

Factors Affecting the Spread of Cookies During Baking

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Biography of R. Carl Hoseney, PhD

Carl Hoseney has BS, MS, and PhD degrees from Kansas State University. He was a research chemist for the Agriculture Research Service of the U. S. Department of Agriculture of 15 years and then a Professor at Kansas State University for 25 years before retiring in 1997. Upon retiring he co-founded R&R Research Services and has served as its president since then. He is also the Editor-in-Chief of the Journal of Cereal Chemistry.

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Although cookies are well known to this audience it should be pointed out that in Europe and most of the rest of the world they are called biscuits or sweet biscuits. On a formula basis we can differentiate cookies from bread as the cookie formula is higher in sugar, fat and lower in water. In the case of cakes the levels of sugar and fat in the formula are similar but generally cookies have a much lower level of water.

Cookies come in many shapes and sizes. Cookies vary in the formula used and also in the type of equipment that forms and deposits the cookie on the baking surface. Cookies can be classified as made by rotary mold, rotary cut, wire cut, etc. For this presentation I would like to divide the cookie world into 2 categories, those that spread (increase in lateral dimension) during baking and those that do not. One type of cookies that do not spread is those made by rotary mold. These are cookies that are embossed with a trade name and other decorations. It is important that the cookies do not spread during baking as that would distort the embossing and leave it difficult or impossible to read. This clearly is not desirable. The most important factor in this type of cookie not spreading is the very low level of water in the dough. Based on the flour the water is less than 20%. This not only includes the water added to the formula but also the moisture in the flour. With this low level of water the cookie dough is somewhat dry and crumbly. Force is required to form the dough into a cohesive mass. Much of the cohesive force is created by the fat in the formula. The dough has a very high viscosity and therefore

does not flow under the force of gravity in the timeframe of baking. The low level of water in the formula is insufficient to dissolve the sugar in the formula. The effect of sugar dissolving will be discussed in more detail later in this presentation.

The second type of cookie dough that does not spread during baking is cookies that are cut from a dough web. Examples of this type are animal crackers and Vienna fingers. In forming the dough web the flour's gluten is developed into a continuous network. This holds the elastic web together. The continuous gluten network also has a high viscosity and again does not allow the cookie dough to flow under the force of gravity. Although both of these examples have a high viscosity that keeps the dough from flowing the factors causing the high viscosity are quite different. As discussed above the rotary mold cookie's low water is insufficient to form a continuous network and depends on the flour particle and sugar crystals to generate the high viscosity. With web type cookie dough, the water in the formula is much higher and the sugar content is lower, the combination of these factors allows the formation of the continuous gluten network. Of course, it takes work to form the continuous network and this is provided by the mixing of the dough and particularly by the sheeting of the dough.

Cookies that Spread During Baking

The cookies of interest here are sugar-snap, ginger snap and many of the highly flavored cookies for example chocolate chips, oatmeal raisin, etc. The dough is generally soft with essentially no elastic character. For deposit on the baking band the dough is generally forced through an orifice and cut with a reciprocating wire. This gives the process the name of wire-cut cookies. The formula for this type of cookie is relative high in sugar (~ 60% of flour weight)

and shortening (~ 30% of flour weight) and with a moderate level of water (~ 25% of flour weight). It should be noted that at room temperature the solubility of sugar is about 2 g per g of water. Even if all the water in the formula is available to act as a solvent there is insufficient water to solubilize the sugar. Of course, part of the water is bound to the flour and thus not available to act as a solvent. Therefore, it is clear that part of the sugar is not dissolved in the cookie dough and remains as solid crystals. Experimental data with the above formula shows that about one-half of the sugar stays in the crystalline form after mixing at room temperature. The solid particles increase the viscosity of the dough and results in a slower the flow of the dough at room temperature. The lack of solid particles and the resultant lower viscosity of the dough is one of the major problems with attempting to replace sucrose with corn syrup in the cookie dough formula.

Another important property of sucrose is the increase in volume that results when sucrose dissolves. Crystalline sucrose has a density of about 1.6 g/cc. Taking the inverse of this to give cc/g results in approximately 0.6 cc/g. Thus for ever gram of sucrose that dissolves there is an increase of 0.6 cc of liquid. This is not significant if the level of sucrose is small. However, in the above cookie formula for every 100 g of flour there is 60 g of sugar, multiplying 60×0.6 results in a volume increase of 36 cc. To put this in perspective that is more than the 25 cc from the water in the formula. It is also noteworthy that the amount of sucrose in solution increases as the temperature increases. Remember that only about 50% of the sucrose in the formula was dissolved during mixing at room temperature. Thus, the solvent increases during the early stages of baking allowing the cookie to continue to spread.

For a cookie to spread during baking the viscosity of the dough must be such that the force of gravity will cause the dough to flow during the timeframe of baking. For this to be true the continuous phase must be the aqueous phase (water plus dissolved solids). This then infers that the gluten is not developed and does not form a continuous phase in this type of cookie dough.

Factors Controlling the Viscosity of Cookie Dough

As detailed above the cookie dough's continuous phase is water and the material dissolved in the water (mainly sucrose). It is well known that adding more sugar to the formula will increase spread of cookies. To understand why two factors must be kept in mind. First at room temperature the aqueous phase is saturated with sugar, so additional sugar just gives more crystals and not more liquid. This in itself would greatly increase the viscosity of the dough and reduce the spread. Second, as the system is heated (baking) more and more of the sugar is dissolved giving an increase in the amount of liquid. Thus, the additional sugar results in more spread during baking.

The most effective agent to affect the cookie spread is anything that binds water. Water binding is a controversial subject. Many think that a water molecule binds to a site on a polymer and stays there, this is not what happens. A water molecule may attach to a site for a short period of time but then it comes off to be replaced by another water molecule. Irrespective of our concept of water binding, it is a fact that part of the water in a complex food system is not available to act as a solvent for solutes (soluble materials such as sucrose). This also holds true for the water being subject to freezing. Thus anything that "binds" water

decreases the amount of water that can act as a solvent and thereby increases the viscosity of the dough.

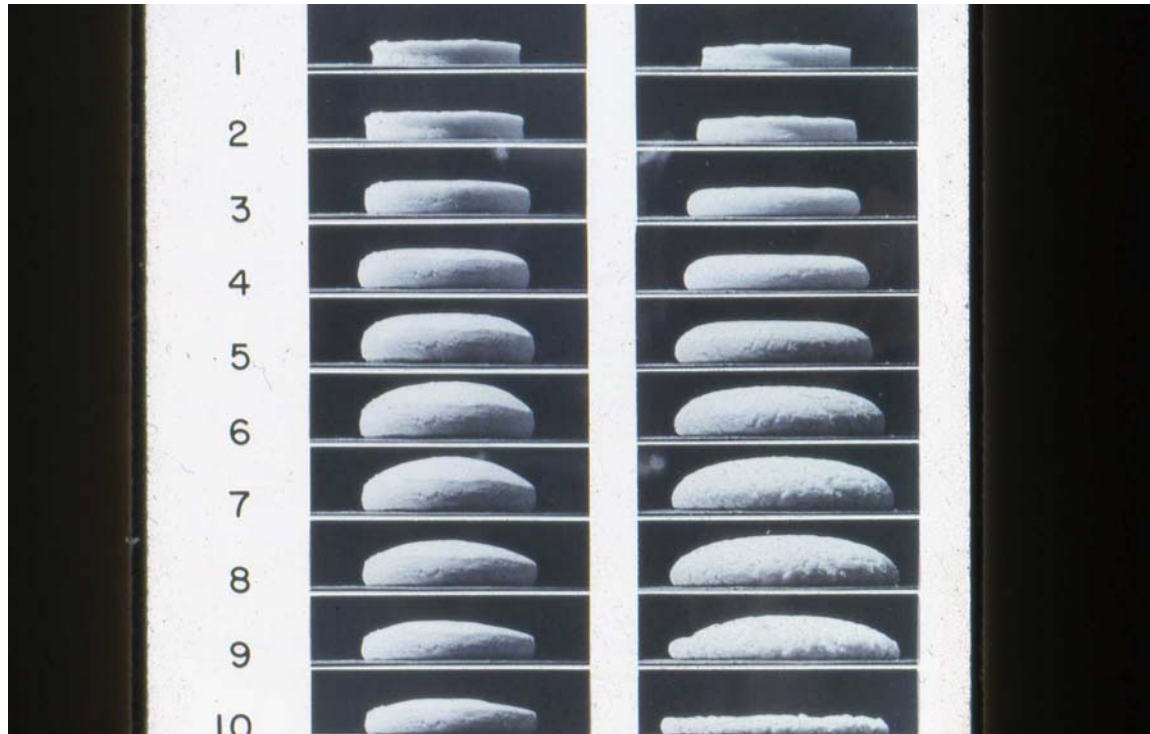


Figure 1. Time-lapse photographs of cookies from good (right side) and poor (left side) quality cookie flours as a function of baking time (in minutes on the left). (From Yamazaki and Lord, 1971)

Time-lapse photography can be used to follow the spread of cookie dough during baking. A camera mounted on a laboratory oven door that has a glass window will work. It is also important to have something near the cookie with a known dimension that does not change materially during baking, a small steel block for example. Then pictures can be taken at set intervals (15 min or so). The width of the cookie and the steel block can be measured off the prints and the cookie dimensions can be corrected to a constant by reference to the steel block. Figure 1 shows pictures of cookies during baking from good quality cookie flour and from

poor quality cookie flour. The picture clearly shows that cookies made from good quality flour spread to a much greater extent than cookies from the poor quality flour. In Figure 2 the width of the cookie is plotted versus the baking time. From this plot it is clear that the cookie increases in width at a constant rate up to a point and then stops spreading. We will discuss the stopping of the spreading in the next section. The slope of the line up to the stopping point is the rate at which the cookie spreads. Since gravity is the driving force for the spread and gravity is constant, the rate of spread is determined by the viscosity of the cookie dough. Cookie dough with a low viscosity will spread more than dough with a higher viscosity.

Plots such as the one in Figure 2 are very useful in comparing the performance of cookie flours. If the formula used is constant, then the differences in slope are caused by differences in the flour. There appears to be two major components of flour that have the major effects on cookie spread. First is the starch, particularly the damaged starch (starch that is damaged during milling). Second is the arabinoxylans (used to be called pentosans) these are major components of the cell walls in wheat endosperm. Wheat starch adsorbs about 30% of its weight in water, damaged starch on the other hand can adsorb up to 10X that amount. The arabinoxylans also adsorb large amounts of water. The amount of arabinoxylans and possibly their chemical structure can vary from wheat to wheat. The other very useful aspect of the plot in Figure 2 is when the flour used is held constant we can easily see the effects of various formula components. For example, this could be used to screen a number of fiber sources to see which has potential as a formula ingredient.

Setting or Stopping the Spread

When I ask students what causes the cookie to stop spreading I usually get the answer that water is lost during baking and thus the viscosity increases. This is a reasonable answer but it overlooks

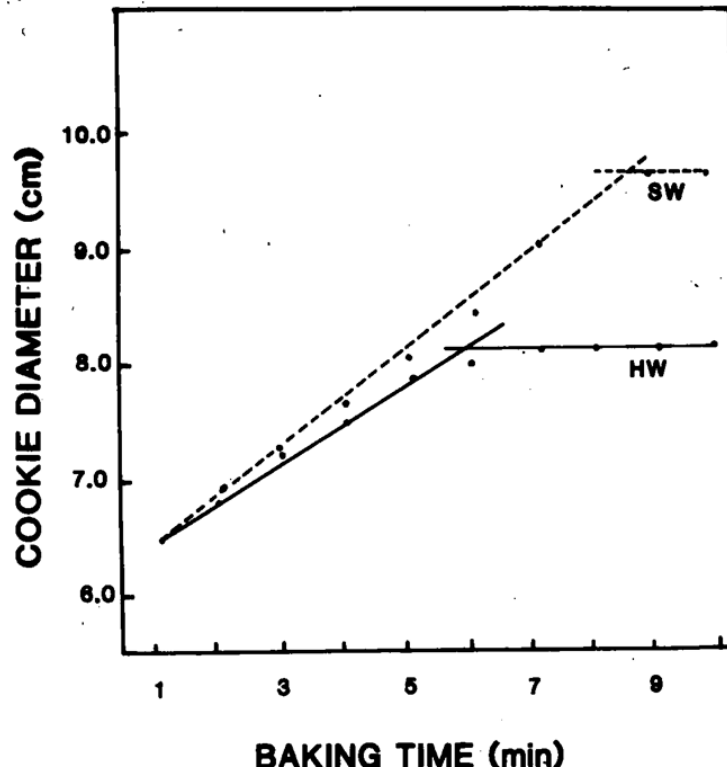


Figure 2. The width of cookies made from soft wheat flour (SW) and a hard wheat flour (HW) plotted as a function of baking time.

the fact that the stop in spread is sudden and the loss of water is gradual. Thus another explanation is needed. As discussed above the continuous phase in cookie dough is the aqueous phase but what about in the cookie? This can be determined with a series of simple experiments. Assuming the continuous phase of the cookie is sugar placing the cookie in a petri dish with water overnight should result in a cookie that has been totally dispersed. However this was not the case, although wet, the cookie still holds its shape. The next assumption is that starch is the continuous phase. This can be tested by soaking the cookie overnight in an amylase solution. This also fails as the cookie is still intact the next morning. The third guess is that the protein is the continuous phase, soaking the cookie in a proteolytic enzyme solution shows that this is correct as the cookie is dispersed by the next morning. If we think

about it, this makes sense. Earlier we saw that cookie dough that was developed (i. e., formed a web of gluten) did not spread during baking. Thus, it is the formation of a continuous gluten phase that is responsible for the stopping of the cookie spread during baking.

The next question, what is responsible for the transformation of the cookie dough with its continuous aqueous phase to a cookie with a continuous protein phase? For the dough to not form a continuous gluten web the gluten must remain in the flour particle and although hydrated the gluten does not have the mobility which is necessary to form a web. In other words the gluten remains in a glassy state as it was in the flour particle. At room temperature when water is added to flour the gluten in that flour goes through a glass transition that gives it mobility and results in the formation of elastic dough. However, in cookie dough the high level of sugar stops this from happening at room temperature. However it does occur when the temperature is raised. Thus during baking a temperature is reached that allows the gluten to go through the transition and thereby to gain mobility and interact with other gluten molecules. This causes the viscosity of the system to rapidly increase and stops the spread of the cookie.

Another interesting aspect is that the temperature at which the gluten goes through the glass transition depends, at least in part, on the protein content of the flour. Additional parts of the complex phenomena appear to be the protein-to-sugar ratio and the gluten type (weak versus strong).

The spread of cookies during baking is complex. It is mainly controlled by the viscosity of the cookie dough. However, in some cases the set point (where the cookie stops spreading) can also be an important factor.