Salt: When Should Salt Be Added to Meat Being Grilled?

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Many cooks add “salt” (of course, they mean sodium chloride including impurities) to “meat” (pieces of muscular tissue from animals) before “grilling” (thermal treatment by contact with a solid surface at a temperature well above 100 °C, e.g., 300 °C) because they think and say that the salt enters into the meat. However, the loss of an aqueous solution (“juices”) by the meat, due to collagen shrinkage during heating, is an indication of an outward flow that can prevent salt penetration. Using scanning electron microscopy (SEM) with X-ray analysis, it can be shown that only a very thin outside layer is salted (Kuehne, 1988). However, capillarity allows some salt penetration in meat for some meats only (where fibre bundles are loosely grouped).

This question of salting meat before, during or after grilling was discussed at the second INRA Seminar of Molecular Gastronomy in November 2000 in Paris (This, 2000); cooks, culinary teachers and scientists discussed the “more appropriate” time for adding salt to meat being grilled. This was naive, because the question was not technical but artistic, and terms such as “good” or “better” are too subjective to be defined; as well, no unique answer could be given to “more appropriate”, because the goal is not clearly defined (This and Gagnaire, 2008). Moreover, even for such a simple question as when to add salt to meat and why, the chefs attending the seminar had different ideas, with no demonstration that their ideas could work properly.

Some chefs proposed to add the salt before grilling, saying that the salt would enter into the meat during cooking. This idea is also given by some culinary books (Bernardi, 1853; Bocuse, 1976), but no measurement was ever made in kitchens, to the best of our knowledge.

Other cooks recommended to add the salt during grilling, because (they said) the colour would be improved. Again, they did not compare the same piece of meat processed in the two ways.

Also, some cooks advised adding the salt after grilling, because “otherwise salt draws juices out of the meat”; this third idea can also be found in many culinary books (Bretonnel, 1896; Robuchon, 1993), and again, no rigorous test was made.

Interestingly, no cook present at this seminar had read the scientific literature about the question (articles such as Zhou and Wang (1998) are generally unknown in culinary circles). In order to know whether the culinary “precisions” (This, 2005) given by cooks and culinary books about salt were right or wrong, we first measured the mass of various meat samples covered with salt as a function of time at room temperature. The losses were compared with measurement of thermally processed meat before it was shown why, in some cases, capillarity could be responsible for some salt absorption in meat during cooking. Finally, we used SEM with X-ray analysis to measure the salt content in the meat before and after grilling.

Juice Extraction by Salt

In order to understand first how much “juice” could be extracted from meat by salt at room temperature, samples of beef muscular tissues (Longissimus dorsi, cut perpendicularly to the muscular fibres, and Diaphragma crus dextrum sinistrum, cut parallel to the fibres) and chicken muscular tissues (M. pectoralis major, intact) were purchased from a local butcher. Meat pieces were put in cups and completely covered with sea salt (brand La Baleine) at a number of fixed temperatures. At various times, the samples of animal tissues were taken out from the salt, washed, dried with absorbing paper and compressed air, and weighed (Mettler balance, precision 0.0001 g). Then they were transferred into fresh salt.

Figure 71.1 shows the variation of the mass of meat stored in salt as a function of time. It can be observed that two regimes are recorded, and the second one corresponds apparently to the formation of a crust, slowing down water transfer. However, the time constant for the loss of “juice” is very long compared with the time usually used for grilling meat (minutes).

Of course, these results are obtained at room temperature, and the exudation is faster at the temperature applied during grilling (up to 400 °C at the lower surface, about 50 °C inside the meat). However, assuming a Fickian diffusion of salt or of juices extracted by osmosis, this effect would not be much increased. Indeed, if one assumes a monodimensional diffusion of salt or water, the second Fick law for the particle flux in moles of molecules per unit area per unit time (J) holds that:

\[ J = - D \frac{dc(x,t)}{dx} \]
where $c(x,t)$ is the concentration at distance $x$ and time $t$, with the diffusion coefficient:

$$D = \frac{1}{f} k_B T$$

where $k_B$ is the Boltzmann constant, $T$ the absolute temperature and $f$ the frictional coefficient. At 298 K, $D = 1.33 \times 10^{-5}$ cm² s⁻¹ for Na⁺, so that it would reach only $1.7 \times 10^{-5}$ cm² s⁻¹ at 373 K (Atkins, 1990).

This can be compared to salt diffusion into a gel, as plant or animal tissues are indeed complex gels (see the chapter on this); when a strong gelatine gel is made from 1 g food gelatine dissolved in 250 g of water, coffee powder or methylene blue used as a colour marker diffuses in the gel at a maximum velocity of about 15 mm per day at 18 °C (Figure 71.2). For a 5 min grilling process, assuming the speed is not changed, the penetration depth of salt would be only 0.05 mm.

Of course, such crude calculations are not enough, as meat is cooked at more than 100 °C (it should be noted, however, that in all parts except the outside very thin layer, temperature is limited at about 100 °C because water is present). However, in this case, the introduction of salt should be even more difficult, because collagen and sarcomere shrinkage during meat cooking expels juices (Obuz and Dikeman, 2003; Kopp et al., 1977; Lepetit et al., 2000). It appears that at room temperature, the effect of salt as shown in the previous result is negligible compared with the juice loss by collagen contraction (Figure 71.3) (This, 1998).

Moreover, Figure 71.4 shows that a much faster capillary effect can occur during grilling; the contraction of meat under heating creates slits between bundles of muscular fibres, so that any salted solution created by the dissolution of salt crystals in the juices at the upper surface is very rapidly absorbed by capillarity; for example, for a viscous silicon oil, the capillary motion occurs at about 1 mm/s (Quéré, 1997; De Gennes et al., 2013).

**How Much Salt Goes into Meat during Grilling?**

As the various effects can have contradictory results, a direct SEM determination of the salt in meat cooked in culinary conditions was performed. Beef meat (Charal Inc., total mass 316 g, Longissimus dorsi) was cut perpendicularly to the axis of muscular fibres into two slices of thickness between 1.0 and 1.2 cm each. At the opening of the bag, it was observed that some juice was lost. The two slices were dried with absorbent paper and kept at room temperature until thermal equilibrium. Each slice was divided into two identical parts (left part of slice A: sample 1; right part of slice A: sample 2; left part of slice B: sample 3; right part of slice B: sample 4), and the raw meat was weighed. Exactly 2 min before grilling, samples 1 and 2 were salted on one side (1.000 g of the same salt as used previously). Samples 3 and 4 were salted after grilling, also on one side (same quantity of the same salt).

Grilling was performed in a non-stick pan (diameter 25 cm), without fat, heated by a Scholtes electric stove at full power (1500 W), pre-heated for 20 min. For the two samples (1 and 3) that were salted before grilling:

- salt was deposited on only one side of the meat, with a distribution as regular as possible;
- 2 min after salt deposition, meat was cooked for 60 s on each side, salted side first;
- after grilling, there was a 120 s rest on a plate with a previously weighed filter paper to collect the juice, and meat and juice were weighed.
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For the two samples (2 and 4) that were salted after grilling: grilling was for 60 s on each side; salt was regularly deposited on one side of the meat, after meat was put on a plate with filter paper; meat was turned to the other side, followed by a 120 s rest, and finally; meat and juice were weighed.

When the meat was cooked, fragments of each sample were cut for SEM study with X-ray analysis. The scanning electron microscope used (Model JEOL JSM-5200) had a maximum magnification of 100,000. The X-ray analysis by energy dispersion was done using a Link ISIS system by Oxford Instruments (Charlot et al., 2007; Roland and Haschke, 2007). The mass measurements in the second experiment (grilling) are given in Figure 71.5.

For SEM with X-ray analysis, the observations are difficult because of the high water content in meat. The mass proportions (in %) are given in Table 71.1.

The grilling process chosen for being as close as possible to the one cooks use in their kitchens generates a meat with red inside. When salted before cooking, a grey outside was obtained, in contrast to the meat salted after grilling, which was darker. The two meats dried slowly after cooking.
Samples 1 and 2 had the same treatment, but they do not contain the same quantity of salt. It is assumed that the more important juice loss of sample 2 eliminated some salt.

Meat salted before grilling contained less salt than raw meat, and they seem less salted than the others (Wirth, 1991). Possibly, the juices they lost dissolved the salt out.

This shows that, in the specific conditions of our experiments, salt put on meat before grilling does not enter more than 3 mm inside the meat (i.e., the natural roughness of the meat): the culinary idea is thus refuted.

This result is easy to interpret, as meat is made from muscular fibres coated with collagen-rich tissue (Girard, 1988). Due to this structure, salt penetration should be different depending on whether meat is cut perpendicular or parallel to the muscular fibres (Laroche, 1998).

Finally, we have to add that Table 71.1 does not include interesting results from previous experiments showing that meat cooked directly in aluminium pans contains some aluminium, compared with the same meats cooked in the same aluminium pans but with some oil or salt added to the pan before putting in the meat. Salt and oil seem to make a protective crust against metal migration into the meat.

### REFERENCES


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<td>Mass Proportion of Various Elements in Grilled Meat</td>
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