 6 MW, 5 CV; 7 MW, 0 CV. $X^2 = 19.2$. $\chi^2 = 7.81$ for 3 df, $\alpha = 0.05$.

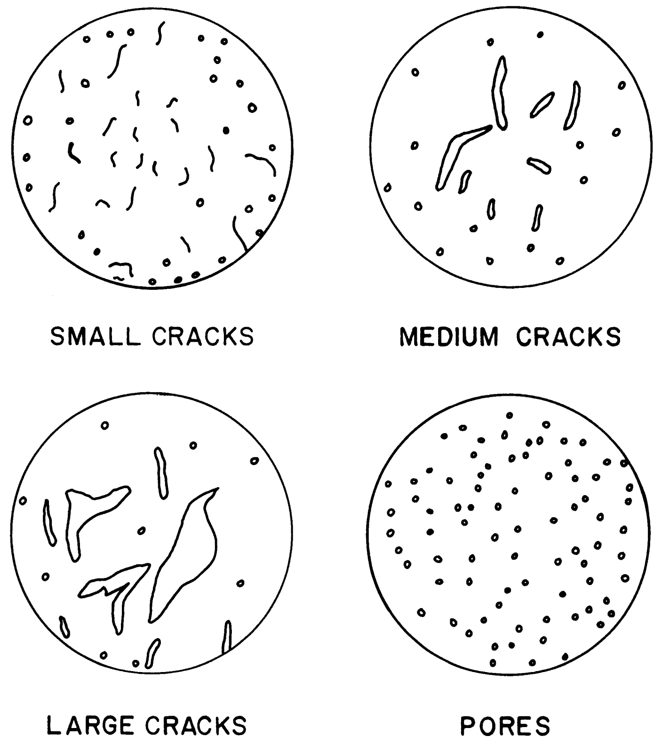

Fig. 1. Four top crust surface patterns observed on lean-formula cakes.

TABLE IV
Surface Characteristics of Cakes Baked with Convection Heating First, Classified by Time When Heating Mode Changed

Minutes of Convection Heating, Convection Heating First	Cracks[a]				
	Small	Medium	Large	Pores	Total
Observed values					
⩾20 min of convection	1	9	2	0	12
⩽15 min of convection	0	0	0	12	12
Totals	1	9	2	12	24
Expected values under independence					
<20 min of convection	0.5	4.5	1	6	12
>15 min of convection	0.5	4.5	1	6	12
Totals	1	9	2	12	24

[a]Number in each cell represents number of cakes in that category.
[b]⩾20 Min convection includes: 20 convection oven (CV), 3 microwave oven (MW); 25 CV, 2 MW; 30 CV, 1 MW; and 35 CV, 0 MW. ⩽15 Min convection includes: 15 CV, 4 MW; 10 CV, 5 MW; 5 CV, 6 MW; and 0 CV, 7 MW. $X^2 = 24.0$. $\chi^2 = 7.81$, for 3 df, $\alpha = 0.05$.

presence of pores. To scale such a range would require the assumption that the presence of pores represented one extreme of a continuum and extensive cracking the other extreme. By treating the data as discrete, such an assumption is not needed, yet the relationships between treatment variables and quality attributes can be easily identified.

There is an implied order in the response variable of extent of cracking, however. Methods of incorporating ordering within categories are discussed by Steel and Torrie (1980), Snedecor and Cochran (1967), Fienberg (1980), and Newell (1982). Similarly, an ordering is suggested in the explanatory variable by the experimental design in which minutes in the microwave mode (or in the convection mode) are increased concomitantly with decreases in the other mode. An analysis incorporating order in the explanatory variable might be considered. In this particular experiment, the total sample size was small in relation to the number of cells that would be required for this analysis (eight combinations of heating modes × three levels of top surface appearances or four levels of top surface characteristics). Accordingly, this type of analysis was not attempted.

Fienberg (1980) suggests that a 4:5 ratio of total sample size to number of cells is large enough to use the asymptotic values of χ^2. Alternately, minimum expected cell values of 1.0 may be adequate. The latter value is smaller than earlier suggested values of 5 (Steel and Torrie 1980, Snedecor and Cochran 1967).

The usual ways to deal with small, expected cell counts are either to increase the total sample size or to collapse cells in order to increase counts for individual cells. Increasing sample size will help if low expected cell counts are due to sampling. In our example, if certain combinations of heating modes rarely result in cracks, then low cell counts are important in interpretation of data, and this information is lost if cells are collapsed.

These examples are presented to show how trends in data of this type can be examined quickly. This is important in deciding whether a more detailed analysis is likely to be useful and whether additional experiments should be planned. Therefore, the cross-classification technique appears to be quite useful when applied to data of this type.

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