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**Smoked Foods**

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**Introduction**

Smoking to impart flavour is an ancient gustatory practice – from Roman townspeople’s smoking of sausages over hay or woodchip to medieval Europe’s use of smoking (of fish, after salting, in particular) to impart much-needed flavour in the absence of condiments as well as effecting preservation. Smoking required a flexible and functional architecture – from the open central hearth of the northern European Bronze Age roundhouse to the use of funneled brick chimneys in the 17th and 18th centuries to smoke hams and other meats. Outdoor smoking – often community smoking – of foods depended on the vagaries of weather but remained popular in northern Europe into the late 19th century.

Whereas the tradition of smoking was born out of necessity, these days, its role in preservation is secondary, and it is sought after for its distinctive and multidimensional flavour. Smoke flavour is a complex cocktail of smoky and burnt notes, sweet notes such as vanilla and caramelized sugar, more subtle fragrant notes such as clove, woody and spicy, as well as phenolic and medicinal notes. Smoke is used by chefs and culinary enthusiasts all over the world in an ever-expanding array of both sweet and savoury dishes, in snacks, soups, sauces, rubs and marinades in the food industry, and not forgetting its role in whisky. The American chef Victor Albisu describes smoke as being “as important as salt or garlic or onion … Without it, the food always feels a little empty to me” (Shahin, 2014).

**Smoking Methods**

Traditionally, food can either be cold-smoked or hot-smoked. In the case of cold-smoking, the raw food is usually cured to reduce the moisture content before it comes into contact with a stream of cold smoke (20–30 °C). This usually lasts for several hours, or even days, during which time further moisture is lost from the surface. No direct heat is applied to the food; the flavour develops from the smoke particles deposited on the surface, which reduces surface bacteria, and the odorant and taste compounds penetrate into the food. Wood chips or sawdust can be pyrolysed on electrically thermostated plates, by dropping onto an electrically heated ring, or by friction (Varlet et al., 2007). Salmon is the most popular example of a cold-smoked product and retains its raw translucent deep pink colour, whereas hot-smoked salmon takes on a pale pink opaque appearance.

During hot-smoking, the food is both cooked and smoked at the same time, and the food acquires flavour from the smoking process, from the glycation reaction, from lipid degradation and from the interactions between these processes. As in cold-smoking, the food is usually cured and seasoned prior to smoking, and the process is typically long and slow, being carried out between 50 and 80 °C for up to 24 hours, often in a drum fuelled by a firebox containing woodchips/sawdust or a propane gas burner. Meats (beef or pork ribs, or larger cuts) are very popular hot-smoked foods.

Liquid smoke (Figure 77.1) is the leading technology used by the food industry, particularly for the large-scale production of bacon and ham. It is obtained by condensation of smoke from fast pyrolysis reactors. Once mixed with water, the product can be further fractionated and refined to obtain the desired flavour.

**Odorants in Smoke**

Given the range of methods and smoking parameters (typically 400–500 °C for 12–24 hours) and the different sources of smoke (hardwoods, softwoods, peat or corncobs), quite a range of flavours can be achieved. The odorant compounds responsible for the flavour (Figure 77.2) are formed from the burning of the cellulose, hemicellulose and lignin in the wood or peat. One group of compounds that is very important for the odour of smoke is the guaiacols. They are formed from lignin, which is a polymer of phenylpropanoid alcohols such as coniferyl and syringyl alcohols. When these break down, they form guaiacols and syringol, respectively, of which the former tend to have low thresholds and impart a variety of odours (Figure 77.2).

- Guaiacol is one of the most important odorant compounds generated in smoke. Its odour is described as phenolic, smoky, spicy, woody and medicinal, and it has a very low odour threshold of 3 ppb in water.
- Methylguaiacol (threshold 21 ppb) is structurally related, with a similar odorant character and threshold,
but it is present in much lower amounts than guaiacol and therefore has less of an impact.

• 4-vinylguaiacol (threshold 3 ppb), again structurally related, is far more mellow, providing warm spicy notes, and can be reminiscent of smoky bacon.

• Figure 77.2 shows the structural resemblance of these guaiacols to vanillin (20 ppb). Vanillin is present at much lower levels but gives the sweet creamy vanilla notes present in some smokes.

• Similarly, eugenol (6 ppb) and isoeugenols impart a characteristic woody clove note.

• Syringol makes a major contribution to smoke odour, but its threshold is much higher than that of the guaiacols (1850 ppb). It gives smoke desirable characteristics such as vanilla, powdery, balsamic and spicy notes.

• 4-methylphenol (or p-cresol) (50 ppb) is derived from the coumaryl alcohol component of the hemicelluloses and has a more phenolic and medicinal note than the guaiacols.

A second group of compounds, generally referred to as furans, are formed primarily from hemicellulose, which is a branched polymer of pentose and hexose units. At high temperatures, these dehydrate to give a variety of furans and pyranones similar to those formed during caramelization.

• 2-furfural is quantitatively the major volatile component in smoke. It is described as sweet, woody and bread-like, but its threshold (3000 ppb) is relatively high and its contribution tends to be less than that of the
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Guaiacols. This five-carbon molecule is derived from the pentose units in the hemicellulose, as well as from the hexoses. It is one of the more reactive components of smoke and is likely to undergo condensation reactions with other aldehydes, many of which are generated in the glycation reactions.

- Maltol has a sweet caramel candy-floss aroma, but with an odour threshold of 35,000 ppb, it only contributes a sweet nuance to smoke odour.

Different Smoking Materials

Hardwoods are produced by deciduous trees such as oak, beech, hickory, mesquite, pecan or applewood and are generally preferred to softwoods produced from evergreen trees such as pine and fir. Softwoods have a higher lignin content (24–33%) compared with hardwoods (19–28%), but also contain a resin, which burns to give a harsh note to the smoke. Oak (62% cellulose/hemicellulose, 24% lignin) (Toledo, 2008) gives a strong but sweet smoke due to the high hemicellulose content. On the other hand, applewood gives a mild smoke, as the cellulose/hemicellulose fraction is only 28% and the lignin 38%.

Grasses, which are the basis for peat, have 10–30% lignin, and this varies with the geographical origin and the depth of the peat in the ground (Harrison and Priest, 2009). The less stable hemicelluloses degrade over time, so the deeper the peat is in the ground, the longer the degradation period, and the lower the hemicellulose content becomes. This reduces the formation of the sweeter carmellic furans and pyranones in the smoke but maintains the characteristic smoky guaiacols, which are formed from the more stable lignins. Those that have been shown to be particularly important for the peaty note are 5-methylguaiacol and 3-ethylphenol (Mall and Schieberle, 2019).

Texture

Smoking also produces changes in texture. During the curing step of smoked fish production, dry salt is layered over the surface of the fillets and dissolves into the flesh, drawing moisture out. Throughout the drying step, moisture evaporates (Figure 77.3), and the surface proteins denature and coagulate, producing a tough and sticky layer, i.e., the “pellicle”, to which smoke compounds can readily adhere (Flick and Kuhn, 2012). This layer contains a higher concentration of phenolics in fattier smoked fish because they are deposited onto the surface, but in leaner fish, 60% of phenolics can penetrate deeper than the surface layer (Stolyhwo and Sikorski, 2005). Moreover, the salmon tail contains a lower lipid level and higher moisture level than the neck (Robb et al., 2002) resulting in a hydrophilic environment, so the salt can diffuse readily through the flesh. The higher lipid level in the neck and belly produces a hydrophobic environment, slowing the rate of salt diffusion through the fillet and resulting in a lower salt concentration below the surface layer. In the neck, the surface evaporation rate is faster than the rate of water diffusion to the surface due to the hydrophobic conditions, causing the surface to dry out rapidly, trapping the moisture in the flesh and producing a softer pellicle. These textural changes also influence the rate of absorption and penetration of the volatiles. During the hot-smoking of meat, a similar “bark” is formed, which is also full of glycation-derived flavours.

Health Aspects

As we know from the tobacco industry, smoke also contains known carcinogens. A range of polyaromatic hydrocarbons (PAH) are formed during the smoking process, of which benzo[a]pyrene is classified as a Group 1 carcinogen by the International Agency for Research on Cancer (IARC). In Iceland, where traditionally meat is smoked by the indigenous population for months at a time, high levels of PAHs and a high incidence of stomach cancer were observed (Bailey and Dungal, 1958). Similar associations were observed in smoke-dried meat in Nigeria (Alonge, 1988). However, such extreme smoking conditions are exceptions, and almost all smoked foods conform to regulatory requirements. The EU regulatory limit for benzo[a]pyrene in smoked fish products is 2 ppb. Most smoked salmon samples come 100 times lower

FIGURE 77.3 Changes in smoked salmon during curing and smoking.
than that, but hot-smoked salmon can occasionally reach levels up to 200 ppb. However, concerns about the occurrence of PAHs in smoke flavourings (liquid condensates) led the EU to initiate an evaluation of smoke flavourings, and as a result, several were removed from the market. In 2015, Parker et al. (2018) developed a zeolite-based filter that could remove up to 95% of PAHs from a smoke stream, which allowed the preparation of smoked ingredients with greatly reduced levels of PAHs. Aiming to show no adverse effect on the aroma, they discovered that the flavour was more rounded and balanced when the new filter was applied (Chua et al., 2019).

Applications of Smoke

From its origin as an ancient method of “shelf-life” extension, smoke has featured for many centuries in traditional artisanal products, whether they be traditionally smoked meats, fish or cheese. Many are specific to the country or region, with smoked sausages being specialties of Germany, Poland and Lithuania, smoked paprika from Hungary, the chipotle (a traditional smoked chili pepper) from Mexico, and kippers (herring) and Arbroath smokies (haddock) being famous in Scotland. Extending into beverages, whisky and lapsang souchong tea are classic smoky products. Over the last few decades, there has been a marked growth in the consumption of smoked foods. We have experienced an increase in the use and sophistication of the enthusiast’s home-smoking apparatus, but more notably, the food industry is using smoked ingredients to enhance flavour and fulfil the increased customer demand for smoky BBQ flavour snacks, marinades and condiments. Common smoked ingredients are smoked salt, smoked pepper, smoked water for brining and smoked oils. What is exciting today is the innovation from chefs and culinary experts worldwide as they seek to expand the use of smoke into novel ingredients, recipes and restaurant theatre, where a dish can be presented under a cloche, which provides a waft of the heady and fragrant smoky aroma when it is lifted. Smoke is making its way into the sweet categories, with chefs exploring its use in ice cream, syrups, chocolate, ales and ginger beer, and its creative use in cocktails has even brought us the smoked Martini, with its own trail of smoke. This versatile ingredient presents a world of opportunity.

REFERENCES