For thousands of years, grilling on an open fire has been a unique cooking technique to produce foods that have a smoky flavour. This procedure provides the characteristic roast flavour. This tradition-rich preparation method is used in every culture around the world, and different cultures have developed a variety of methods to optimize the roasting process of their dishes. However, little attention has been given to what remains after the cooking process. Accordingly, ash may be hiding interesting yet unexplored properties (Myhrvold, 2011).

For the preparation of leek ash, the leeks are burned at 300 °C using hot air in a convectomat (0% air humidity and 80% blower speed) for 35 minutes. After cooling, the ash is pulverized in a blender and passed through a hair sieve (Oldenbourg, 2013). The ash has a nice earthy and smoky aroma and still a scent of leek. It also tastes like soil and smoke and a little bit salty. In Figure 4.1, photos of the leek ash are shown.

**Characterization of Leek Ash**

The properties of leek ash have been studied using different techniques. First of all, optical microscopy was used to get a closer look at the ash using photomicrographs of leek ash (Figure 4.2), it can be observed that the morphology does not differ much from the morphology present in bright field mode. On the right side, a picture was captured under polarized light mode. Polarized light microscopy is used to study crystal structures of different kind of materials. Using the polarizer filter, the transmitted light is polarized linearly in one direction. When this polarized light is transmitted by a birefringent specimen, it is blocked by another filter, called the analyser, which is oriented at 90° to the polarizer. Crystalline regions of the specimen appear bright only if the polarization is changed by the specimen due to its birefringence or to stress in the material (Spiess et al., 2009). Consequently, it can be observed that leek ash contains bright crystalline structures. In Figures 4.2 and 4.3, these ash crystals are shown in greater detail using higher magnification.

These figures show that there could still be some crystals present even after burning the leek at 300 °C. Hence, to ensure the crystallinity, X-ray diffraction (XRD) was used, which is a common method to characterize crystal structures (Bergmann and Schaefer, 2005; Kühl and Linnemann, 2017). Figure 4.4 shows the graph of the XRD measurement. One can see an increase and a decrease of the baseline and some sharp peaks. The broad peak of the baseline is an indication of an amorphous structure due to the presence of carbon, and the distinct peaks are evidence for crystal structures, as they are present in salts and minerals. Therefore, the XRD analysis also confirms the results of the polarized light microscopy pictures.
In order to determine the composition of leek ash, samples were analysed with scanning electron microscopy (SEM). This is a method to get detailed information about the surface topography and the composition of a sample by using a focused beam of electrons to scan the surface (McMullan, 1995; Gaisford et al., 2016). Figure 4.5 shows SEM pictures with sizes ranging from 300 to 500 µm and finer details than the light microscopy pictures. Furthermore, the pictures show particles with a rough surface while maintaining the typical morphology of ashes. The following pictures (Figure 4.6) are micrographs with even higher magnification. Some of them demonstrate patterns that do not look like completely burned plant structures (a and b) and vascular tissue (c, d, e and f). Furthermore, the last two pictures (g and h) show rough and porous surfaces resulting in a massive
surface enlargement. This property leads to a high adsorption of liquids because of capillary forces within the large numbers of infinitesimal indentations.

Another feature of SEM measurement is the analysis of elemental composition (Figure 4.7b). Table 4.1 reveals an average percentage of elements in the focused spots (Figure 4.7a). The main elements are carbon and oxygen, followed by potassium and calcium and other elements such as phosphorus, sulphur, chlorine, sodium, magnesium and zinc. This composition correlates with the composition of ash in general, which contains oxides and carbonates of different metals, for instance CaO, Fe₂O₃, MgO, MnO, P₂O₅, K₂O, SiO₂, Na₂CO₃, NaHCO₃, etc. These components form crystal structures, which have already been seen. This is due to highly ordered atomic arrangement, meaning that their atoms are arranged in an ordered geometric pattern. For a more exact determination of the composition, more methods and measurements are required.

The plant remains can also be investigated by another measurement: in thermogravimetric analysis (TGA), substances can be burned under controlled conditions such as temperature rates, different atmospheres or a variety of pressures. The weight of a sample is measured over time as the temperature changes until a constant weight is reached (Coats and Redfern, 1963; Ardö, 2011). Figure 4.8 demonstrates the TGA measurement of leek ash under nitrogen atmosphere and air. The small drop at the beginning is due to adsorbed water, which evaporates. In both measurements, the weight of the ash decreases, starting at 288 °C in a nitrogen atmosphere, and 247 °C under ambient air conditions. This decrease confirms that the leek is not incinerated entirely during the manufacturing process. It is also obvious that, under nitrogen conditions, more mass remains, while in contrast, when it is heated under air, more sample is burned. This is because oxidation reactions can occur due to the oxygen content of air, and the compounds can be burned to carbon dioxide. Under a nitrogen atmosphere, this does not occur because of the absence of oxygen, which leads to the incomplete burning of the ash under nitrogen.

**“Labmade” Cheese**

The porous surface of ashed materials, which could be seen in the SEM pictures, is responsible for the high adsorption capacity of water and other substances. This property is a good platform to develop edible mould. The enzymes produced from the edible mould may lead to odour intensification. This particular effect of edible mould is used in cheese maturing, e.g., in the production of blue cheese, Roquefort, Camembert or Brie (Hayaloglu, 2016; Brehme, 2019).

Cheese maturing with ashes was also attempted in our laboratory, as described in detail in the following (Kaesereibedarf, 2019; Carroll, 2010; Vilgis, 2018).

First, 1.5 L of fresh raw milk (Gill’s Weidenhof, Mainz Bodenheim) was heated up to 36 °C, and six drops of liquid calf rennet (Bunte Kuh Käsereibedarf) were added. The milk mixture was left in the oven at a constant temperature of 36 °C for about 1 hour. The cheese curd was then cut into cubes and placed in the oven at 36 °C for another 2 hours (Figure 4.9a). The cheese mass was sieved through a cotton cloth and further liquid was...
FIGURE 4.6 Scanning electron microscopy pictures of leek ash (see main text for explanation of the various pictures).
pressed out (Figure 9b, c and d). The mass was formed into a ball, halved and placed in a 25% salt bath for 2 hours with frequent turning (Figure 9e and f). Finally, the cheese was patted dry and one half covered with leek ash (Figure 9g and h). Both halves were kept under a crystallizing dish, ensuring air circulation. An earlier development of edible mould on the ash-covered cheese was observed (Figure 9i and following pictures). Both cheeses developed a very intense odour. The ash-covered cheese had more of an earthy, musty odour.

**Meat Maturation**

The texture and flavour development of meat depends on the muscle fibres and their components. Figure 4.10 illustrates a muscle fibre, which is composed of capillaries, mitochondria, cell nucleus, blood vessels, collagen and myofibrils. These myofibrils consist mainly of actin and myosin proteins, which build the sarcomeres and are responsible for muscle contraction (Vilgis, 2015; Rayment et al., 1993).
After the death of an animal, the aerobic metabolic processes
and the production of adenosine triphosphate (ATP), which
provides energy for the muscle movements, are interrupted.
Therefore, the actin-myosin complexes are immobilized and
the muscle becomes stiff and rigid as rigor mortis sets in
(Vilgis, 2015; Luther, 2009). During meat maturation, enzym-
atic softening of the structure hardened by rigor mortis is there-
fore highly desirable. Enzymes located in the muscle and in the
sarcoplasm are responsible for this process; these enzymes are
cathepsins and calpains, which have different modes of action
and interfaces. Calpains are only activated when calcium
ions are released, while cathepsins are activated post mortem
when the pH value is sufficiently low. The calpains act on the
bonds of the myofibrils at the M-discs, while the cathepsins
act predominantly on the peptide bonds in the proteins of the
myofibrils, actin and myosin (Vilgis, 2015). This is indicated
in Figure 4.11.

With longer maturing time, bonds are systematically cut, the
cohesion of the fibrils becomes weaker, and the firmness and
elasticity decrease. Hence, the various proteins of the myofibrils
are cut at different places and the meat becomes more tender.
These processes are initiated after slaughter, progressive cooling
and the associated reactions in the phosphagen system. After
slaughtering, ATP continues to be produced and degrades to
inosine monophosphate (IMP) via adenosine diphosphate (ADP)
and adenosine monophosphate (AMP). IMP and glutamic acid
are synergistically responsible for the umami taste of foods. At
pH values around 6.5, calcium ions begin to be released, which
activate calpain. Only after the onset of rigor mortis (at about
pH = 6, when there is hardly any ATP left) do cathepsins begin
to become active. The pH value drops further, and the enzymes
break down proteins (Vilgis, 2015).

These biochemical processes are altered by coating the meat
with ash. Leek ash contains potash (potassium carbonate), which
increases the pH value because of its alkalinity. We confirmed
this by measuring pH over several days (pH = 7.8 ± 0.2). The
lowering of the pH value through the accumulation of protons
from ATP degradation is decelerated (“buffered”), and ATP deg-
gradation, IMP formation and calpain activity are slowed down.
The muscles are first cut primarily at the protein bonds by
cathepsins. This altered pathway in the molecular processes can
explain the extraordinarily soft texture of the meat. The faster the
ash is applied after slaughter, the more pronounced these effects
may be (Vilgis, 2015).

A nice demonstration has been recently developed in the res-

taurant einsunternull (Oldenbourg, 2013).

Recipe for Ash-Ripened Danish Duck (by Andreas
Rieger)

Ash-Ripened Danish Duck (144 Portions)
12 Danish ducks (approx. 3000 g), plucked, without head and feet
leek ash (1000 g)
FIGURE 4.9 Cheese production showing (a) renneted milk, (b) cheese curd (c, d, e) after sieving and pressing out of liquid, (f) in saltwater bath, (g, h) finished cheese and cheese (i, j) after 12 days and (k, l) after 20 days.
Remove the entrails and throat from the ducks. Open the abdominal cavity of the ducks wide, push a meat hook through the base of the neck and let it hang for 5 days at 0 °C (change the draining trays for blood every day and make sure that the ducks do not touch each other). Dismantle the ducks on the fifth day: cut off the sebaceous gland and discard; cut off the wings; cut off the legs, bone out hollowly and cut off the excess fat up to 10 mm with poultry scissors; separate the breast on the carcass from the torso with the scissors close to the ribs and cut the raven bone horizontally to the breast with a boning knife; remove the overlapping fat of the breast with the scissors. Roll breast and leg meat completely in the ashes and tap off excess. Hang the breast with a meat hook on the inside from the small hole and place the legs on the meat side next to each other on a 1/1 GN (Gastronorm) plate. Let both mature for at least 10 days at 0 °C in the refrigerator and turn them once every 2 days so that the meat is not wet.

**Duck Cooking (Results in 8 Portions per Double Breast/2–3 Portions per Leg)**

- 4 matured breasts or legs of duck
- 10 mL rape seed oil, raw vegetable quality
- Iodized salt to taste
- Sunflower oil for frying

Preheat the convector to 250 °C combined steam (25% humidity/40% blower). Slide a 1/1 GN 65 mm tray into the bottom rack and a 1/1 GN 100 mm punch insert into the third rack from below. Both meat pieces are taken out of the refrigerator shortly before cooking, completely rubbed with rape seed oil and salted from all sides. (See Figures 4.12 and 4.13.)

**Chest**

Place on the bone in the perforated inset and apply to cook for 11–12 minutes. Then let it rest for at least 15 minutes – maximum 25 minutes – in the warming drawer at 60 °C. Fill a medium pan with sunflower oil (about 10 mm) and heat to about 200 °C. Remove the breast from the bone and fillet, place in the pan with the skin side and fry until crispy golden yellow. Turn once briefly before removing and fry the meat side for 3 seconds. Let the meat rest again for 1 minute under the heat lamp and cut lengthwise into 10 mm slices; salt.

**Haunch**

Place on the meat side in the perforated inset and cook for 12–14 minutes. Then let it rest for at least 15 minutes – maximum 25 minutes – in the warming drawer at 60 °C. Fill a medium pan with sunflower oil (about 10 mm) and heat to about 200 °C. Place the skin side of the leg in the pan and fry until crispy golden-yellow. Turn once briefly before removing and fry the meat side for 3 seconds. Let the meat rest again for 1 minute under the heat lamp and cut lengthwise into 8 mm slices; salt.

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Ash in the Kitchen

REFERENCES


FIGURE 4.12 (a) The whole plucked duck after 1 week hanging. (b) Powdered ash is applied so that the duck breast is completely blackened. (c) The hollowed and ashed legs, ready to ripen.

(Courtesy of Andreas Rieger)

FIGURE 4.13 Served ash-ripened duck.

(Courtesy of Rene Riis for einsunternull)

