Color-Changing Indicator to Monitor the Time-Temperature History during Cooking of Meats

GUILLERMO J. FAVETTO, JORGE CHIRIFE, OSVALDO C. SCORZA and CARLOS HERMIDA*

Frigorifico Rioplatense S. A., Ruta 9, Km. 32-1/2, Gral. Pacheco, Pcia. de Buenos Aires, Argentina

(Received for publication August 20, 1987)

ABSTRACT

Development of a time-temperature integrator based on color changes produced by the chemical reaction between reducing sugars and amino acids (i.e. fructose, glucose, lactose) and L-lysine (Maillard’s reaction), is described. The indicator is particularly suitable to provide an objective method for confirming that a given temperature in the inner part of a meat product cooked in water in hermetically sealed packages, was achieved. This is needed to ascertain inactivation of the foot and mouth disease (FMD) virus and is required for meat imported from countries in which the FMD virus is present. The indicator is placed at the surface of the meat package and will avoid the need of opening the package for inspection.

The temperature and the time at which meat has been cooked is very important from the point of view of health regulations. For instance, United States animal health regulations require that importation of meat muscle from countries in which the foot and mouth disease (FMD) virus is present, be restricted to meat which has been cooked to a specific internal temperature; i.e. about 70°C (5,12). Various methods have been proposed to determine the final cooking temperature in the inner part of the meat. Among them, are enzyme activity determinations (4,8), changes in the electrophoretic patterns of low-salt soluble proteins (3,7) and a protein “coagulation test” (12,13). All these methods, apart from specific advantages or disadvantages, have the limitation that they can not be done quickly as is required for food inspectors of meat-import countries. Currently, one of the most accepted methods for monitoring the cooking process of meats for export in countries where the FMD virus is endemic, is the so called “pink juice test”. Food inspectors in the ports of entry verify the degrees of cooking by pressing out the juice of a piece of meat making a subjective evaluation of the presence or absence of “pink” color. Beside the highly subjective nature of this test it has other severe limitations. It can not be applied to meat pieces smaller than a cube of 1.5 in. in size; this precludes export of valuable meat products such as ground beef, beef patties, or prepared meat meals. The “pink juice” test is not applicable to cured meats because of the characteristic “pink” color of cured products. Since the pink juice disappears only at temperatures between 80 and 85°C (8) this represents an undesirable over-cooking of the meat since the FMD virus is inactivated at about 70°C in muscle.

Recently, a system of temperature indicators (heat-sensitive discs) which are suspended in the center of a bag of cooked ground beef, has been developed (2). This type of temperature indicator shows a color change when a pre-selected temperature is reached; this device provides no information concerning how long the system remained above the selected temperature, nor how far it rose above. This system permits food inspectors from import countries to verify that a given temperature has been reached in the “coldest” point of the package by opening it and checking the color of the indicator disc. Under the system of inspection used in many meat-importer countries, upon arrival of imported meat products samples are selected at random ensuring that every package has the same chance of being inspected. This means that all meat packages must contain a temperature indicator device in its “coldest” point. Obviously, this is not possible for small portions destined for the retail market. Thus the principle of placing a temperature-only indicator in the center of a meat package works only for packages which are to be opened for reprocessing after removal of the temperature sensitive device.

Instead of using a temperature indicator which registers the maximum internal temperature, it would be possible to use a time-temperature integrator indicator placed on the surface of the package. A time-temperature integrator is a device which registers a response according to the combined effect of time and temperature, and can be used to verify if the cooking conditions (temperature and time) allowed the desired internal meat temperature to be reached. The purpose of the present work is to describe the development of a time-temperature integrator particularly suitable for meats which are cooked in water in hermetically sealed packages. The indicator is based on color changes produced by the chemical reaction between reducing sugars and amino acids (known as Maillard’s browning), and is intimately fixed at the surface of the meat package.
MATERIALS AND METHODS

Thermal processing of meat products
All meat products (ground beef, goulash) were used without the indicator and were heated only to determine the time for the cold-spot to reach a given temperature.

Ground beef
Preparation of ground beef sample for thermal processing in water was similar to that described by Blackwell et al. (2). Lean beef trimmings were ground using a die plate of 0.3 cm and hand-packed into a 17 x 32-cm flexible high-density polyethylene cooking tube of 80 μm thickness to a total amount of 2.43 kg of ground beef. A weight was tied to the bottom of the tube to prevent floating and the entire unit placed in a 120-L steam-jacketed stainless steel kettle. Water temperatures for processing were maintained at 98, 93, or 88°C ± 1°C. Proximate analysis of raw ground beef was moisture 70.0%, protein 21.5% and fat 7.5%, as determined by AOAC (1) procedures. A thin thermocouple probe (panel mounted digital thermocouple thermometer) was positioned in the cold-spot of the cooking tube and tied to a plastic frame placed perpendicular to the tube.

Ready-to-eat Hungarian goulash
A thermoformed flexible pouch (10 cm x 12 cm x 3 cm) of high density polyethylene (100 μm thickness) was filled with 452 g of goulash sauce (65%) and cubed meat pieces (35%) having 3 cm of side; air was removed before sealing in a “Tiromat” thermoforming, vacuum producing and sealing machine, manufactured by Kraemer and Grebe (W. Germany). The thermocouple wire was introduced through the seal area; the sensing junction was secured in the center of a piece of meat (3 x 3 x 3 cm) which was positioned in the geometric center of the pouch using a thin plastic frame placed across the package. The pouch was processed at 98 and 93°C in the same way as described for ground beef.

Preparation of the time-temperature indicator
Filter paper (Whatman 40) discs of 3 cm in a diameter were soaked in a solution (buffered to pH 7.0) of sugar-l-lysine (composition described below), excess solution removed and hermetically sealed in flexible high-density polyethylene of 50 μm thickness. The encapsulated indicators were stored at -18°C. The composition of the different sugar-l-lysine solutions were as follows. Solution (A) contained fructose 55.54% (w/w), l-lysine 9.09% and phosphate buffer 35.37%; solution (B) contained glucose 28.40%, l-lysine 4.11% and phosphate buffer 67.49%, and solution (C) lactose 16.63%, l-lysine 9.09% and phosphate buffer 35.37%; solution (B) contained lactose 16.63%, l-lysine 6.25% and phosphate buffer 77.12%. All chemicals were analytical reagent grade.

Heating of the time-temperature indicator discs
The encapsulated indicators were heated alone in a water bath at 98, 93, 88°C, and occasionally, at 83°C. The temperature of the water bath was regulated to ± 0.1°C using a thermostat. At appropriate intervals the discs were removed, cooled in water and their color was determined as described below.

Reproducibility of color development in heated indicator discs
Ten different filter paper discs were soaked in solution (A), drained, encapsulated as described, heated at 98°C during 30 min, and their color (Suv) was determined.

Activation of the indicator discs
Color development (browning) due to Maillard’s reaction may also occur at room temperature, albeit much more slowly than at cooking temperature. For this reason, once the sugar-amino acid solutions are prepared and the paper discs soaked, color development may occur very slowly as a function of storage time (and temperature). This will introduce a problem since final color of the indicator after water cooking of meat packages, will reflect not only the prevailing time-temperature conditions during cooking, but also the previous thermal history of the indicator. This was solved simply by storing the indicators in a freezer at -18°C until they were used.

Color measurement
The discs were removed from their sealed envelopes and their color was measured using a Hunterlab Labscan spectrophotometer (11495 Sunset Hills Road, Reston, Virginia 22090, U.S.A.). The color function metric saturation, Suv, was chosen as the most suitable function to describe the development of color (9). The CIE tristimulus values X, Y, Z, for illuminant C, were converted in the color function Suv according to

\[
S_{uv} = \frac{13[(u - u_0)^2 + (v - v_0)^2]^{1/2}}{4X + 15Y + 3Z}
\]

\[
u = \frac{9Y}{X + 15Y + 3X}
\]

RESULTS AND DISCUSSION

Reproducibility of color development and activation of the indicator discs
Table 1 shows the mean value and standard deviation of measured color values in heated indicator discs soaked in

<table>
<thead>
<tr>
<th>Trial</th>
<th>Color value (S uv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.6679</td>
</tr>
<tr>
<td>2</td>
<td>0.6632</td>
</tr>
<tr>
<td>3</td>
<td>0.6916</td>
</tr>
<tr>
<td>4</td>
<td>0.6926</td>
</tr>
<tr>
<td>5</td>
<td>0.6884</td>
</tr>
<tr>
<td>6</td>
<td>0.7191</td>
</tr>
<tr>
<td>7</td>
<td>0.6914</td>
</tr>
<tr>
<td>8</td>
<td>0.6785</td>
</tr>
<tr>
<td>9</td>
<td>0.6823</td>
</tr>
<tr>
<td>10</td>
<td>0.7243</td>
</tr>
</tbody>
</table>

Mean: 0.6899
Standard deviation: 0.0195

a After heating 30 min in water bath at 98°C.

b See Materials and Methods.

JOURNAL OF FOOD PROTECTION, VOL. 51, JULY 1988
TABLE 2. Stability of color value ($S_u$) during frozen storage (at $-18^\circ$C) of indicator discs soaked in solution A.  

<table>
<thead>
<tr>
<th>Storage time (days)</th>
<th>Color ($S_u$) of unheated indicator</th>
<th>Color ($S_u$) of heated* indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0112</td>
<td>0.6785</td>
</tr>
<tr>
<td>30</td>
<td>0.0104</td>
<td>0.6944</td>
</tr>
<tr>
<td>120</td>
<td>0.0165</td>
<td>0.6800</td>
</tr>
</tbody>
</table>

*See Materials and Methods.

Table 2 shows that frozen storage was sufficient to stop Maillard’s reaction in the indicator discs soaked in solution A; color development during up to 120 d of frozen storage was almost negligible. Also, the final color after heating the indicator at 98°C during 30 min seemed to be independent of the storage time; this indicates that the formation of colorless browning intermediate compounds is also effectively inhibited.

Reproducibility and activation tests were also done for solutions B and C and the results were similar to those obtained with solution A.

Effect of time and temperature on color development in the indicator discs

It is well known that color development due to Maillard’s reaction between sugars and amino acids is a function of reaction time and temperature (9). The specific rate of color development also depends on factors such as, type and concentration of sugar and amino acid, pH (and type of buffer used to adjust it), water activity of the medium, etc. (6,9,10,11). Figure 1 and Fig. 2 show a plot...
of the color function metric saturation, $S_{uv}$, as a function of heating temperatures and time for the indicator discs soaked in the different sugar-1-lysine solutions. There is a period of rapid color increase and then the rate of color development tends to diminish. The data show clearly the sensitivity of color changes of the indicator discs to the combined effect of time and temperature. As expected, the rate of color development follows the order fructose > glucose > lactose. The data in Fig. 1 and Fig. 2 show that the proposed indicator system developed a suitable response (a color change) as a function of heating temperatures and time, in a range of temperatures typical of water-cooking of meat in hermetically sealed packages (i.e. 88 to 98°C).

The potential of the indicator system developed to monitor meat cooking may be best illustrated by analyzing the heating curves (evolution of the temperature in the cold-spot of the package) during water-cooking of a flexible pouch filled with Hungarian goulash and in tube-cooking of ground beef. In these products the rate of heat transfer is mostly controlled by a combination of conduction and convection inside the package. With reference to Fig. 3 suppose that an internal temperature of 70°C has to be reached in the inner part of a meat cube placed in the geometric center of the pouch; this is obtained after 44 min of immersion in the water bath at near boiling temperature (98°C). Thus an indicator disc soaked in solution A and placed at the surface of the package should have developed a color value, $S_{uv} = 0.825$ (Fig. 1) to match the above time-temperature condition. If the pouch was processed at a temperature lower than “boiling”, i.e. at 93°C instead of 98°C it will take 77 min of processing (Fig. 1) to reach the same color value (iso-color) in the indicator disc. This value is in excess of that required to reach 70°C in the inner part of the test meat piece (Fig. 3) and thus gives a safety margin for inactivation of the FMD virus.

Similar reasoning can be made when using the indicator disc soaked in the “less-reactive” solution B. In this instance 44 min of heat processing at 98°C corresponds to a $S_{uv} = 0.610$ (Fig. 2). If the indicator was heated at 93°C instead of 98°C the “iso-color” ($S_{uv} = 0.610$) would have been obtained after 74 min of heating; this time is enough (in excess) to reach 70°C in the inner part of the test meat piece cooked at 93°C.

During tube-cooking of ground beef it is desirable to reach a higher internal temperature, i.e. 85°C, to cause inactivation of the FMD virus; this is because ground beef may be contaminated with lymph nodes, bone marrow and clotted blood (2). Figure 4 shows the evolution of internal temperature during tube-cooking of ground beef at water temperatures of 98, 93 and 88°C. To attain an internal temperature of 85°C about 115 min of heating at near boiling temperature (98°C) would be required; this is out of the limits of utilization of indicator discs soaked in solution A or solution B. However, utilizing solution C the above time-temperature conditions are matched by a color value $S_{uv} = 0.485$ (Fig. 2). If for one reason or another the water temperature during processing dropped to 93°C instead of 98°C, the “iso-color” ($S_{uv} = 0.485$) would be obtained only after 210 min of processing; this time guarantees (in excess) that the meat package reached 85°C in its cold-spot in spite of the lower processing temperature.

Use of the indicator system proposed may be summarized as follows: (a) determine experimentally the temperature evolution in the “cold-spot” of the meat package of the precise size and shape at two or three processing temperatures in the cooking range; (b) select a sugar-amino acid system which upon heating at the temperatures of interest gives an adequate response and determine its color development curves, as those shown in Fig. 1 and Fig. 2; and (c) state the desired minimum internal temperature needed to inactivate the FMD virus, and with the previous information (a,b) calculate the “iso-color”.

It must be emphasized that the results are applicable only to meat packages of a precise size, shape and composition because these factors determine the time for the cold-spot to reach a given temperature. Also, the rate of heating must be preferentially determined in work situations to avoid some effect due to variation in the initial bath temperature caused by different meat-to-bath volume ratios.

**CONCLUSIONS**

The results presented here suggest that the system of a color-changing time-temperature integrator placed at the surface of a meat package, may be potentially valuable for monitoring the time-temperature history during cooking in relation to the inactivation of the FMD virus. Further research is in progress on the processing of meat products with the time-temperature integrator in place on the surface of the package and animal inoculation to test inactivation of the virus in the heated products. The main advantages of the system proposed are the following: (a) Meat inspectors from import countries may be able to verify easily the cooking history of meat packages by measuring the color (using a standard spectrocolorimeter) of the indicator disc fixed at the surface of the package (or eventually introduced between the layers of a multilaminated packaging film); alternatively, the color of the disc may be compared visually with a standard color chart (i.e. like a color pH scale). This inspection will avoid the need of opening the package which is required by systems which solely utilize a temperature indicator placed in the “coldest” point of the package. (b) The chemicals used in the preparation of the temperature indicator (sugars, amino acids) are safe since they are normal components of foods; thus, any accidental leakage or transfer from the indicator to the food would not constitute a danger to human health. (c) Due to the simplicity of its preparation and the nature of chemicals used, the cost of each indicator disc is expected to be very low; this is most important for use in single portion ready to eat frozen meat meals because of their relatively low weight.

It must be indicated that present method would be susceptible to fraud because an unscrupulous processor could pre-heat the indicator paper before applying it to the package. However, this is also true for temperature-only indicators which are suspended in the center of the package;
these indicators are accepted by United States animal health authorities for monitoring the cooking of meats for export in countries where the FMD virus is endemic. Periodic inspections in the processing plants by food inspectors from local animal health services, are the routine way to minimize this kind of fraud.

REFERENCES


D'Aoust and Sewell, cont. from p. 541

REFERENCES