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Expansion

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During culinary processes, different kinds of expansion can be observed. For example, bread fermentation (before baking) is associated with a volume increase of the dough, because carbon dioxide is formed through yeast metabolism (Belitz et al., 2014). Also, during cooking, some cakes expand when they contain leavening agents specifically selected to produce gases (see the chapter on chemical leavening in this book).

Here, we focus, rather, on a different class of expansions that occur during cooking, such as for soufflés, choux, puff pastry and Durham popovers. For example, soufflés are preparations that are traditionally made from a thick preparation (such as sauce blanche, a cream patissière or a fruit purée) and whipped egg whites; the two parts are mixed, and the mixture is poured into ramekins and cooked in the oven at a temperature between 150 °C and 250 °C for 20–60 min depending on their size (Saint Ange, 1925). It is considered a success when the preparation expands. But why does such an expansion occur?

**Early Experiments**

In the prehistory of molecular and physical gastronomy, i.e., before the scientific project of the discipline had not been clearly identified and named (1988), the late Nicholas Kurti (Budapest, 1908–Oxford, 1998) studied soufflés experimentally, and he even cooked a soufflé publicly during a lecture at the Royal Institution of London. In the report of this lecture (Kurti, 1969), he wrote:

> The experiments with this roast leg of lamb taught me the obvious thing, namely that continuous monitoring of the temperature inside the dish one is preparing could be very useful. So I started experimenting with various other dishes, notably with soufflés, which are fairly tricky to prepare. There is always some doubt when to take them out and I thought that the normal method of peeping furtively into the oven, perhaps shaking the dish a little bit to see whether the soufflé still wobbles, or is firm enough, could be done away with if one monitored the temperature. So I carried out quite a few experiments with both savoury and sweet soufflés, and the results of a typical run are shown in Figure 4, which gives the temperature measured about 2 cm below the surface of the mixture at the start. This is first of all a rapid rise, followed by a levelling out, and in fact the temperature even drops a bit because as the soufflé rises, cold parts from the bottom reach the tip of the thermometer. After about 20 minutes, the rise in temperature begins again and gets accentuated, and I found that if one removes the soufflé when a temperature of about 70 °C is reached, it is done pretty well to perfection. About ten minutes before the beginning of this lecture, we placed a soufflé à la Chartreuse in the oven and connected the thermometer to a chart-recorder. When the right temperature is reached we shall take it out of the oven and you will be able to see whether the fact that we had a thermometer in the soufflé that we tried to judge the cooking time by a basic scientific method in any way impaired its qualities or its taste. I think it is a sad reflection on our civilization that while we can and do measure the temperature in the atmosphere of Venus we do not know what goes on inside our soufflés.

However, experiments that I did later in collaboration with Kurti (in my laboratory, in Buc, France, or in Oxford, UK, after 1986) did not show the temperature behaviour that Kurti initially observed (Figure 40.1), i.e., no “temperature drop” was detected. For these cheese soufflés and for all the others that were studied in the following years (This, 2002), the recipe and the protocol were constant:

1. a “roux” was prepared with 75 g flour and 75 g butter;
2. the mixture was heated up to 100 °C, and, when a light brown colour was obtained (this is also described more technically in terms of heat transfer and heating time), 400 mL of milk was added;
3. after this “béchamel” was thickened by slow cooking, 50 g grated cheese and four egg yolks were added; four egg whites were whipped separately and mixed into the cheese béchamel; the soufflés were cooked in terracotta ramekins 15 cm in diameter, 10 cm deep; they were filled up to 8 cm and cooked in a De Dietrich P5447 oven with a K thermocouple (precision 0.1 °C, checked with ice and water, plus with boiling water) inserted 4 cm above the bottom of the ramekins.

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**Expansion**

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Figure 40.1 shows the temperature increase in the centre of the soufflés as a function of time. In this particular experiment, a slight slowing of the increase is observed after 10 min, but for other experiments, this did not occur.

It is interesting to observe that, when Kurti did his first experiments, and also when we did our first experiments with soufflés, beginning on 16 March 1980, the expansion of soufflés was said to be due to the dilatation of air bubbles from the egg whites (Montagné, 1994).

However, the simple application of the ideal gas law showed that this “theory” could not explain the doubling of volume for soufflés. In my first calculation, the ideal gas law was applied between the initial state, characterized by a pressure $P_1 = 1$ atm, a volume $V_1$ and room temperature $T_1 = 20$ °C (293 K); for the final state, the maximum expansion was obtained for an inner temperature of $T_2 = 100$ °C (373 K) that was obviously too high (because the soufflé would have been overcooked). But even with these assumptions, and assuming that the pressure in the soufflé was always 1 atm, the relationship:

$$\frac{P_2 \cdot V_2}{P_1 \cdot V_1} = \frac{nRT_2}{nRT_1}$$

(40.1)

led to an expansion ratio equal to 1.27 only, which does not explain the factor of 2 to 3 that can sometimes be observed. Assuming a pressure higher than 1 atm in the soufflé (due to the resistance of the crust, for example), the ratio is even lower (indeed, the pressure inside soufflés was measured to reach about 0.24 mm Hg at the end of the cooking process, so that the expansion ratio is not really changed). I proposed an improved theory in 1994, after observing bubbles at the surface of soufflés being cooked; this led to the assumption that the main mechanism of soufflé expansion is water evaporation rather than bubble dilatation. This observation was validated by many experiments, such as using a glass vessel for cooking, and also by weighing a soufflé before and after cooking: soufflés with an initial mass around 100 g (before cooking) lose 10 g after being cooked for 20 min at 180 °C. This means that more than 12 litres of steam are formed during cooking, a result that explains the actual soufflés’ expansion. Moreover, this means that very large soufflés could be obtained if the top crust of the soufflé is made impermeable to steam. For a soufflé made from 3 eggs, 250 mL of milk, 80 g of grated cheese and 40 g of flour, the total water mass is about 295 g; the maximum volume, i.e., the volume of a completely dry soufflé, would be 185 litres!

Testing Culinary Precisions

For soufflés, culinary precisions were tested as well, generally in terms of expansion. In particular, it was proposed by some chefs that the expansion would be improved by using very firm whipped egg whites, whereas other chefs proposed that bigger soufflés would be obtained using quite soft whipped egg whites. After preliminary experiments that I carried out in 1993 (Blanchet, 1993), I thoroughly tested the effect of firmness of egg whites on soufflé preparation. The cheese béchamel was divided into two equal parts, and foams of different firmness made from the same egg whites (after pooling) were added to both parts; in the first one, the whites were whisked until the first soft peaks were observed, while in the second, the egg whites were so firm that an egg in its shell (62 g) could stand on top of them without sinking. The soufflés were placed in identical ramekins 15 cm diameter, 10 cm deep, filled up to 8 cm. They were cooked in the same oven (De Dietrich P5447), for the same time, and the volume of the two soufflés was compared (of course, the experiment was replicated). The difference is shown in Figure 40.2.

The explanation of the difference is easy to understand, using the more correct theory of steam formation at the bottom of the ramekin; when a soufflé with soft egg whites is cooked, steam bubbles formed at the bottom of the ramekin, where the temperature is high, rise up through the soufflé preparation and explode at the upper surface of the soufflé; however, in a soufflé with firm egg whites, the firmness of the foam prevents (partially) the
bubbles from rising through the soufflé preparation; the upper layers are pushed upwards. Perhaps also the microstructure of the upper crust better retains the steam bubbles, but this remains to be determined.

As another validation of this theory, I tested in 1994 whether soufflé expansion was different depending on the position of the ramekins in the oven, and I showed that, in accordance with the right mechanism of expansion (primarily water evaporation), soufflés expand much better and faster when the ramekins are put on the hot bottom of ovens. Later, during one of my public monthly seminars, I even demonstrated that soufflés can expand when soufflés are cooked in this way even if the egg whites are not whipped (This, 2010), to the astonishment of the chefs attending the experiment.

Other Expansions of This Kind
Soufflés are not the only preparation that expand through water evaporation (This and Kurti, 1995). Indeed, with Nicholas Kurti, we also investigated “cannelés” and “Durham popovers”, but more recently, experiments were also performed on choux, cakes and bread. Cannelés and Durham popovers are made using pancake dough (milk, egg, sugar and flour) cooked in small dedicated vessels such as muffin tins, and choux are made from doughs containing water, flour, butter and eggs, directly cooked as small batches directly on a hot metallic plate in the oven. For cakes, the composition can change, but the dough often also contains flour, sugar and egg, and indeed, it was proposed by chefs that “eggs make preparations expand” (This, 2009).

However, the observation of puff pastry can easily show some expansion without eggs, and more when the number of layers is increased. For example, Figure 40.3 shows the results obtained from the same dough after various numbers of folds (1, 2, 3, 4, 5, 6, 7), during one of the French monthly seminars on molecular gastronomy (see chapter “The monthly INRAE-AgroParisTech seminars on molecular gastronomy” in Part II of this book). For such pastry, there can be considerable expansion, but the dough contains no egg. Indeed, chefs in the past confused the presence of eggs and the presence of water provided through egg addition, and this is how they invented an “expanding principle” that never existed.

FIGURE 40.3  The same dough for puff pastry was folded (simple turns) more and more, and samples were isolated at each step. After cooking, the expansion is bigger for a larger number of foldings, and also the thickness of the sheets decreases.

One by One?
The preparation of choux is particularly interesting regarding how molecular gastronomy can discuss culinary precision (see also the chapter “Culinary precisions and robustness of recipes”). For making choux or “gougère” (choux with cheese, a specialty of Burgundy, France), many recipes recommend boiling water and butter in a pan and then adding flour. On very low heat, the batter is kneaded, and, when this batter has cooled, whole eggs are added to the dough, which is then cooked in the oven.

We have been interested in choux pastry puffs because they are mentioned in many cookbooks (Carême, 1847; Escoffier et al., 1903; Saint Ange, 1925; Pellaprat, 1936; Montagné, 1994; Mathiot, 1995). Authors insist that the eggs have to be added very specifically to the batter, some books even adding that the mixing time must be equal during the introduction of each egg. This seemed strange, since it might be thought that, as long as the resulting paste was homogeneous, the mode of adding the given quantity of eggs should have no influence.

For example, as early as 1739, Massialot (1717) gives one recipe for “benoites, ou pets de putain”: they are small choux, and it is advised to add the eggs two by two into the dough. In 1901, Escoffier et al. (1903) also proposed to add the eggs two by two, but they write that “more firmness is obtained by adding the eggs three by three”. Gilbert (one author of the former book) gives the same indication in one of his sole-authored books (Gilbert, 1898). In 1919, Darenne and Duval (1919) indicated that the eggs have to be added all together, but never by fractions, “i.e., two by two or three by three”. In 1925, Madame Saint Ange wrote (Saint Ange, 1925) that, in a dough for choux, the eggs have to be added “with a rigourously constant interval”, and she adds that the dough is lighter when the dough is aerated while mixing the eggs. In 1924, de Pomiane proposes to add the egg differently (Pomiane, 1924): “boil water, butter and salt; then add the flour in rain; dry while eating, and add the eggs one by one”.

However, later, Prosper Montagné (1936) proposes a different process: “Add 12 to 14 eggs, depending on their size, two by two”. Much inconsistency thus appears in all this literature, and this is an indication that the question was ill-discussed. Indeed, even if microscopic studies of the raw dough show the presence of air bubbles, the expansion is mainly due to water evaporation. This was tested at the November 1993 Séminaire of Molecular Gastronomy: the water–butter–flour mixture (“panada”) was divided into two equal parts, and eggs (four) were added differently to these two batters, using a whisk. In the first half, eggs were added one by one, the number of whisk turns being counted; in the other half of the panada, the four eggs were added all together. Because the assumption was that mixing was more important than the means of egg introduction, the half with eggs introduced together was mixed with twice the number of whisk turns as in the first case. Then choux pastry puffs were formed on a oven plate, with parallel rows of both preparations, and they
were cooked together. A blind test on more than 50 guests showed that the more mixed preparation was preferred to the other.

Following this experiment, it was reasoned that, if air bubbles were indeed the key to success in making choux pastry puffs, a better expansion could be obtained if egg whites were separated from the yolks before being introduced into the panada, whipped separately and then mixed into the rest of the mixture. In a second experiment, conventional choux pastry puffs and choux pastry puffs made from panada added with whipped egg whites expanded similarly.

In a third experiment, conventional choux pastry puffs were compared with choux pastry puffs made by thoroughly mixing panada and egg yolks and then adding whipped egg whites, in the hope that the total number of air bubbles would be higher. In this third case, the expansion was found to be about one-third better for the new kind of choux pastry puffs. From a culinary point of view, however, the surface of the more foamy choux pastry puffs was less appreciated than the classical choux pastry puffs because they did not have the usual smoothness.

Finally, the number of untested culinary precisions about soufflés and their relatives remains important, and it is to be hoped that the culinary schools of today, now including science and cooking approaches, can conduct tests so that correct theories can be developed.

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