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Mini Review

*Corresponding author
Shane T. McDonald, PhD
Principal Flavor Chemist
Kalsec® Inc
3713 West Main Street
Kalamazoo, MI 49006, USA
E-mail: SMcDonald@kalsec.com

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Comparison of Health Risks of Smoked Foods as Compared to Smoke Flavorings: Are Smoke Flavors "Healthier"?

Shane T. McDonald*

Principal Flavor Chemist, Kalsec® Inc., Kalamazoo, MI 49006, USA

KEYWORDS: Smoke flavorings; Smoked foods; Cancer; Toxic.

ABBREVIATIONS: PAH: Polycyclic Aromatic Hydrocarbons; IOFI: International Organization of the Flavor Industry; B*a*P: Benzo[*a*]pyrene ; EFSA: European Food Safety Association; WHO: World Health Organization.

INTRODUCTION

Smoking is cooking food (usually meat) indirectly over a fire or smoke-generating system. This is in contrast to grilling, where the meat is cooked directly over the heat source.[1] It is believed that smoking foods first occurred thousands of years ago, when it was discovered that meat hung up to dry in smoked-filled caves remained edible longer plus developed a pleasant flavor. Originally carried out to preserve meat and fish, in modern times smoking is typically used to impart its characteristic flavor.[2] Smoking also imparts anti-oxidative and anti-microbial compounds into food, as well as carbonyl compounds that cause the traditional color and texture of smoked foods. However, smoke also deposits harmful chemicals, such as Polycyclic Aromatic Hydrocarbons (PAH), some of which are considered carcinogenic.[3] These compounds are the subject of the health concerns discussed in this article.

Smoking foods was originally carried out in kiln with little control over the smoking process. More modern smoke generators burn hardwoods under controlled conditions of temperature and forced air recirculation. However, it is difficult to control, messy, and may leave tar deposits in the food.[2] The two basic methods of traditional smoking are: cold smoking (temperatures less than 33 ˚C) and hot smoking, employing temperatures from 70 to 80 ˚C. Smoke can also be made using thermostated plates and friction smoking. The alternative is to use smoke flavorings.[4]

SMOKE FLAVORINGS

The International Organization of the Flavor Industry (IOFI) defines smoke flavorings as complex mixtures of components of smoke obtained by heating untreated wood to pyrolysis by a limited and controlled amount of air, dry distillation or superheated steam, then collecting the wood smoke in an aqueous collection system. Alternatively, the smoke can be distilled, condensed, and separated to collect the aqueous phase. The principle components of smoke flavorings are carbonyl compounds, organic acids (especially acetic), and phenolic compounds.[5]

Figure 1 depicts a simplified flow process for condensed smoke flavor manufacture. Hardwood sawdust is dried to specific moisture content, and then transferred to a smoke generator. There the sawdust is ignited and allowed to smolder to create a plume of smoke. The plume passes through a primary tank where the upward flow of smoke meets a countercurrent spray of water, which condenses the smoke. The water/condensate recirculates through the chamber until a specified acidity (typically 10% as acetic acid) is attained. The condensed smoke passes through a settling chamber where tar and ash, hydrophobic constituents of smoke, fall out of suspension and settle to the bottom to be removed. The aqueous layer is decanted and

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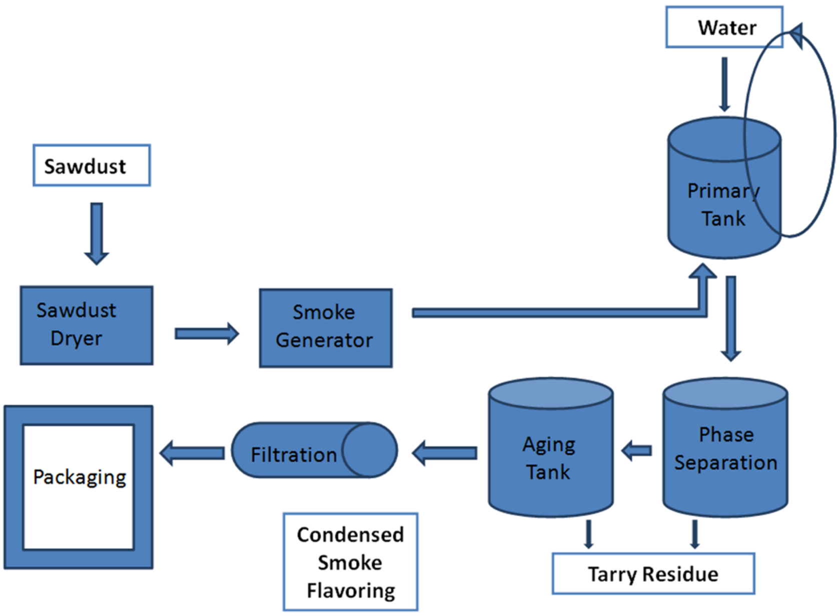

Figure 1: Schematic on condensed smoke flavor manufacture.

sent to aging tanks for further settling of tar. The aqueous layer is again decanted, filtered and packaged.[2] Because many of the more toxic compounds in wood smoke are hydrophobic, smoke flavoring should have less of these compounds due to the settling and filtering, which does not happen in traditional wood smoking.

TOXIC CHEMICALS IN SMOKE

The European Food Safety Association (EFSA) has been actively evaluating the safety of smoke flavorings, finding some are genotoxic to animals.[6] Interestingly, while the safety of the flavorings is being scrutinized, it appears that the smoking of foods directly from wood smoke is not regulated at all in Europe.[7] PAH are considered to be a contaminant by the European Commission and the maximum allowable level of Benzo[*a*]pyrene (B*a*P) is 2 *ug*/kg wet weight for smoked meats, poultry, and seafood.[8] Also, a recent announcement from the World Health Organization (WHO) pointed to the increased of cancer, especially colorectal cancer, from the consumption of processed meats. Processes that were mentioned included fermenting, curing, and salting as well as smoking.[9]

Wood smoke contains over 300 compounds, mostly phenols, carbonyls, acids, furans, alcohols, esters, lactones; as well as PAH. The proportion of these constituents depends on the type of wood employed, wood moisture, wood particle size, and the process of smoke manufacture.[10,11] The PAH are noted for their mutagenic and carcinogenic qualities, while the phenols are responsible for most of the flavor and preservative properties. The phenols do not appear to be a major safety concern, and there is very little evidence of mutagenicity of the phenol found in smoke, such as syringol, eugenol, phenol, cresols, vanillin and guiaicol based on the Ames assay.[11] Furthermore, there is little correlation between phenolic content and PAH content. Therefore, it is possible to have desirable smoke flavor (derived in part from phenolic compounds) and low PAH content.[12] So, preferred manufacture processes are those that reduce or eliminate PAH while favoring the phenolic compounds.

PAH are produced from the incomplete combustion or thermal decomposition (pyrolysis) of organic material. The quantity and composition of PAH in smoke are closely related to the reaction conditions, temperature, and amount of air, so they will vary widely. The marker compound of PAH is often B*a*P. Other PAH found in smoke, smoke flavors, and smoked foods include benzo[*a*]anthracene, benzo[*b*]flouranthene, dibenzo[*a,h*]anthracene and indeno[1,2,3-*c,d*]pyrene.[13] PAH containing four fused rings are considered weakly carcinogenic (e.g. benz[*a*]anthrecene and chrysene). PAH with five or more rings such as dibenz[*a,h*] anthrecene, B*a*P, indeno[1,2,3-*cd*]pyrene, benzo[*b&k*]flourathene and benzo[*ghi*]perylene are regarded as potentially genotoxic and carcinogenic.[13,14] Although B*a*P has been used as a marker for carcinogenic PAH, the European Commission has decided that a more valid marker would be the total of four to eight specific PAH.[8,15]

PAH IN FOODS

Smoked food products contain PAH. Gomaa et al[13] demonstrated that while PAH were found in poultry products made by smoking and by addition of smoke flavorings, the products made by traditional smoking had higher PAH concentrations. For instance, turkey breast product made by smoking had 1.9 *ug*/kg carcinogenic PAH while the same type of product with liquid smoke had no detectable carcinogenic PAH. Likewise, turkey sausage made by smoking had 1.6 and 1.1 *ug*/kg carcinogenic PAH, compared to the smoke flavored product with 0.2 *ug*/

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kg. Turkey bacon made by smoking had 1.6 *ug*/kg *vs.* 0.4 *ug*/kg carcinogenic PAH for the smoke flavored product (see Table 1).

Chen and Lin[16] studied various methods of cooking employed to cook duck meat and the formation of PAH. The cooking methods studies were steaming, roasting, smoking, liquid smoke flavoring, and charcoal grilling. For each cooking treatment, duck meat was cooked for three or four different lengths of time, except for liquid smoke flavors, which was treated for 24 hours only. Sixteen PAH were monitored, with five being identified as carcinogenic. The highest concentrations of PAH were found in duck steaks with skin cooked by charcoal grilling, followed by charcoal grilling without skin, smoking, roasting, steaming, and smoke flavorings. Carcinogenic PAH were highest in smoked duck steaks, followed by charcoal grilling and roasting. No carcinogenic PAH were found in steamed or duck steaks flavored by liquid smoke flavorings. Increased cooking times for all cooking techniques increased PAH concentration and carcinogenic PAH (other than steaming).

Hattula et al[17] compared cold-smoking of trout fillets using traditional flue smoking to the use of two different liquid smoke flavorings. Thirty-one PAH were analyzed, with seven deemed to be carcinogenic. Total concentrations of PAH were less for liquid smoked products compared to traditionally smoked products. This study was concerned with the release of PAH into the environment due to escaping flue gasses and wash water from cleaning the flues. There was much less PAH release due to liquid smoke flavoring than traditional smoking.

One reason for the reduced levels of PAH in foods with smoke flavorings is the removal of the most toxic compounds by settling. As mentioned, after the smoke is condensed into water, the mixture is stored in tanks to allow a resinous, tar-like substance to settle out. The liquid top layer is decanted and filtered for use. White et al[18] analyzed seven commercial liquid smoke flavorings. Four of the flavorings had no detectable PAH, while the other three had total PAH concentrations ranging from total from 53 ppb to 59 ppb. Four procured resins which had settled out during storage had concentrations of B*a*P ranging from 25 to 3500 ppb. A later study by Guillen et al[19] compares five commercial European liquid smoke flavorings. PAH levels were ob-

Authors	Year	Meat Type	Total PAH (*ug*/kg)	Carcinogenic PAH (*ug*/kg)	BaP (*ug*/kg)	Smoke Type
Gomaa et al[13]	1993	Turkey breast	5.9	1.9	0.1	Wood smoked
		"	2.8	nd	nd	Liquid smoke flavoring
		Turkey sausage	8.4-9.6	1.1-1.6	nd-0.1	Wood smoked
		"	3.8	0.2	nd	Liquid smoke flavoring
		Turkey bacon	9.3	1.6	0.4	Wood smoked
		"	3.2	0.4	nd	Liquid smoke flavoring
		Pork bacon	9.2	0.7	0.5	Wood smoked
		"	4.5	0.2	0.2	Liquid smoke flavoring
		Beef sausage	14.4	4.2	1.1	Wood smoked
		"	5.6	0.6	0.2	Liquid smoke flavoring
Chen & Lin[16]	1997	Duck breast	154-527	18-52		Wood smoked
		"	0.3	nd		Liquid smoke flavoring
Hattula[17]	2001	Trout	650-1200	7.1-25.8	0-3.4	Wood smoked
		"	200-480	1.4 -12.7	nd	Liquid smoke flavoring
Varlet et al[4]	2007	Salmon fillets			0.072-0.092	Wood smoke - "smoldering"
		"			nq-0.070	Wood smoke - "thermostated plates"
		"			0.071- 0.111	Wood smoke - "friction"
		"			0.047- 0.085	Liquid smoke flavoring

nd: not detected.
nq: not quantifiable.

Table 1: Reported values for Total PAH, Carcinogenic PAH, and B*a*P for meats treated with wood smoke and liquid smoke flavorings.

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served from as high as nearly 3200 ppb to as low as 50 ppb. Total carcinogenic PAH had much lower levels, from a high of over 17 ppb to less than 1 ppb total carcinogenic PAH. B*a*P levels varied with total and carcinogenic PAH. The three smoke flavors with elevated total PAH and carcinogenic PAH had over 10 ppb B*a*P while the other two had no detectable PaH.

Techniques can be employed to make wood smoking and smoke condensate flavors safer. A study in Europe[20] described a district in Hungary that ate home-smoked meats employing softwoods for smoke. Stomach cancer for that population was twice that of Hungary as a whole. B*a*P level on the home-smoked foods in this district was 4.16 *ug*/kg. In contrast, Hungary as a whole and Germany had B*a*P levels in both home-smoked and industrially smoked meats of less than 1 *ug*/kg. Roda et al[21] assayed the B*a*P content of smoke made by a simulated home smoking system and three industrial-type systems. They found that the home-smoking style has B*a*P contents over 12 *ug*/kg while other methods of smoking were less than 1 *ug*/kg, the level which the cancer risk was considered to be "tolerable". The lowest level was by an indirect method in which the smoke was generated at relatively low temperature of 300 to 400 ˚C. The production of B*a*P increases as the temperature of smoke formation increases from 400 to 1000 ˚C.

A study by Varlet et al[4] looked at smoking salmon by three industrial smoking systems plus the use of liquid smoke. There were other toxic PAH detected, but only B*a*P have maximum residue limits established. The levels of B*a*P in all four methods were quite low (less than 0.1 *ug*/kg), but the use of liquid smoke flavor tended to have the lowest levels. The maximum residue limit of B*a*P in foods smoked by wood pyrolysis is 5 *ug*/kg, according to the levels fixed by the European Commission for smoked seafood. However, liquid smoke is regulated as a flavor, and according to Council Directive 88/388/EEC, the maximum levels of B*a*P in smoke flavorings is 0.03 *ug*/kg. It is then possible to exceed allowable limits using smoke flavorings. In this study, organoleptic differences were observed from fish smoked using liquid smoke flavoring as compared to the other techniques where the fish was smoked by wood pyrolysis. A study by Birkeland and Skara[22] compared salmon filets smoked by a liquid flavoring as compared to one cold-smoked with wood chips. No detectable B*a*P was found in any of the smoked fish samples.

EFSA[15] studied the effect of smoking distribution on B*a*P concentration. Direct smoking tended to have higher B*a*P levels than indirect or liquid smoke. Filtering the smoke reduced the B*a*P levels considerably. Filtering direct or indirect smoke resulted in levels of B*a*P similar to liquid smoke.

Table 1 summarizes studies that compare various cuts of meat treated using wood smoke as compared to the same types of meat treated using liquid smoke flavorings. Generally, total PAH, B*a*P, and carcinogenic PAH contents are lower for meats treated with liquid smoke flavorings as compared to wood smoke. However, industrial smoking techniques can reduce the content of these compounds to levels similar to the liquid smoke flavorings. Note that the newest study had the lowest PAH contents, as industrial knowledge and awareness increase.

SUMMARY AND CONCLUSIONS

Smoking foods, whether by conventional wood smoke or by smoke condensate flavors, can add to the risk of cancer when the foods are consumed. Generally, foods with smoke flavorings will have less PAH then foods conventionally smoked due to the purification process during condensate manufacture. The toxic compounds are not soluble in the aqueous condensate and precipitate and largely removed by decantation and filtration. However, awareness of the toxicity of PAH has led to techniques to reduce their content in industrially smoked foods as well as smoke condensate flavored foods. In any case, WHO recommendations are for moderate consumption of such foods to reduce the risk of cancer.[23]

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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