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ANALYTICAL CHALLENGE

Solution to rubbery egg challenge

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In natural sciences (what the great English physical chemist Michael Faraday called "natural philosophy"), there is no "demonstration", because one cannot prove anything except in mathematics [1]: as physical and chemical "theories" are reduced models of reality, i.e., imperfect descriptions of phenomena, the only way that science can operate is by refutation. The implementation of this idea when applied to hard-boiled eggs was at the root of the introduction of the "eggs at 6× °C" [2].

In the 1980s, when I asked colleagues about the coagulation of egg white, the answers were strange: physicists answered that it occurred because of the formation of a chemical gel, and chemists answered that it was through the making of a physical gel. Indeed my experiment of "uncooking" an egg, using sodium borohydride ($NaBH_4$) to cut disulfide bridges, showed that the energy of chemical bonds between proteins was between that of weak bonds and covalent bonds (about 75 % of covalent bonds [3]). Note that this was published as early as 1996 and the IgNobel prize was awarded for recent work without considering the 1996 result [4]. Anyway, the question about what makes eggs rubbery remained. In France, chefs say that if you cook eggs for more than 10 min, the egg white becomes rubbery. Is it true? And if it is true, why is it so?

The experimental test is easy: just put an egg in boiling water and cook for various lengths of time: 1 min, 2 min, …, 10 min, 20 min, and so on. You will be able to observe that the longer the cooking time, the more rubbery the eggs become. In addition, more "cooked egg" odour is evident.

Now, why? With the simple theory that egg-white proteins (which make up about 10 % of the mass of egg whites [5]) form a solid matrix with trapped water it is hard to explain the effect of boiling time on the texture of boiled eggs. However, one has to recall that there are different kinds of proteins with different denaturation temperatures (Table 1) [6].

Of course, denaturation and coagulation are not the same, but we shall not discuss here questions of terminology [7] and we shall simply admit that the aggregation of proteins can be obtained after denaturation as a result of the formation of disulfide bridges. This leads to the prediction that different coagulated states can be obtained at different temperatures. For example, a first gel due to ovotransferrin (13 % of the total quantity of proteins in egg white; 686 amino acid residues and 15 disulfide bridges [8]) can form when egg white is heated at more than 61 °C, and this state should be very soft and slightly opaque. This was demonstrated by heating eggs at 65 °C for more than 25 min (Figs. 1 and 2).

When the temperature is increased and reaches 70 °C, a second gel starts to form as a result of ovomucoid denaturation (11 % of the total amount of proteins in the egg white; 186 residues; 3 domains with 3 disulfide bridges per domain) and the consistency of the egg white becomes harder, and so on, until all thiol-containing proteins have coagulated, including the major ovalbumin (45 %; 355 amino acid residues; two disulfide bridges and four free thiols). This can explain why, in the traditional way of cooking, hard-boiled eggs can become rubbery—for long processing times. At the beginning, only the surface of the egg is heated much and it gets its consistency through many coagulated proteins. After some time, however, the temperature becomes higher than the denaturation point of all proteins and the gel becomes hard and rubbery.

This article is the solution to the Analytical Challenge to be found at http://dx.doi.org/10.1007/s00216-015-8872-2.

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Table 1 Denaturation temperature of the various proteins in the chicken eggs

Proteins	Denaturation temperature (°C)
Egg white	
Ovotransferrin	61
Ovomucoid	70
Lysozyme (globulin G1)	75
Ovalbumin	84.5
Globulins G2 and G3	92.5
Egg yolk	
LDL	70
HDL	72
α-Livetin	70
β-Livetin	80
γ-Livetin	62
Phosvitin	>140
Whole egg yolk	65–70 (because of LDL)

LDL low-density lipoprotein; *HDL* high-density lipoprotein

Of course, using precise temperature control one can make specific eggs with precise coagulation of the egg-white proteins and egg yolk proteins; these new eggs were collectively described as “egg at 6× °C, even if this name is misleading, as the temperature can be increased to more than 69 °C.

Fig. 1 An egg thermally processed at 65 °C for 1 h (Photo by Hervé This)

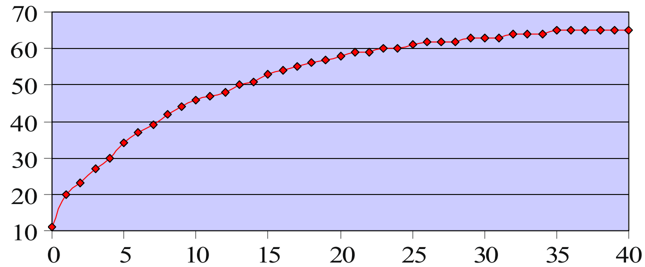

Fig. 2 Temperature (°C) in the center of an egg processed in an oven (whose temperature is fixed at 65 °C) as a function of processing time (min)

Now, is the issue fully solved? Yes and no. Yes, for all the reasons given above, but no because the famous French writer Jules Verne wrote in *The Mysterious Island* [9] that the eggs of sea turtles do not coagulate even in boiling water. Here is another challenge....

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