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**HIGH-FREQUENCY COOKING**

# Browning Methods in Microwave Cooking


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**Microwave cooking, because of its penetrating nature and minimum generation of environmental heat, yields a product that may differ in appearance, surface texture, and eating characteristics from a product cooked by conventional methods. One such important characteristic, desirable in many cooked foods, is a certain amount of browning of the food surface. This paper describes a method which utilizes the addition of materials normally found or used in foods to give microwave-cooked foods the characteristic browning of conventional cooked foods with a minimum of cooking time.**


IN CONVENTIONAL OVENS the process of cooking to the center of food masses by conduction requires a temperature gradient, in which surface temperatures are usually much higher than the final cooked temperature of the food. For example, a gas-fired oven may be maintained at 300° to 400° F. to produce a meat roast with an internal temperature of 140° F. Under these conditions, browning of the surface is readily obtained. In microwave cooking, which is the phrase used to describe cooking in equipment of the Radarange type (Raytheon Manufacturing Co.), the ambient temperature in the cooking space is approximately room temperature. Any rise in temperature in this space is due to heat loss from the food to its environment. In these electronic ranges alternating electric fields are generated by a magnetron oscillating at a frequency of 2450 megacycles. The energy of electromagnetic waves, which are called microwaves at this frequency, is immediately absorbed within the food mass. The resulting increase in thermal energy in the food depends on an interaction between the microwave energy and the particles of which the food is composed, such as electrons, atoms, molecules, and charge carriers. This interaction occurs throughout the food mass, instantly produces heat, and results in rapid cooking.

Normally, food is cooked in utensils which are not receptive to the microwave energy. The food is the absorber of energy, and it shows a definite pattern of absorption, with the lowest temperatures initially at the surface and at a point deep within a large food mass. Economy of energy is inherent in the microwave method compared with the conventional situation, in which the temperature of the environment is raised, in order to heat and cook through the mass of food by conduction. However, this economy of energy has important consequences which affect the acceptance of foods cooked by the microwave method. The food habits of consumers require that the food surface have certain familiar characteristics. The normal charred appearance of steak, the deep brown color of roast beef, and the golden brown color of pie crust are notable examples. A substantial percentage of the flavor and odor is also determined by the reactions causing these color changes. Proper use of microwave cooking requires that these "cooked" colors be obtained, so that the resulting food product will not demand major adjustments in food habits of consumers.

The normal cooked color of foods is a function of temperature, time, and composition. In many foods cooked by microwaves, natural browning occurs to an acceptable degree. Generally the long-time cooking foods show considerable color. Meat roasts and large chickens are in this group. Users of Radarange equipment have employed various substances such as sauces or salts to obtain a desirable color—e.g., a chestnut flour and chicken fat sauce have been used in poultry cooking, and salt pack for meat roasting. In this laboratory, dough made of either regular cake flour or chestnut flour did not brown in microwave heating. However, good results were obtained with commercially available powdered gravy mixes sprinkled on the surface of chopped meat patties and chops. Although a desirable color and flavor were obtained by this method, the degree of browning and flavor was not easily controlled. Processes employing deep fat browning or pre-broiling have also been used successfully. Incorporating sauces—e.g., Worcestershire—into the ground meat and marinating roast pork gave desirable color. Considerable work was done by Treisch (*7*) using chopped nuts, brown sugar, corn flakes, etc., to improve the surface characteristics of microwave cooked foods. She also employed certified food colors in an edible oil vehicle to obtain brown colors. However, certification of certain of the colors, FDC orange 1, 2 or SS, and red 32 (oil red XO), has been challenged recently. Any use of food colors should be made with this caution in mind.

The chemistry of browning reactions has been extensively studied, particularly in connection with dehydrated and concentrated foods. The chemical basis for the reaction was first proposed by the French chemist, Maillard, in 1912. Hodge (*3*) has reviewed the literature and suggested several reaction systems which can produce the brown nitrogenous polymers known as melanoidins which are generally considered among the "pigments" of cooked-food color. Hydroxymethylfurfural is an intermediate product when the browning reactions begin with glucose and glycine. The aim of most of the work reviewed by Hodge was the control of food discoloration such as occurs with dehydrated products. However, highly desirable characteristics are imparted to such foods as coffee, breakfast cereals, bread, and roasted nuts by these same browning reaction products. Barnes and Kaufman (*1*) found that special flavors of commercial importance could be obtained through the reactions of amino acids and sugars.

Lea and Hannan (*2*) have reported on the browning reaction and reviewed the results of studies with particular food products. In the case of high-protein foods, the reaction has nutritional significance, in that changes in nitrogenous components may alter the biological availability of amino acids. Lea and Hannan (*5*) incubated a dry mixture of caseinate and glucose at 37° C. and 70% relative humidity. During the first 5 days the glucose reacted with the $\epsilon$-amino groups of the lysine side chains of the protein in a 1 to 1 ratio. Over a period of 30 days the other essential amino acids reacted, including 90% of the lysine, 70% of the arginine, and 30% of the histidine. Therefore, although some of these browning reactions are undesirable from the point of view of food preservation and nutrient retention, they are essential for normal surface coloration.

In this report the use of the Maillard type of reaction to brown foods cooked by microwaves is described.

## *Experimental Procedures and Results*

Experiments were carried out in Radaranges, Models 1161 (1.5- to 1.6-kw. cooking power) and 1170 (0.75-kw. cooking power). The reaction system tested contained an amino acid (glycine) and five- and six-carbon monosaccharides. Initially, a distinct brown color was obtained on the surface of such foods as chicken, chops, fish, steak, bread, and hamburg when a mixture of equal parts of crystalline glycine and glucose (Formula A) was sprinkled on the surface and the food was then cooked. Almost any shade of brown could be obtained on the sprinkled surface of a slice of bread by varying the heating time. There was an indication that the portion treated showed selective absorption and became hotter than untreated portions. Controlled experiments showed that the treated slices were 11° F. warmer inside.

The following variables were considered:

- Optimum proportions of coloring agents
- Means of controlling the degree of color
- Temperature and time dependence of the reaction
- Influence of the contributed flavor on the cooked product
- Degree of adhesion of the added material
- Effect of pH
- Method of application to various foods

Lea and Hannan (*4*) showed that reducing sugars and the free amino groups of proteins combine initially in a 1 to 1 ratio which subsequently increases to a 1.5 to 1 ratio. The best relative proportions for Formula A of the amino acid and reducing sugar were determined in microwave heating tests of the dry mixture on the surface of white bread, which absorbs microwave energy at a high rate. The results are shown in Table I.

**Table I. Effect of Ratios of Glucose to Glycine on Rate of Browning of Bread Slices in Microwave Heating**

| *Ratio of Glucose to Glycine Weight* | *Rate of Browning* |
|---|---|
| 1 to 1 | Fast |
| 2 to 1 | Fast |
| 3 to 1 | Slow |
| 4 to 1 | Slow |
| 5 to 1 | Slow |

When an equal amount of water was combined with Formula A and the solution heated conventionally, in a beaker, browning began at 218° F. and the solution turned dark brown between 222° and 226° F. When equal amounts of glucose and monosodium glutamate (Formula B) were combined, a similar test gave initial browning at 212° F. and was completed between 225° to 230° F. The latter reaction occurred over a range of 18° F., whereas the glycine reaction occurred over a range of 9° F. under the conditions studied.

The reaction depended on the pH of the solution, with higher pH values accelerating the color development. When Formula A with equal parts of water was tested at pH 9 and pH 10 (using sodium hydroxide to adjust), microwave heating of the latter produced a dark brown color when the lower pH material was still light. In all cases, Formula A at pH 10 browned faster and became about 11° F. hotter during a 2-minute heating period of the sample solutions.

In this type of reaction, Lea, Hannan, and Rhodes (*6*) found that 1 mole of water was liberated for each mole of sugar combined with protein. Concentrated and dehydrated sugar-protein foods exhibited the browning reaction spontaneously but required far longer periods of time than those being considered here. Nevertheless, the moisture present under reacting conditions would be expected to influence the result. Such was the case when Formula A was tested with various water contents.

When water and Formula A were combined in a 4 to 1 ratio, the browning reaction did not occur. Smaller ratios of water delayed but did not prevent the reaction. Frequently, the amount of water on food surfaces is large; thus it was considered that a desiccant might prove desirable.

In preliminary beaker tests in which calcium chloride was added to the formula, the reaction was delayed. However sodium carbonate was found to accelerate the reaction. With a given amount of sodium carbonate added to Formula A, the reaction velocity varied inversely with the moisture content. Phosphorus pentoxide (anhydrous) was found to accelerate the browning reaction. One part of phosphorus pentoxide (anhydrous) to 3 parts of Formula A in dry powder, at a temperature of 140° F., produced color as soon as the mixture was hydrated. However, the reaction products were unsightly and a strong caramel aroma was noticed.

In comparing sodium carbonate and sodium hydroxide in Formula A to adjust the pH to 10, the latter was superior, producing better color and about 11° F. higher temperature in the sample solution. No satisfactory method was found for using the exothermic dissolution of sodium hydroxide in Formula A and water, although this effect accelerates the coloring. Powder instability contributed to the rejection of the use of sodium hydroxide.

## *Application to Foods*

In microwave cooking tests with chops and steaks, the major problem was to develop the reaction at ordinary cooking temperatures and times of 1 to 2 minutes

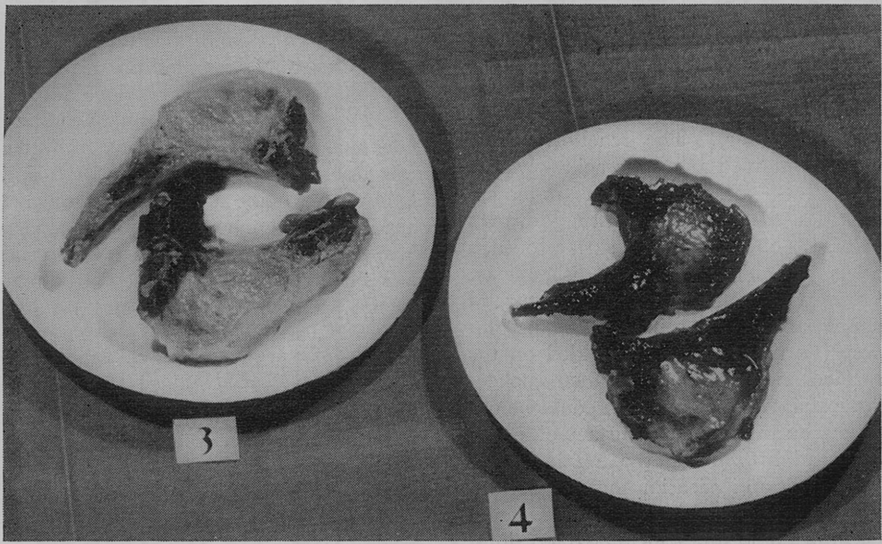



Figure 1. Pork chops

3. No formula used
4. Cooked with Formula C

per portion. A secondary problem was the tendency of the juice from the meat to dilute and remove the reacting material from the surface. Re-use of the gravy by basting on subsequent portions of steaks and chops resulted in good color.

For direct use, however, xylose was substituted for glucose and sodium carbonate added to adjust to pH 9 (Formula C, 40% xylose, 40% glycine, 20% sodium carbonate). This mixture began coloring action at 160° F., and caused browning at 169° F., and charred color at 172° F. The sample had a final pH of 7.5.

Formula C then was tested on pork chops. The relatively low reaction temperature was a distinct improvement in the case of chops. A 59-gram pork chop was cooked in 1.25 minutes at 0.75 kw. after being sprinkled with 2 grams of the powder. A very desirable brown color and a charred appearance which contrasted well with the white cooked pork were obtained. In addition, the chops had a slightly sweet taste, which was very pleasant. Figure 1 compares this product cooked both with and without the use of the browning formula.

The combination of arabinose and glycine adjusted to pH 9 with sodium carbonate was also tested (Formula D). It colored slightly at 176° F. and fully at 206° F.; however, it contained an uncommon monosaccharide which did not equal the performance of xylose and this material was not developed further. The temperature relations for the formulas tested are summarized in Table II.

### *Microwave-Cooked Chicken*

When Formula A was used on chicken cooked in 10 minutes at 1.6 kw. the skin browning developed slowly, becoming evident in 3 minutes, and pronounced in 9 minutes. Where the reacting materials were too concentrated, a slightly bitter taste was noted. It was, therefore, desirable to dilute the formula from the 1 to 1 ratio of sugar and amino acid, to cook the bird out of the juice, and to use the mixture sparingly and evenly. The resultant coloring was then satisfactory and the reaction time relationships were very good. In these tests Formula A was diluted with sodium chloride and nonfat milk solids. This modification of Formula A was made up as follows:

| *Ingredient* | *Per Cent* |
|---|---|
| NaCl | 25 |
| Nonfat milk solids | 25 |
| Glucose | 20 |
| Glycine | 20 |
| $Na_2CO_3$ | 10 |

In addition, an egg white wash was first used on the chicken as an adhesive agent for the browning material. When the wash was applied and the well-ground powder sprinkled evenly over the raw chicken, a distinctly pleasant golden brown coloring characteristic of roast chicken was obtained. No off-flavors were noticed in the product. In Figure 2, the ordinary color of microwave-cooked chicken is compared with the results obtained using this formula. Further tests indicated that the procedure could be simplified. The browning ingredients and 0.8 gram of paprika were suspended in the white of one egg and this applied to the surface of the chicken.

**Table II. Effect of Formula Changes on Coloring Temperatures**

| *Formula* | *Temperature, °F.* *Began coloring* | *Complete* |
|---|---|---|
| A | 218 | 222–226 |
| B | 212 | 225–230 |
| C | 160 | 169–172 |
| D | 176 | 206 |

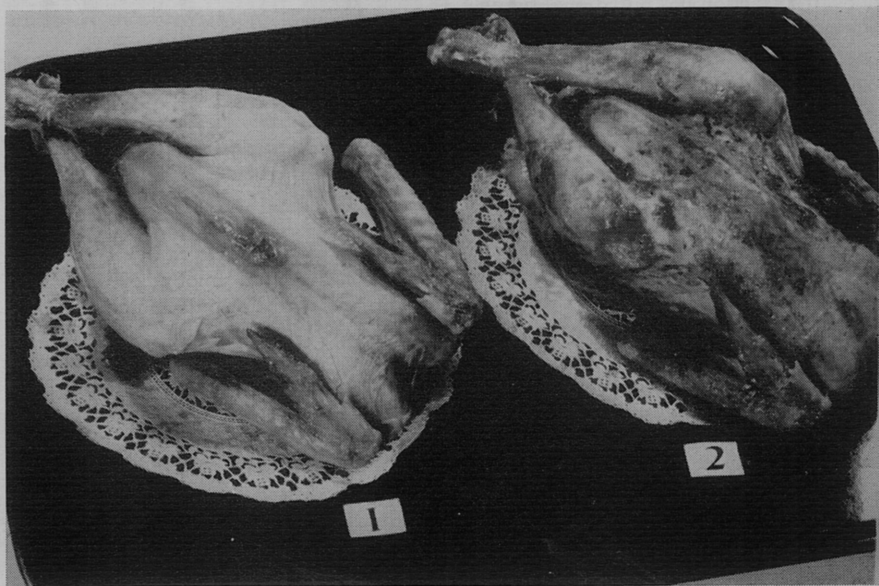
The coloring materials used in the ratio of 1 part of powder to 454 parts of chicken would cost less than $0.015 for a 5-pound chicken.

### *Pie Crusts*

It was assumed that microwave thawing and/or cooking of frozen meat and poultry pot pies, which are packed with uncooked crusts over cooked contents, offered no special advantage over conventional thawing and cooking, because of lack of crust browning. This supposition was confirmed, but observation of thawed and reheated 8-ounce products indicated the fact that the interior surface of the top crust was golden brown, while

Figure 2. Roast chicken

1. No formula used
2. Cooked with modified Formula A



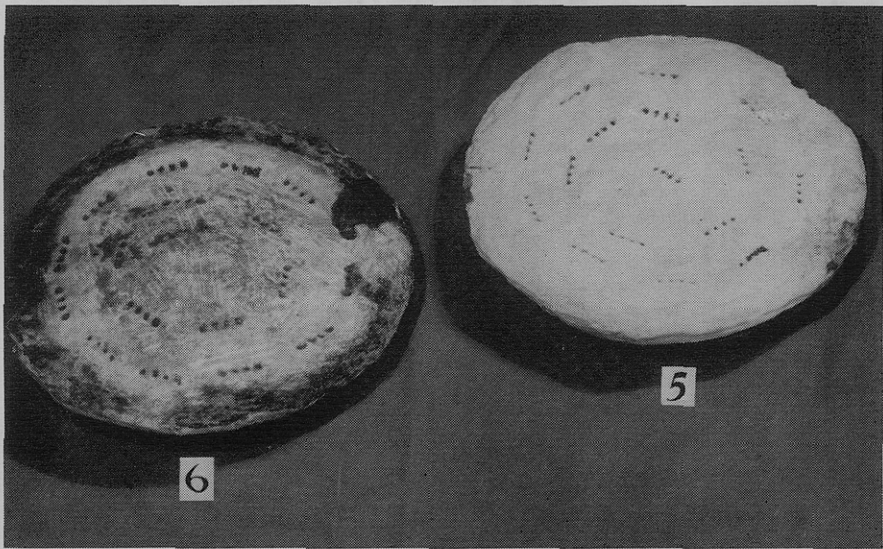


*Figure 3. Pie Crust*

5. No formula used
6. Cooked with modified Formula A

the outside was pale white. These tests with small pot pies were conducted in the aluminum plates in which they were packed. External crust browning could be obtained by increasing microwave cooking time, but only with thermal damage to the interior crust and contents. Formula A sprinkled on the surface gave a spotted dark brown color in 6 minutes at 0.75 kw., the time required for thawing and reheating at this power level. As the conventional single service handling of this product requires 35 to 40 minutes, it was felt that some benefit might be derived from further study.

The use of a sodium chloride–impregnated, saturated paper over the pie surface was found to produce a good surface color on microwave cooking, but the added salt affected the flavor. The coloring effect was attributed to increased heat on the exterior crust caused by the greater conductivity of microwaves by the extra surface salt. This phenomenon is called "browning by enhancing the skin effect of the microwave energy."

When monosodium glutamate was used in place of salt on the surface of the crust, a good even browning was obtained. In direct application of this material to the surface of crusts, it was found that coloring was a function of crust thickness and surface moisture. Heavy crust, sprinkled with monosodium glutamate and moistened, gave a good color. However, a flavor problem entered, as a moderate to a strong satiety effect was observed.

To obtain a more neutral taste, Formula A (with sodium chloride and nonfat milk solids) was used. Two grams were incorporated directly into a prepared pie crust mix, prior to mixing. In this case, it was desirable to roll the crust thin with a minimum of antiadhesive flour or to use waxed paper and no flour. It was found that 199 grams of filling heated to 150° F. in 1 minute at 1.6 kw. and the 5-inch diameter top crust browned uniformly.

Formula A adjusted to pH 9 with sodium carbonate (40% glucose, 40% glycine, 20% sodium carbonate) also produced a desirable brown color. This undiluted material was faster than the modified formula.

An 8-inch fruit pie containing 29 ounces (823 grams) of cooked fruit was prepared with top and bottom crusts to which Formula A adjusted to pH 9 with sodium carbonate was added at a rate of 3.5 grams per 284 grams of dry crust mix. This pie baked in 7.5 minutes at 1.6 kw. Borosilicate glass (Pyrex, Corning Glass Works, Corning, N. Y.) was a satisfactory utensil for bottom crust cooking as long as the pie contents were of a dry type—e.g., experimental bean or rice pie—but with wet filling (apple) the bottom did not cook thoroughly in this utensil. Therefore, a relatively porous material, Bakoware (Keyes Fibre Co., Waterville, Maine), was used. This special paper pie plate permitted excess moisture in the crust to be transmitted through the utensil and evaporate, allowing cooking of the bottom crust. The time relations for this process were such that thorough browning of the top crust coincided with doneness of the bottom crust. Microwave cooking is facilitated by such aids as cooking by inspection.

The pie crust browning agents were considered to have enhanced the taste of the crust by the majority of the trained panel who tasted the product. Normally, additional crust additives, such as butter, brown sugar, or egg wash would be used further to improve the appearance of such products.

The most satisfactory combination of browning ingredients for an 8-inch pie involved a decrease in the quantity of Formula A in the crust to 1.7 grams and an addition of the formula to a surface wash for application on the top crust. The latter contained 6 ml. of whole milk, 6 ml. of egg yolk, and 2.5 grams of Formula A. Figure 3 indicates the effect of using the foregoing procedure with Formula A as a component of the pie crust, as compared with the result using the unaltered pie crust formula.

Sodium bicarbonate was used successfully in place of sodium carbonate in these formulas in the same proportion, and, because it is more convenient to use, it is recommended over the latter.

The alkalinity of the foods is not increased by the addition of the browning agents. Although the concentrated powder is at pH 8, with the formula containing sodium bicarbonate, the final pH of the foods after cooking is on the acid side—e.g., pH 6.5 to 7 for browned chicken.

## Discussion

The time relations for medium and small loads cooked by microwaves are such that cooking occurs without the benefit of surface coloring. In approaching this problem, the effort has been to consider the ingredients normally present in foods, which contribute to the color in roasting and other processes. Concentration of such materials on the surface often accomplishes in minutes by microwave cooking what frequently requires several hours in conventional cooking.

The electrical properties of the foods and added materials must also be considered. Sometimes the environment of the food may be changed to duplicate conventional browning, but it is not necessary to resort to separate lamps or a heated atmosphere to accomplish this. Such methods will be the subject of a separate report. For the foods considered in this study, the treatments described appear to be the best. Emphasis has been placed on the use of natural food materials.

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