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Rice Product Volatiles: A Review

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The flavor composition of rice and its products has been extensively investigated during the last two decades. This review summarizes the compounds that have been identified in the volatiles of wild rice, scented rice, raw rice, cooked rice, rice bran, Soong-Neung, and rice cake.

In many parts of the world rice is the major component of the diet. To most Americans rice is a rather bland-tasting food, but in many cultures minor chemical changes can make rice and its products unacceptable for human consumption. As a result, flavor chemists for the last two decades have been attempting to better understand rice flavor chemistry. A brief summary of this work was published earlier (Maga, 1978a), but significant advances have been made since then, and since most of the research in this area has appeared in foreign journals that may not be readily available to the American researcher, this current review was compiled. Specific topics covered in this review include the volatiles identified in wild rice, scented rice, raw rice, cooked rice, rice bran, Soong-Neung, and rice cake.

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Wild Rice. North American wild rice (*Zizania aquatica*) is unique in that the grain is harvested in a moist state and permitted to undergo a biochemical and micro-

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Table I. Volatiles Associated with Wild Rice (*Zizania aquatica*)[a]

benzyl alcohol	2-ethyl-3,6-dimethylpyrazine
1-propanol	2-ethyl-5,6-dimethylpyrazine
benzaldehyde	2-(2-furyl)pyrazine
cinnamaldehyde	2-(2-furyl)-5(6)-methylpyrazine (T)
2-pentenal (T)[b]	6,7-dihydro-5*H*-cyclopentapyrazine (T)
2-methyl-5-*n*-propylfuran (T)	2-methyl-6,7-dihydro-5*H*-cyclopentapyrazine
2-acetylfuran	5-methyl-6,7-dihydro-5*H*-cyclopentapyrazine (T)
5-methyl-2-acetylfuran	methyl-6,7-dihydro-5*H*-cyclopentapyrazine (isomer) (T)
2-propionylfuran (T)	2-ethyl-6,7-dihydro-5*H*-cyclopentapyrazine
2-furfural	2,5-dimethyl-6,7-dihydro-5*H*-cyclopentapyrazine
5-methylfurfural	3,5-dimethyl-6,7-dihydro-5*H*-cyclopentapyrazine
furfuryl alcohol	pyridine
methyl 2-furoate	2-methylpyridine
2,5-dimethyl-3(2*H*)-furanone	methylpyridine (isomer) (T)
benzofuran (T)	4-ethylpyridine (T)
dibenzofuran (T)	ethylpyridine (isomer) (T)
2-cyclopentenone	2,3-dimethylpyridine
cyclohexanone (T)	dimethylpyridine (isomer) (T)
2-cyclohexanone (T)	2,3,6-trimethylpyridine (T)
3-methyl-2-cyclohexen-1-one	2,4,6-trimethylpyridine
acetophenone	dimethylethylpyridine (3 isomers) (T)
methylacetophenone (T)	4-formylpyridine (T)
1-phenyl-2-propanone	4-methyl-2-pyridine (T)
indan-1-one	1-ethyl-2-pyridine (T)
1,2,3,4-tetrahydronaphthalen-1-one (T)	quinoline (T)
γ-butyrolactone	pyrrole
γ-valerolactone	1-acetylpyrrole
2-pyrone (T)	pyrrole-2-carboxaldehyde
phenol	5-methylpyrrole-2-carboxaldehyde (T)
o-cresol	methylindole (T)
m-cresol	oxindole (T)
p-cresol	acenaphthene (T)
dimethylphenol (2 isomers) (T)	benzimidazole (T)
3-ethylphenol	benzonitrile (T)
3-ethyl-4-methylphenol (T)	benzothiazole
3-ethyl-5-methylphenol (T)	benzyl cyanide
vinylphenol (T)	biphenyl
o-methoxyphenol	biphenylmethane (T)
4-ethyl-2-methoxyphenol	chloroform
2,6-di-*tert*-butyl-*p*-cresol	dibutyl phthalate (T)
o,o'-biphenol (T)	diethyl phthalate
pyrazine	dimethyl phthalate (T)
acetylpyrazine	1,2-dimethoxy-4-methylbenzene
methylpyrazine	ethylcyclopentene (T)
ethylpyrazine	ethylnaphthalene
vinylpyrazine	1-methylnaphthalene
2,3-dimethylpyrazine	2-methylnaphthalene
2,5-dimethylpyrazine	methylpyrazole (T)
2,6-dimethylpyrazine	phenyl isocyanate (T)
trimethylpyrazine	3-*n*-propyl-1-cyclopentene (T)
2-ethyl-3-methylpyrazine	styrene
2-ethyl-5-methylpyrazine	*p*-toluidine (T)
2-ethyl-6-methylpyrazine	tolunitrile (2 isomers)
tetramethylpyrazine	

[a] Withycome et al. (1978). [b] T = tentative identification.

biological fermentation, resulting in a darkly pigmented product with unique flavor properties that have been described as "tea-like", "grainy", "earthy", or "toasted" (Withycombe et al., 1978).

One major study appears in the literature that identifies the volatiles associated with such a product (Withycombe et al., 1978). Their data are summarized in Table I. Whole kernel Manomin strain wild rice was fermented for 5 weeks and then parched at 60–71 °C until the moisture content was reduced to approximately 7%. Through the use of a gas chromatographic stream splitter, odor descriptions were reported. In general, odor descriptions were characteristic of compounds that were formed during the thermal processing of the rice. Specific examples include "smoky" associated with phenols, "toasted" and "roasted" with certain pyrazines, and "tea-like" and "green" from pyridines.

Earlier, Frank et al. (1976) had reported on the roles of specific microflora and fermentation temperature on the resulting sensory properties of wild rice. A portion of their data are summarized in Table II, and as can be seen, fermentation conditions can significantly influence the flavor properties of wild rice. A similar but expanded study on wild rice fermentation parameters influencing flavor was reported by Melinger et al. (1982).

Scented Rice. Scented rice is rice from certain varieties that have stronger aromas than traditional rice. Some researchers also refer to scented rice as "aromatic", "popcorn" or "pecan" rice. The major far-eastern variety is Basmati while the major American variety is Della. In certain parts of the world, these scented varieties are highly desirable. As a result, both plant breeders (Tripathi and Rao, 1979) and numerous flavor chemists have been interested in better understanding the composition of this rice.

Typical of these is a series of papers authored by Tsuzuki (Tsuzuki et al., 1975a,b, 1977, 1978, 1979, 1981; Tsuzuki and Tanaka, 1981), who have reported only minor

Table II. Influence of Bacterial Type, Fermentation Time, and Temperature on the Flavor of Wild Rice[a]

bacterial strain	fermentation time, °C	fermentation time, days	flavor description
no inoculum	4	14	tea-like, grainy
no inoculum	21	7	strong putrid
Flavobacterium solare 255	4	7	astringent, grassy, tea-like
Flavobacterium solare 255	4	14	astringent, toasted, strong
Flavobacterium solare 266	4	7	grassy, grainy
Flavobacterium solare 266	4	14	black tea, earthy
Achromobacter sp. 307	4	7	bland, grassy
Achromobacter sp. 307	4	14	tea-like, earthy
Achromobacter sp. 308	4	7	grassy, tea-like
Achromobacter sp. 308	4	14	strong earthy
Achromobacter sp. 134	4	7	tea-like, earthy
Achromobacter sp. 314	4	14	strong black tea
Pseudomonas ambigua 2	21	4	strong tea-like, slightly earthy
Pseudomonas ambigua 2	21	7	strong earthy, strong tea-like
Pseudomonas reptilivora 10	21	4	tea-like, earthy
Pseudomonoas reptilivora 10	21	7	putrid, earthy
Pseudomonas aeruginosa 28	21	4	slightly purtrid
Pseudomonas aeruginosa 28	21	7	earthy, putrid
Pseudomonas putida 120	21	4	grassy, tea-like, slightly earthy
Pseudomonas putida 120	21	7	putrid, earthy
Micrococcus sp. 30	21	4	earthy, tea-like, slightly putrid
Micrococcus sp. 30	21	7	strong earthy, slightly putrid
Micrococcus sp. 113	21	4	earthy, tea-like
Micrococcus sp. 113	21	7	putrid, earthy

[a] Frank et al. (1976).

and usually insignificant differences in the volatile compositions of regular and scented rice. The most extensive investigation of scented rice aroma was reported by Yajima et al. (1979) in which 114 compounds were identified. When the volatiles from traditional rice were compared to scented rice, traditional rice had higher amounts of 4-vinylphenol, 1-hexanol, and 1-hexanal but lower amounts of indole than scented rice. In addition, scented rice had an unidentified compound not present in regular rice and α-pyrrolidone, which was also not found in regular rice.

Recently, Buttery et al. (1982, 1983b) reported that the compound 2-acetyl-1-pyrroline is a major factor contributing to the aroma of scented rice. Buttery et al. (1983a) also reported that leaves of the *Pandanus* species were found to contain approximately 1 ppm of 2-acetyl-1-pyrroline. This then justifies the practice of cooking rice with pandan leaves whereby a scented rice aroma is imparted to the product. These leaves contain approximately 100 times more of this compound than is present in common rice varieties.

Buttery et al. (1983b) found that scented rice varieties contained 0.04–0.09 ppm of 2-acetyl-1-pyrroline whereas

Table III. Volatiles Associated with Scented Rice

methanal[a]	2,4-nonadienal[c]
ethylene[a]	naphthalene[c]
ethanal[a,b]	carvone[c]
ethyl acetate[c]	*n*-heptadecane[c]
ethanol[c]	citral[c]
hydrogen sulfide[d]	benzyl acetate[c]
dimethyl sulfide[d]	*trans*-2-*cis*-4-decadienal[c]
dimethyl disulfide[d]	nicotine[c]
methyl mercaptan[d]	*n*-octadecane[c]
n-butyl mercaptan[d]	*trans*-2-*trans*-4-decadienal[c]
propanal[a,b,e,f]	2-tridecanone[c]
2-propanone[a,b]	geranyl acetone[c]
1-butanal[a]	β-phenylethyl alcohol[c]
2-butanone[a]	quinoline[c]
1-pentanal[a,c,e,f]	*n*-nonadecane[c]
1-hexanal[a,b,c,e,f]	benzothiazole[c]
n-nonane[c]	1-dodecanol[c]
n-decane[c]	γ-nonalactone[c]
n-butyl acetate[c]	phenol[c]
1-butanol[c]	2-pentadecanone[c]
2-heptanone[c]	*n*-eicosane[c]
xylene[c]	α-pyrrolidone[c]
1-heptanal[c]	γ-decalactone[c]
d-limonene[c]	*n*-heneicosane[c]
pyridine[c]	6,10,14-trimethyl-pentadecan-2-one[c]
2-methylpyridine[c]	γ-undecalactone[c]
n-dodecane[c]	*n*-docosane[c]
ethyl caproate[c]	methyl palmitate[c]
2-pentylfuran[c]	ethyl palmitate[c]
n-pentanal[c]	farnesol[c]
4-methylpyridine[c]	tricosane[c]
cyclohexanone[c]	α-hexylcinnamic aldehyde[c]
1-octanal[c]	diethyl phthalate[c]
3-methylpyridine[c]	4-vinylphenol[c]
trans-2-heptenal[c]	farnesyl acetone[c]
methylheptenone[c]	*n*-tetracosane[c]
1-hexanol[c]	indole[c]
1-nonanal[c]	methyl stearate[c]
trans-2-hexenol[c]	methyl oleate[c]
n-tetradecane[c]	ethyl oleate[c]
trans-2-octenal[c]	*n*-pentacosane[c]
benzyl alcohol[c]	methyl linoleate[c]
trans-linalool oxide[c]	ethyl linoleate[c]
1-octen-3-ol[c]	dibutyl phthalate[c]
2-heptanol[c]	myristic acid[c]
cis-linalool oxide[c]	palmitic acid[c]
menthone[c]	caproic acid[c]
2,4-heptadienal[c]	2-ethylcaproic acid[c]
3-vinylpyridine[c]	heptanoic acid[c]
2-ethylhexanol[c]	capryric acid[c]
1-decanal[c]	nonanoic acid[c]
n-pentadecane[c]	furoic acid[c]
benzaldehyde[c]	succinic acid[c]
trans-2-nonenal[c]	capric acid[c]
linalool[c]	lauric acid[c]
1-octanol[c]	tridecanoic acid[c]
2-undecanone[c]	pentadecanoic acid[c]
n-hexadecane[c]	stearic acid[c]
n-undecanal[c]	oleic acid[c]
methyl benzoate[c]	linoleic acid[c]
phenylacetaldehyde[c]	nonadecanoic acid[c]
trans-2-decenal[c]	eicosanoic acid[c]
menthol[c]	2-acetyl-1-pyrroline[g,h]
α-terpineol[c]	

[a] Tsuzuki et al. (1975b). [b] Tsuzuki et al. (1977). [c] Yajima et al. (1979). [d] Tsuzuki et al. (1978). [e] Tsuzuki et al. (1981). [f] Tsuzuki and Tanaka (1981). [g] Buttery et al. (1982). [h] Buttery et al. (1983b).

common rice varieties had approximately 10 times less (<0.006 to <0.008 ppm). Also, their data would indicate that the compound is probably thermally produced since it was only detected in cooked rice and not in raw rice. Buttery et al. (1983b) reported that the odor threshold for 2-acetyl-1-pyrroline is 0.1 ppb, and it has been described

Table IV. Volatiles Associated with Unprocessed (Raw) Rice[a]

acetaldehyde	*o*-xylene	2-nonanone
acetone	2-acetylfuran	nonanal
ethanol	α-pinene	2,4-octadienal
2-methylpropanal	2-heptenal	1,2-dimethyl-3-ethylbenzene
1-propanol	*n*-propylbenzene	1,2,4,5-tetramethylbenzene
2-butanone	1-ethyl-4-methylbenzene	1,2,3,5-tetramethylbenzene
butanal	benzaldehyde	2-nonenal
3-methylbutanol	1,3,5-trimethylbenzene	1,2,3,4-tetramethylbenzene
2-methylbutanal	6-methyl-5-hepten-2-one	2-decanone
benzene	2-octanone	naphthalene
3-penten-2-one	2-*n*-pentylfuran	decanal
2-pentanone	octanal	2,4-nonadienal
pentanal	1,2,4-trimethylbenzene	2-decenal
2,5-dimethylfuran	2,4-heptadienal	2-undecanone
2-methylpentanal	Δ^3-carene	2-methylnaphthalene
toluene	1,2,3-trimethylbenzene	2,4-decadienal
2-hexanone	*p*-cymene	1-methylnaphthalene
hexanal	*trans*-β-methylstyrene	phenylacetaldehyde
2-hexenal	*p*-diethylbenzene	2-dodecanone
ethylbenzene	2-octenal	2-ethylnaphthalene
p-xylene	*m*-diethylbenzene	2-dodecenal
m-xylene	1,3-dimethyl-5-ethylbenzene	18 unidentified ketones
2-heptanone	*o*-diethylbenzene	8 unidentified alkylbenzenes
heptanal	*p*-methylbenzaldehyde	3 unidentified aldehydes
2-butylfuran	1,3-dimethyl-4-ethylbenzene	2 unidentified furans
2,4-hexadienal	1,4-dimethyl-2-ethylbenzene	

[a] Bullard and Holguin (1977).

as possessing a popcorn odor. Thus, it would appear that the major compound responsible for the difference in smell between common and scented cooked rice varieties is 2-acetyl-1-pyrroline.

For reader information, the volatiles identified to date in scented rice are summarized in Table III.

Raw Rice. Surprisingly little research has been devoted to the volatiles associated with raw rice. Only one extensive study has appeared in this area (Bullard and Holguin, 1977). As seen in Table IV, over 70 compounds were identified and the presence of another 30 compounds indicated. However, although the authors claimed the rice to be "unprocessed", it is apparent from their methodology that this was not actually the case. Unpolished California Brown Pearl rice was ground to 40-mesh size and exposed to 50 °C for 4 h; thus, one would question the potential role of enzymatic activity in the formation of flavor compounds due to the grinding process and resulting temperature of incubation. However, the authors did report that the volatiles associated with a 7-h collection time at ambient temperature were not significantly different than those observed when isolation conditions were 50 °C for 4 h. It is also interesting to note that their primary objective was to identify rice volatiles that could have application as bait attractants for rodents. They also reported that no individual compound identified had the characteristic aroma of uncooked rice.

Cooked Rice. It is a well accepted fact that when rice is stored at elevated temperature and then cooked, a stale flavor is apparent. This has been attributed to free fatty acid formation (Yasumatsu et al., 1964; Yasumatsu and Moritaka, 1964; Hwangbo and Lee, 1976) and lipid oxidation resulting in the formation of carbonyl compounds (Yasumatsu et al., 1966b; Chikubu, 1970).

As a result, attempts have been made to eliminate or minimize this objectionable off-flavor from developing. For example, Yamamoto and Kogure (1969) added various amino acids to boiling rice and reported that L-lysine hydrochloride was effective in eliminating the typical stale odor. They postulated that the carbonyls responsible for stale odor reacted with the ε-amino group in lysine, thus inactivating them. On the basis of model system studies, Furuhashi and Ayano (1971a) reported that L-cysteine and L-histidine hydrochloride were also effective in controlling stored rice odor. In working with stored rice, Furuhashi and Ayano (1971b) reported that it was necessary to add 80–160 mg % of L-lysine hydrochloride to eliminate stale flavor. In this study, they also reported that the carbonyls pentanal and hexanal were primarily responsible for stale rice flavor. Through gas chromatography, Aisaka (1977) reported that fresh rice that was cooked had 3–5 times the amount of volatiles as stale cooked rice. Among these volatiles, the lower boiling fraction represented 80–90% of total aroma compounds while in the stored rice this fraction only accounted for 45% of the total. In contrast, C3–C6 carbonyls in the stored rice accounted for 30% of total aroma compounds, which was 10 times more than in fresh rice. In addition, Aisaka (1977) fractionated cooked rice aroma compounds into acidic, neutral, and basic fractions and reported that the basic fraction displayed characteristic cooked rice aroma. Earlier, Obata and Tanaka (1965) reported that the photolysis of L-cysteine and L-cystine resulted in a product that possessed the aroma of cooked rice. Volatiles identified in the mixture included hydrogen sulfide, ammonia, and ethanal.

Recently, Tsugita et al. (1983) compared the cooked flavor of rice stored at 4 °C to that stored at 40 °C for 60 days, with the latter temperature resulting in stale rice. A series of free phenolic acids were identified and quantitated in both rice products. At 4 °C a total of 334 μg of free phenolic acid/100 g of rice was measured while at 40 °C a total of 896 μg was found, representing a 2.7-fold increase. However, the potential role of phenolic acids on rice flavor was not discussed. In addition, the relative amounts of 27 different volatiles were compared. The major compound found at both temperatures was hexanal, which increased with temperature. The next most plentiful compound was 1-hexanol, which decreased with temperature. Total volatile compound concentration increased 1.6-fold with an increase in temperature.

Tsugita et al. (1980) evaluated the influence of rice milling degree on resulting cooked rice aroma. Whole rice was milled to yield 92, 85, 75, and 50% rice. The resulting products were cooked and the volatiles analyzed. A total of 40 compounds were identified. Total volatile content was highest in the 92% milled rice and decreased with increased milling. Thus, they concluded that the outer surface layers of rice play an important role in the formation of cooked rice odor.

An extensive study on cooked rice volatiles was reported by Yajima et al. (1978). The isolated volatile fraction represented 4.8 ppm by weight of the cooked rice utilized. Approximately 65% of this was found in the acidic fraction, 33% in the neutral fraction, and less than 1% in the basic fraction. In all, 100 compounds were identified, over 90 of which had not previously been identified in cooked rice.

In another extensive study by Kato et al. (1983), the influence of parboiling two rice varieties (Nakateshinsembon and Bluebonnet) on their cooking qualities, texture, protein, lipid, free phenolic acid levels, and volatile composition was evaluated. Parboiling significantly increased free phenolic acid levels from approximately 300–400 to 900–1200 μg/100 g of rice in the two varieties. This in turn was concluded to influence texture. At these levels perhaps flavor could also be influenced (Maga, 1978b). The headspace analyses of either cooked or boiled rice of both varieties that was either unparboiled or parboiled resulted in the indentification of 29 volatiles. Parboiling resulted in higher levels of pentanal, hexanal, *trans*-2-alkenals, *trans*-2, *trans*-4-decadienal, and 2-pentylfuran with resulting lower levels of 1-pentanol, 1-hexanol, and 1-heptanol. The higher alkanal levels probably resulted from enzymatic activity on rice lipids during the soaking process associated with parboiling. Headspace chromatographic patterns were essentially the same for both varieties, although their overall sensory properties were judged to be different. Thus, the generated gas chromatographic data did not appear to be sensitive or complete enough to demonstrate volatile differences between the two varieties.

A list of volatiles that have been identified to date in cooked rice is shown in Table V. As is the case with many foods, no specific compound nor family of compounds to date has been identified that can be directly related to cooked rice aroma.

Rice Bran. Fujimaki et al. (1977) have reported that although large quantities of rice bran are available throughout the world, little if any is actually consumed by humans, due to its characteristic odor. As a result, several groups have investigated the volatile composition of rice bran. Their results are summarized in Table VI.

Mitsuda et al. (1968) flushed rice bran for 4 h with nitrogen gas, and via a series of traps, they were able to separate and identify a series of nine common alcohols and eight carbonyls, none of which could be directly correlated as being typical of rice bran aroma.

Undoubtedly, the most detailed study of rice bran volatiles was reported as two separate publications (Fujimaki et al., 1977; Tsugita et al., 1978). Over 270 compounds were detected, of which approximately 170 were identified. The major components identified were 4-vinylguaiacol and 4-vinylphenol, both of which were described as possessing a characteristic unpleasant odor. The only reservation about their reports is the fact that the volatiles were collected by exposing rice bran in water to a 2-h atmospheric steam distillation, which probably generated a major portion of the thermally produced compounds that they reported. However, one could argue that similar conditions may exist during certain food preparations and thus the data are realistic. In any event, the whole steam volatile concentrate derived from rice bran was fractionated into acidic, basic, phenolic, and neutral

Table V. Volatiles Associated with Cooked Rice

xylene[e]	2-decanone[f]
o-xylene[b]	6-methyl-5-hepten-2-one[e-g]
m-xylene[b]	6-methyl-3,5-heptadien-2-one[e]
p-xylene[b]	2-undecanone[e]
limonene[e]	2-pentadecanone[e]
p-cymene[e]	2-heptadecanone[e]
cumene[e]	2-nonadecanone[e]
pentadecane[e]	6,10,14-trimethylpentadecan-2-one[e]
hexadecane[e]	isophorone[e]
heptadecane[e]	acetophenone[e]
octadecane[e]	ethyl acetate[f]
nonadecane[e]	ethyl benzoate[e]
dodecane[d]	geranyl acetate[e]
naphthalene[e,f]	ethyl myristate[e]
methylnaphthalene[e]	methyl palmitate[e]
eicosane[e]	ethyl palmitate[e]
heneicosane[e]	ethyl stearate[e]
methanol[d]	ethyl oleate[e]
ethanol[d]	ethyl linoleate[e]
butanol[e]	pyridine[e]
3-methyl-1-butanol[e]	2-methylpyridine[e]
pentanol[e-h]	3-methylpyridine[e]
hexanol[d-h]	2-ethylfuran[f]
2-ethyl-4-methylpentan-1-ol[e]	2-pentylfuran[f-h]
heptanol[f-h]	pyrazine[e]
octanol[e,g,h]	2-methylpyrazine[e]
1-octen-3-ol[e-h]	2,3-dimethylpyrazine[e]
2-ethylhexanol[e]	2,5-dimethylpyrazine[e]
1-nonanol[g,h]	2,6-dimethylpyrazine[e]
benzyl alcohol[e,g,h]	2,3,5-trimethylpyrazine[e]
linalool[e]	guaiacol[e]
2-phenylethyl alcohol[e]	phenol[e]
nerolidol[e]	*p*-cresol[e]
pentadecanol[e]	4-vinylguiacol[e]
ethanal[a,d,f]	4-vinylphenol[e,g,h]
propanal[a,b,f]	caproic acid[e]
butanal[c,f,h]	caprylic acid[e]
2-methylpropanal[c,f]	nonanoic acid[e]
pentanal[a,b,d-h]	capric acid[e]
3-methylbutanal[e]	lauric acid[e]
hexanal[a,b,d-h]	tridecanoic acid[e]
heptanal[e-h]	myristic acid[e]
trans-2-hexenal[e-h]	pentadecanoic acid[e]
octanal[e-h]	palmitic acid[e]
trans-2-heptenal[e-h]	hexadecenoic acid[e]
nonanal[e-h]	stearic acid[e]
trans-2-octenal[e-h]	oleic acid
decanal[e-h]	linoleic acid[e]
trans-2-nonenal[e-h]	linolenic acid[e]
trans-2-decanal[e]	aniline[e]
trans-2-*cis*-4-decadienal[e]	BHT[e]
trans-2-*trans*-4-deca-	quinoline[e]
dienal[e-h]	benzothiazole[e]
furfural[e]	2,3-dimethyl-2-nonen-4-olide[f]
benzaldehyde[e-h]	indole[e]
phenylacetaldehyde[e-h]	diethyl phthalate[e]
2-propanone[a,b,d,f,g]	dibutyl phthalate[e]
trans-3-penten-2-one[e]	benzene[f]
2-heptanone[e-h]	toluene[f]
2-octanone[e-h]	ethylbenzene[f,h]
3-octanone[e]	6-methyl-5-hepten-2-one[h]
2-nonanone[e-h]	

[a] Yasumatsu et al. (1966a). [b] Yasumatsu et al. (1966b). [c] Endo et al. (1977). [d] Legendre et al. (1978). [e] Yajima et al. (1978). [f] Tsugita et al. (1980). [g] Tsugita et al. (1983). [h] Kato et al. (1983).

portions. As seen in Table VII, only approximately 80% of the concentrate was recovered. Also, Fujimaki et al. (1977) reported that sensory evaluation revealed that the neutral fraction had a rice bran like odor most similar to that of the whole volatile concentrate. Since the major volatiles found were the two phenols memtioned above, Fujimaki et al. (1977) concluded that they play a major role in contributing to the aroma of both steam-distilled rice bran and cooked rice. The authors cited data reported by Steinke and Paulson (1964) and Fiddler et al. (1967)

Table VI. Volatiles Associated with Rice Bran

n-decane[c]	1-heptanal[c]	1-hexanal[a,c,e]	2-decanone[c]
n-undecane[c]	acetone[a]	ethanal[a]	6-methyl-3,5-heptadien-2-one (isomers)[c]
n-dodecane[c,e]	trans-2-hexenal[c]	1,3,5-trimethylbenzene[c]	isophorone[c]
n-tridecane[c]	1-octanal[c]	styrene[c]	2-undecanone[c]
n-tetradecane[c]	trans-2-heptenal[c]	1-ethyl-2-methylbenzene[c]	4-methylacetophenone[c]
n-pentadecane[c]	1-nonanal[c]	p-cymene[c]	geranylacetone[c]
n-hexadecane[c]	trans-2-octenal[c]	1,2,4-trimethylbenzene[c]	β-ionone[c]
n-heptadecane[c]	3-furfural[c,d]	p-diethylbenzene[c]	6,10,14-trimethylpentadecan-2-one[c]
n-octadecane[c]	ethyl formate[c]	n-butylbenzene[c]	2-heptadecanone[c]
n-nonadecane[c]	ethyl acetate[c]	1,3-dimethyl-5-ethylbenzene[c]	2-octadecanone[c]
n-eicosane[c]	n-butyl acetate	o-diethylbenzene[c]	2,3-dimethylpyrazine[c]
n-heneicosane[c]	ethyl myristate[c]	1,2,3-trimethylbenzene[c]	tetramethylpyrazine[c]
n-docosane[c]	methyl palmitate[c]	1,4-dimethyl-2-ethylbenzene[c]	quinoline[c]
n-tricosane[c]	ethyl palmitate[c]	1,2,4,5-tetramethylbenzene[c]	2-methylquinoline[c]
n-tetracosane[c]	methyl oleate[c]	1,2,3,5-tetramethylbenzene[c]	thiazole[c]
limonene[c]	ethyl oleate[c]	indene[c]	2-methylthiazole[c]
benzene[c]	ethyl linoleate[c]	1,2-dimethoxybenzene[c]	2-acetylthiazole[c]
toluene[c]	4-nonanolide[c]	naphthalene[c]	2-methylbenzothiazole[c]
ethylbenzene[c]	2,3-dimethyl-2-nonen-4-olide[c]	1-methylnaphthalene[c]	benzothiazole[c]
p-xylene[c]	dihydroactinidiolide[c]	2-methylnaphthalene[c]	3-formylthiophene[c]
m-xylene[c]	acetaldehyde ethyl-n-pentyl acetate	methanol[a,e]	2-formylthiophene[c]
o-xylene[c]	2-pentylfuran[c]	ethanol[a,c,e]	1,8-cineol[c]
n-propylbenzene[c]	2-acetylfuran[c]	1-propanol[a,c]	methylanthranilate[c]
1-ethyl-4-methylbenzene[c]	pyridine[c]	2-butanol[a]	indole[c]
1-pentanol[a,c]	2-methylpyridine[c]	1-butanol[a,c]	skatole[c]
3-methylbutanol[a]	2,6-dimethylpyridine[c]	3-methyl-1-butanol[a,c]	guaiacol[b]
1-hexanol[a,c,e]	3-methylpyridine[c]	2-furfural[c,d]	phenol[b]
linalool oxide[c]	4-methylpyridine[c]	1-decanal[c]	o-cresol[b]
1-octen-3-ol[c]	2,4-dimethylpyridine[c]	benzaldehyde[c]	p-cresol[b]
1-heptanol[c]	3,4-dimethylpyridine[c]	trans-2-nonenal[c]	3,5-xylenol[b]
linalool[c]	3,5-dimethylpyridine[c]	5-methylfurfural[c]	4-vinylguaiacol[b,d]
1-octanol[c]	2-methylpyrazine[c]	phenylacetaldehyde[c]	4-vinylphenol[b]
1-nonanol[c]	2,5-dimethylpyrazine[c]	trans-2-decenal[c]	2-methylbutyric acid[b]
furfuryl alcohol[c,d]	2,6-dimethylpyrazine[c]	deca-2,4-dien-1-al (isomers)[c]	caproic acid[b]
benzyl alcohol[c]	capric acid[b]	2-phenyl-2-butenal (isomers)[c]	enanthic acid[b]
2-phenylethyl alcohol[c]	benzoic acid[b]	3-penten-2-one (isomers)[c]	caproylic acid[b]
1-butanal[a]	lauric acid[b]	2-heptanone[c]	pelargonic acid[b]
3-methyl-1-butanal[a,c]	tridecylic acid[b]	6-methylheptan-2-one[c]	hexadecenoic acid[b]
propanal[a]	myristic acid[b]	3-octanone[c]	stearic acid[b]
1-pentanal[a,c,e]	pentadecylic acid[b]	2-octanone[c]	oleic acid[b]
2-methylbutanal[a]	palmitic acid[b]	6-methyl-5-hepten-2-one[c]	linoleic acid[b]
		2-nonanone[c]	linoleic acid[b]
		3-octen-2-one (isomers)[c]	

[a] Mitsuda et al. (1968). [b] Fujimaki et al. (1977). [c] Tsugita et al. (1978). [d] Kasahara (1976). [e] Legendre et al. (1978).

Table VII. Fractionation Yield and Odor Descriptions of a Rice Bran Volatile Concentrate[a]

fraction	yield, %	odor description
neutral	47.9	oily, cereal rice bran like
phenolic	21.3	guaiacol-like, decayed straw like
acidic	10.4	butter-like, rancid
basic	1.9	pyrazine-like, burnt, cereal
not recovered	18.5	

[a] Fujimaki et al. (1977).

Table VIII. Volatiles Associated with Soong-Neung[a]

carbonyls	pyrazines
acetaldehyde	2-methylpyrazine
propionaldehyde	2,3-dimethylpyrazine
isobutyraldehyde	2,5-dimethylpyrazine
isovaleraldehyde	2-ethyl-3-methylpyrazine
	2-ethyl-5-methylpyrazine

[a] Cheigh et al. (1975).

that 4-vinylphenol and 4-vinylguaiacol can be derived from the thermal decarboxylation of ferulic and p-coumaric acids, both of which have been reported to be present in the free form in rice (Houston et al., 1963; Yoshizawa et al., 1970).

Later, Tsugita et al. (1978) concluded that lactones, probably derived from thermally induced lipid degradation (Maga, 1976) and thiazoles, especially 2-acetylthiazole, which can be derived from the thermal reaction of sulfur-containing amino acids and carbonyl compounds or the thermal dehydration of thiamin (Maga, 1975), are also major contributors to rice bran aroma.

Dimethyl sulfide has been identified as an objectionable compound associated with rice bran (Namba et al., 1982), the precursor of which was identified as S-methylmethionine sulfonium chloride. Dimethyl sulfide production was found to be dependent upon the age of the rice since new unpolished rice was found to contain 0.3 ppm, while old unpolished rice had 8 ppm. The degree of polishing also influenced dimethyl sulfide levels with less polished rice (more bran) having higher levels.

Soong-Neung. Soong-Neung is a Korean rice-based food prepared from cooked and roasted rice. Roasting is usually done in a temperature range of 125–155 °C (Nam et al., 1973).

A brief report has appeared (Cheigh et al., 1975) indicating that the volatiles associated with this product are primarily carbonyls and pyrazines. As seen in Table VIII, a limited number of these compounds were identified, with the pyrazines probably being formed during the roasting process.

Rice Cake. Kurasawa et al. (1969) reported on the flavor components associated with the hot water extraction of rice cake. Compounds identified included hydrogen sulfide, ammonia, ethanal, 2-methylpropanal, propanal, 3-methylbutanal, and hexanal. The authors claimed that when a synthetic mixture contained the aldehydes in the same relative ratios as found in the product, along with hydrogen sulfide and ammonia, a flavor typical of the original rice cake was produced.

Conclusion. Thus, although a great deal of time and effort has been devoted to an attempt to understand rice flavor, with the possible exception of scented rice, much work is still needed before a complete explanation is available.

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