CHAPTER 1

INTRODUCTION TO RICE AROMA, FLAVOR, AND FRAGRANCE

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1.1 INTRODUCTION

Aroma is one of the diagnostic aspects of rice quality that determines the acceptance or rejection of rice before it is tested (Verma et al., 2012, 2013, 2015). It is also considered as an important property of rice that indicates its preferable high quality and price in the market (Paule and Powers, 1989; Ishitani and Fushimi, 1994). Early research on rice aroma can be traced 30 years back (Buttery et al., 1982, 1983), but more scientific progress in modern analytical techniques has been achieved with the discovery, development, and application of gas chromatography. Gas chromatography received tremendous advances and innovations when combined with mass spectrometry to form the technique known as gas chromatography-mass spectrometry (GC-MS). This technique made identification and quantification of volatile compounds much easier in mixtures of sample matrix and greatly enhanced interest in chemistry of rice aroma. An assessment of all known data reveals that more than 500 compounds have been documented in various aromatic and non-aromatic rice cultivars (Table 1.1) (Widjaja et al., 1996a; Verma and Srivastav, 2016). The primary goals were to identify the compounds responsible for the characteristic rice aroma (Buttery et al., 1982). Many attempts are made to date to search the key compounds for rice aroma (Buttery et al., 1982, 1983), but any single compound or group of compounds that are fully responsible for rice aroma have not yet been reported. The first volatile aroma compound, 2-acetyl-1-pyrroline (2-AP), was reported in 1982 by Buttery et al. (1982) and discovered by Buttery et al. (1983) in 1983 from aromatic rice due to its strong volatile characteristic. 2-AP is the most important flavoring compound of cooked rice since its discovery (Buttery et al., 1982, 1983). Rice consists of balanced complicated mixtures of volatile aroma compounds that impart their characteristic flavor. There are no single analytical techniques that can be used for investigation of volatile aroma compounds in rice sample. Although, currently, many technologies are available for the extraction of rice volatile aroma compounds and these technologies have been also modified time-to-time according to the need, many of them are still under process to emerge into a new form, particularly in the distillation and extraction concept.

TABLE 1.1 List of Rice Aroma Compounds Reported in Rice Cultivars (Verma and Srivastav, 2016)

Aroma Compounds	Aroma Compounds	Aroma Compounds
1. (1*S*, *Z*)-calamenene	2. 2-methyl-decane	3. Heptadecane
4. (2-aziridinylethyl) amine	5. 2-methyl-dodecane	6. Heptadecyl-cyclohexane
7. (2*E)*-dodecenal	8. 2-methyl-furan	9. Heptanal
10. (*E*) -3-Octene-2-one	11. 2-methyl-hexadecanal	12. Heptane
13. (*E*) 6, I0-dimethyl-5,9 undecadien-2-one	14. 2-Methyl-I-propenyl benzene	15. Heptanol
16. (*E)*-14-hexadecenal	17. 2-methyl-naphthalene	18. Hepten-2-ol<6-methyl-5->
19. (*E*)-2, (*E*)-4-decadienal	20. 2-methyl-tridecane	21. Heptene-dione
22. (*E*)-2, (*E*)-4-heptadienal	23. 2-methyl-undecanal	24. Heptylcyclohexane
25. (*E*)-2, (*E*)-C heptadienal	26. 2-methyl-undecanol	27. Hexacosane
28. (*E*)-2, (*E*)-C nonadienal	29. 2-*n*-butyl-furan	30. Hexadecanal
31. (*E*)-2-decenal	32. 2-nonanone	33. Hexadecane
34. (*E*)-2-heptanal	35. 2-nonenal	36. Hexadecane 2,6-bis-(t-butyl)-2,5
37. (*E*)-2-heptenal	38. 2-ocetenal (*E*)	39. Hexadecanoic acid
40. (*E*)-2-hexenal	41. 2-octanone	42. Hexadecanol
43. (*E*)-2-nonen-1-ol	44. 2-octenal	45. Hexadecyl ester, 2,6-difluro-3-methyl benzoic acid
46. (*E*)-2-nonenal	47. 2-pentadecanone	48. Glycerin
49. (*E*)-2-octen-1-ol	50. 2-pentylfuran	51. Hexane
52. (*E*)-2-octenal	53. 2-phenyl-2-methyl-aziridine	54. Hexanoic acid
55. (*E*)-2-undecenal	56. 2-phenylethanol	57. Hexanoic acid dodecate
58. (*E*)-3-nonen-2-one	59. 2-propanol	60. Hexanol
61. (*E*)-4-nonenale	62. 2-tetradecanone	63. Hexatriacontane
64. (*E*)-hept-2-enal	65. 2-tridecanone	66. Hexyl furan
67. δ-cadinol	68. 2-undecanone	69. Hexyl hexanoate
70. (*E,E*)-2,4-nonadienal	71. Hexylpentadecyl ester-sulphurous acid	

TABLE 1.1 (Continued)

Aroma Compounds	Aroma Compounds	Aroma Compounds
72. (*E,E*)-2,4-octadienal	73. 3-(*t*-Butyl)-phenol	74. Indane
75. (*E,E*)-farnesyl acetone	76. 3,5,23-trimethyl-tetracosane	77. Indene, 2,3-dihydro-1,1,3 trimethyl-3-phenyl
78. (*E,Z*)-2,4-decadienal	79. 3,5,24-trimethyl-tetracontane	80. Indole
81. (*S*)-2-methyl-1-dodecanol	82. 3,5-dimethyl-1-hexene	83. I-S, *cis*-calamene lonol 2
84. (*Z*)-2-octen-1-ol	85. 3,5-dimethyl-octane	86. Isobutyl hexadecyl ester oxalic acid
87. \(*Z*)-3-Hexenal	88. 3,5-di-tert-butyl-4-hydroxybenzaldehyde	89. Isobutyl nonyl ester oxalic acid
90. [(1-methylethyl)thio] cyclohexane	91. 3,5-heptadiene-2-one	92. Isobutyl salicylate
93. <6-methyl->Heptan-2-ol	94. 3,5-octadien-2-ol	95. Isolongifolene
96. <*cis*-2-*tert*-butyl->Cyclohexanol acetate	97. 3,7,11,15-tetramethyl-2-hexadecimalen-1-ol	98. Isopropylmyristate
99. 1-(1H-pyrrol-2-yl)-ethanone	100. 3,7,11-trimethyl-1-dodecanol	101. Limonene
102. 1, 2–Bis, cyclobutane	103. 3,7-dimethyl-hexanoic acid	104. Lirnonene
105. 1,1-dimethyl-2-octyl-cyclobutane	106. 3-dimethyl-2-(4-chlorphenyl)-thioacrylamide	107. l-octen-3-o1
108. 1,2,3,4-Tetramethyl benzene	109. 3-ethyl-2-methyl-heptane	110. 2-methyl-butanal
111. 1,2,3-trimethyl-benzene	112. 3-Hexanone	113. Methoxy-phenyl-oxime
114. 1,2,4-trimethyl-benzene	115. 3-hydroxy-2,4,4-trimethylpentyl *iso*-butanoate	116. Methyl (*E*)-9-octadecenoate
117. 1,2-dichloro-benzene	118. 3-methyl-1-butanol	119. Methyl (*Z,Z*)-11,14-eicosadienoate
120. 1,2-dimethyl-benzene	121. 3-methyl-2-butyraldehyde	122. Methyl (*Z,Z*)-9,12-octadecadienoate
123. 1,3,5-trimethyl-benzene	124. 3-Methyl-2-heptyl acetate	125. Methyl butanoate
126. 1,3-diethyl-benzene	127. 3-methyl-butanal	128. Methyl decanoate

TABLE 1.1 (Continued)

Aroma Compounds	Aroma Compounds	Aroma Compounds
129. 1,3-dimethoxy-benzene	130. 3-methyl-hexadecane	131. Methyl dodecanoate
132. 1,3-dimethyl-benzene	133. 3-methyl-pentadec-ane	134. Methyl ester trideca-noic acid
135. 1,3-dimethyl-naph-thalene	136. 3-methyl-pentane	137. Methyl heptanoate
138. 1,4-dimethyl-benzene	139. 3-methyl-tetradecane	140. Methyl hexadecano-ate
141. 1,4-dimethyl-naph-thalene	142. 3-nonene-2-one	143. Methyl isocyanide
144. 10-heptadecene-1-ol	145. 3-octdiene-2-one	146. Methyl isoeugenol
147. 10-pentadecene-1-ol	148. 3-octene-2-one	149. Methyl linolate
150. 17-hexadecyl-tetratri-acontane	151. 3-tridecene	152. Methyl naphthalene
153. 17-pentatricontene	154. 4,6-dimethyl-dodec-ane	155. Methyl octanoate
156. 1-chloro-3,5-bis(1,1-dimethylethyl)2-(2-propenyloxy) benzene	157. 4-[2-(methylamino) ethyl]-phenol	158. Methyl oleate
159. 1-chloro-3-methyl butane	160. 4-acetoxypentadec-ane	161. Methyl pentanoate
162. 1-chloro-nonadecane	163. 4-cyclohexyl-dodec-ane	164. Methyl tetradecano-ate
165. 1-decanol	166. 4-ethyl-3,4-dimethyl-cyclohexanone	167. Myrcene
168. 1-docosene	169. 4-ethylbenzaldehyde	170. *N,N*-dimethyl chloestan-7-amine
171. 1-dodecanol	172. 4-hydroxy-4-methyl-2-pentanone	173. *N,N*-dinonyl-2-phen-ylthio ethylamine
174. 1-ethyl-2-methyl-benzene	175. 4-methyl benzene formaldehyde	176. Naphthalene
177. 1-ethyl-4-methyl-benzene	178. 4-methyl-2-pentyne	179. *n*-decanal
180. 1-ethyl-naphthalene	181. 4-vinyl-guaiacol	182. *n*-decane
183. 1-heptanol	184. 4-vinylphenol	185. *n*-dodecanol
186. 1-hexacosene	187. 5-amino-3,6-dihydro-3-imino-1(2*H*) pyr-azine acetonitrile	188. *n*-eicosanol

TABLE 1.1 (Continued)

Aroma Compounds	Aroma Compounds	Aroma Compounds
189. 1-hexadecanol	190. 5-butyldihydro-2(3*H*)-furanone	191. *n*-heneicosane
192. 1-hexadecene	193. 5-ethyl-4-methyl-2-phenyl-1,3-dioxane	194. *n*-heptadecanol
195. 1-hexanol	196. 5-ethyl-6-methyl-(*E*)3-hepten-2-one	197. *n*-heptadecylcyclo-hexane
198. 1-methoxy-naphtha-lene	199. 5-ethyl-6-methyl-2-heptanone	200. *n*-heptanal
201. 1-methyl-2-(1-methylethyl)-benzene	202. 5-ethyldihydro-2(3*H*)-furanone	203. *n*-heptanol
204. 1-methyl-4-(1-methylethylidene)-cyclohexene	205. 5-*iso*-Propyl-5*H*-furan-2-one	206. *n*-hexadecane
207. 1-methylene-1*H*-indene	208. 5-methy-3-hepten-2-one	209. *n*-hexadecanoic acid
210. 1-nitro-hexane	211. 5-methyl-2-hexanone	212. *n*-hexanal
213. 1-nonanol	214. 5-methyl-pentadec-ane	215. *n*-hexanol
216. 1-octadecene	217. 5-methyl-tridecane	218. Nitro-ethane
219. 1-octanol	220. 5-pentyldihydro-2(3*H*)-furanone	221. *n*-nonadecane
222. 2-methyl-5-isopro-pyl-furan	223. 6,10,13-trimethyl-tetradecanol	224. *n*-nonadecanol
225. 1-pentanol	226. 6,10,14-trimethyl-2-pentadecanone	227. *n*-nonanal
228. 1-tetradecyne	229. 6,10,14-trimethyl-pentadecanone	230. *n*-nonanol
231. 1-tridecene	232. 6,10-dimethyl-2-un-decanone	
233. 1-undecanol	234. 6,10-dimethyl-5,9 undecadien-2-one	235. *n*-octanal
236. 2,2,4-trimethyl-3-carboxyisopropyl, isobutyl ester penta-noic acid	237. 6,10-dimethyl-5,9-undecandione	238. *n*-octane
239. 2,2,4-trimethyl-heptane	240. 6-dodecanone	241. n-octanol

TABLE 1.1 (Continued)

Aroma Compounds	Aroma Compounds	Aroma Compounds
242. 2,2,4-trimethyl-pentane	243. 6-methyl-2-hepta-none	244. Heptacosane
245. 2,2-dihydroxy-1-phe-nyl-ethanone	246. 6-methyl-3,5-heptadi-ene-2-one	247. *n*-octyl-cyclohexane
248. 2,3,5-trimethyl-naph-thalene	249. 6-methyl-5-ene-2-heptanone	250. Nonadecane
251. 2,3,6-trimethyl-naph-thalene	252. 6-methyl-5-hepta-none	253. Nonanal
254. 2,3,6-trimethyl-pyridine	255. 6-methyl-5-hepten-2-one	256. Nonane
257. 2,3,7-trimethyl-octanal	258. 6-methyl-octadecane	259. Nonanoic acid
260. 2,3-butandiol	261. 7,9-di-tert-butyl-1-oxaspiro-(4,5) deca-6,9-diene-2,8-dione	262. Nonene
263. 2,3-dihydrobenzo-furan	264. 7-chloro-4-hydroxy-quinoline	265. Nonnenal
266. 2,3-dihydroxy-suc-cinic acid	267. 7-methyl-2-decene	268. Nonyl-cyclohexane
269. 2,3-octanedione	270. 7-tetradecene	271. n-pentanol
272. 2,4,4-trimethylpen-tan-1,3-diol di-*iso*-butanoate	273. 9-methyl-nonadecane	274. *n*-tetradecanol
275. 2,4,6-trimethyl-decane	276. Acetic acid	277. *n*-tricosane
278. 2,4,6-trimethyl-pyridine (TMP) or Collidine	279. Acetic acid tetra-decate	280. n-undecanal
281. 2,4,7,9-tetramethyl-5-decyn-4,7-diol	282. Acetone	283. *n*-undecanol
284. 2,4-bis(1,1-dimethylethyl)-phenol	285. Acetonitrile	286. Oct-1-en-3-ol
287. 2,4-di(*tert*butyl) phenol	288. Acetophenone	289. Octacosane
290. 2,4-diene dodecanal	291. Alk-2-enals	292. Octadecane
293. 2,4-hexadienal	294. Alka-2,4-dienals	295. Octadecyne

TABLE 1.1 (Continued)

Aroma Compounds	Aroma Compounds	Aroma Compounds
296. 2,4-hexadiene aldehyde	297. Alkanals	298. Octanal
299. 2,4-nonadienal	300. Alkyl-cyclopentane	301. Octanoic acid
302. 2,4-pentadiene aldehyde	303. Anizole	304. Octanol
305. 2,4-pentandione	306. Azulene	307. Octyl formate
308. 2,5,10,14-tetramethyl-pentadecane	309. Benzaldehyde	310. *O*-decyl hydroxamine
311. 2,5,10-trimethyl-pentadecane	312. Benzene	313. Oxalic acid-cyclohexyl methyl nonate
314. 2,5-dimethyl-undecane	315. Benzene acetaldehyde	316. Palmitate
317. 2,6,10,14-tetramethyl-heptadecane	318. Benzene formaldehyde	319. Pentacontonal
320. 2,6,10,14-tetramethyl-hexadecane	321. Benzothiazole	*322.* Pentacosane
323. 2,6,10,14-tetramethyl-pentadecane	324. Benzyl alcohol	325. Pentadecanal
326. 2,6,10-trimethyl-dodecane	327. Bezaldehyde	328. Pentadecane
329. 2,6,10-trimethyl-pentadecane	330. Bicyclo[4,2,0]octa-1,3,5-triene	331. Pentadecanoic
332. 2,6,10-trimethyl-tetradecane	333. Bis-(I-methylethyl) hexadecanoate	334. Pentadecyl-cyclohexane
335. 2,6-bis(t-*butyl*)-2,5 cyclohexadien-I-one	336. Butan-2-one-3-Me	337. Pentanal
338. 2,6-bis(t-*butyl*)-2,5-cyclohexadien-1, 4-dione	339. Butanal	340. Pentanoic acid
341. 2,6-di(*tert*-butyl)-4-methylphenole	342. Butandiol	343. Pentyl hexanoate
344. 2,6-diisopropyl-naphthalene	345. Butanoic acid	346. Phenol
347. 2,6-dimethoxy-phenol	348. Butylated hydroxy toluene	349. Phenyl acetic acid-4-tridecate
350. 2,6-dimethyl-aniline	351. Citral	352. Phenylacetaldehyde
353. 2,6-dimethyl-decane	354. Cubenol	355. Phthalic acid

TABLE 1.1 (Continued)

Aroma Compounds	Aroma Compounds	Aroma Compounds
356. 2,6-dimethyl-heptadecane	357. Cyclodecanol	358. Phytol
359. 2,6-dimethyl-naphthalene	360. Cyclosativene	361. Propane
362. 2,7-dimethyl-octanol	363. *d*-dimonene	364. Propiolonitrile
365. 2-acetyl-1-pyrroline (2-AP)	366. Decanal	367. Propyl acid
368. 2-acetyl-naphthalene	369. Decane	370. *p*-xylene
371. 2-butyl-1,2-azaborolidine	372. Decanoic acid	373. Pyridine
374. 2-butyl-1-octanol	375. Decanol	376. Pyrolo[3,2-d]pyrimidin-2,4(1*H*,3*H*)-dione
377. 2-butyl-2-octenal	378. Decyl aldehyde	379. Styrene
380. 2-butylfuran	381. Decyl benzene	382. Tetracosane
383. 2-butyl-octanol	384. Diacetyl	385. Tetradecanal
386. 2-chloro-3-methyl-1-phenyl-1-butanone	387. Dichloro benzene	388. Tetradecane
389. 2-chloroethyl hexyl ester isophthalic	390. Diethyl phthalate	391. Tetradecanoic acid
392. 2-decanone	393. Diethyl phthalate	394. Tetradecanol
395. 2-decen-1-ol	396. Di-*iso*-butyl adipate	397. Tetradec-I-ene
398. 2-decenal	399. Dimethyl disulphide	400. Tetrahydro-2,2,4,4-tetramethyl furan
401. 2-dodecanone	402. Dimethyl sulphide	403. Toluene
404. 2-ethyl-1-decanol	405. Dimethyl trisulphide	406. *trans*-2-octenal
407. 2-ethyl-1-dodecanol	408. *d*-limonene	409. *trans*-Caryophylene
410. 2-ethyl-1-hexanol	411. Docosane	412. Triacontane
413. 2-ethyl-2-hexenal	414. Dodecanal	415. Tricosane
416. 2-ethyl-decanol	417. Dodecane	418. Tridecanal
419. 2-heptadecanone	420. Dotriacontane	421. Tridecane
422. 2-heptanone	423. Eicosane	424. Trimethylheptane
425. 2-heptenal	426. Eicosanol	427. Tritetracontane
428. 2-heptene aldehyde	429. Ethanol	430. Turmerone
431. 2-heptylfurane	432. Ethenyl cyclohexane	433. Undecanal
434. 2-hexadecanol	435. Ethyl (*E*)-9-octadecenoate	436. Undecane

TABLE 1.1 (Continued)

Aroma Compounds	Aroma Compounds	Aroma Compounds
437. 2-hexanone	438. Ethyl benzene	439. Undecanol
440. 2-hexyl-1-decanol	441. Ethyl decanoate	442. Undecyl-cyclohexane
443. 2-hexyl-1-octanol	444. Ethyl dodecanoate	445. Vanillin
446. 2-hexyl-decanol	447. Ethyl hexadecanoate	448. *Z*-10-pentadecen-1-ol
449. 2-hexylfurane	450. Ethyl hexanoate	451. α-cadinene
452. 2-methoxy-4-vinyl-phenol	453. Ethyl linoleate	454. α-cadinol
455. 2-methoxy-phenol	456. Ethyl nonanoate	*457.* α-terpineol
458. 2-methyI-butanol	459. Ethyl octanoate	460. β-bisabolene
461. 2-methyl-1,3-pen-tanediol	462. Ethyl oleate	463. β-terpineol
464. 2-methyl-1-hexadec-anol	465. Ethyl tetradecanoate	466. γ-nonalacton
467. 2-methyl-2,4-diphe-nylpentane	468. Ethylbenzene	469. γ-nonalactone
470. 2-methyl-3-furanthiol (2-MF)	471. Farnesol	472. γ-terpineol
473. 2-methyl-3-octanone	474. Formic acid hexate	475. δ-cadinene
476. 2-methyl-5-decanone	477. Geranyl acetone	

(*Source*: Adapted from Verma, D. K. and Srivastav, P. P. (2016). Extraction Technology for Rice Volatile Aroma Compounds. *In*: Food Engineering: Emerging Issues, Modeling, and Applications (eds. Meghwal, M., and Goyal, M. R.). Used with permission from Apple Academic Press.)

1.2 AROMA, FLAVOR, AND FRAGRANCE AT A GLANCE

The terms "aroma," "flavor," and "fragrance" are synonyms of each other and do not differ much from each other. Although difficult, an effort is made here to define the terms.

Aroma is a very complex sensation that may be defined as typically pleasant smell arising from plants, (such as leaves, stem, root, fruits, or grains), cooking of plant's parts, etc., and should be agreeable with odor, flavor, and fragrance. Very limited stimuli are available that create sensations of the taste. However, more than 500 volatile compounds (Table 1.1) have been identified (Verma and Srivastav, 2016). Each of these may

potentially contribute to the perception of rice aroma, depending on their concentrations and sensory thresholds.In the case of rice, aroma is a result of a large number of compounds that are present in specific proportion in the field at the time of flowering. It also includes something pleasant smell that we feel from cooked or uncooked rice with distinctive odor, flavor, and fragrance. Efferson (1985) suggested that rice without distinctive aroma is like food without salt for those consumers who prefer rice with strong aroma.

A fragrance is defined as a pleasant or sweet smell and has no more difference with "aroma," and "flavor" because of the synonyms of each other. All the characteristics of the material that produces the sensation of taste, smell, and texture when the material is taken in the mouth are termed as flavor and are also perceived by the general pain, tactile, and temperature receptors in the mouth. Flavor is one of the most important parts of the three main sensory properties that are decisive in the selection, acceptance, and ingestion of a food. Flavor is often the main reason and considered by the consumer as an important quality attribute on the basis of which rice is accepted or rejected.

1.3 IMPORTANCE OF AROMA, FLAVOR, AND FRAGRANCE IN RICE RESEARCH

Aroma in rice grains is contributed by several volatile aroma compounds that are synthesized due to distinct biochemical pathways. More than 200 rice cultivars are recognized to contain numerous volatile aroma compounds (Nijssen et al., 1996). These volatile aroma compounds include a series of compounds like aldehydes, ketones, organic acids, alcohols, esters, hydrocarbons, phenols, pyrazines, pyridines, and other compounds. Apart from these, some other compounds are also present, but they are extracted by the breakdown of chemicals like fatty acids present in samples (Bergman et al., 2000). The volatile aroma compounds released after cooking are different from those released in the field at the time of flowering.

Aroma is considered world's 3rd highest desired trait in rice as well as in India, followed by taste and elongation after cooking (Bhattacharjee et al., 2002; Verma et al., 2012, 2013, 2015). Several types of rice aroma, flavor, and fragrance are reported by many researchers in various type of rice and

rice's products depicted in Table 1.2, for instance, bland-like, bran-like, brown rice, burned-like, burnt-like, buttery-like, cold-steam-bread-like, corn-like, corn leaf-like, cracker-like, dusty-like, earthy-like, fermented sour-like, floral-like, gasoline aroma-like, grainy-like, hot-steam-bread-like, musty-like, nut-like, paint-like, pandan-like, pear-barley-like, plastic-like, popcorn-like, potato-like, rancid-like, raw dough-like, rice milk-like, smoky-like, spicy-like, sulfur-like, tortilla-like, vegetable-like, and white glue-like (Withycombe et al., 1978; Paule and Powers, 1989; Chastril, 1990; Yau and Liu, 1999). Popcorn aroma, which sometimes described

TABLE 1.2 Different Types of Aroma, Flavor, and Fragrance Reported in Rice (Cooked, Uncooked, and Its Product)

Types of Aroma, flavor and fragrance		
✓ Acetone like odor	✓ Fatty type flavor	✓ Oligosulfide odor
✓ Acidic, fruity	✓ Fatty-waxy	✓ Orange-like
✓ Aldehydic type odor	✓ Fermented type odor	✓ Paraffinic
✓ Almond-like	✓ Fishy odor	✓ Peach-like
✓ Aromatic odor	✓ Floral citrus like odor	✓ Peanut type odor
✓ Aromatic, gasoline	✓ Flower-like	✓ Peppermint-like odor
✓ Balsamic odor	✓ Foul odor of rotten eggs	✓ Phenolic-like
✓ Banana-like	✓ Fresh sweet-like	✓ Popcorn-like
✓ Beany-like	✓ Fresh woody-like	✓ Pungent, aldehyde odor
✓ Berry; blossom	✓ Fruity and floral-like	✓ Pungent, suffocating-like odor
✓ Bitter-like	✓ Fruity-like	✓ Pungent-like
✓ Bland type odor	✓ Fungal type odor	✓ Rancid-like
✓ Burnt-like	✓ Fusel oil-like	✓ Raspberry-like
✓ Buttery flavor	✓ Gasoline type odor	✓ Raw mushroom-like
✓ Buttery, creamy	✓ Grape-like	✓ Repulsive pungent odor
✓ Cabbage type	✓ Grassy alcoholic	✓ Roasted nuts-like
✓ Camphor-like odor	✓ Green and beany-like	✓ Roasted-like
✓ Caramel-like	✓ Green and grass-like	✓ Rose-like
✓ Cheesy type	✓ Green and slightly fruity-like	✓ Rotten cabbage or eggs

TABLE 1.2 (Continued)

Types of Aroma, flavor and fragrance		
✓ Cherry-like scent	✓ Green leaf like	✓ Rubbery, pungent, acid type
✓ Chicken-like	✓ Green tomato-like	✓ Seasoning-like
✓ Chocolate type	✓ Green waxy oily fatty	✓ Slight aromatic
✓ Citrus-like	✓ Green-like	✓ Slight phenolic
✓ Citrus-woody profile	✓ Hay-like	✓ Smoky-like
✓ Clove, phenolic type	✓ Herbaceous-like	✓ Sour type
✓ Cocoa type	✓ Herbal-like	✓ Soapy-like
✓ Coconut-like	✓ Honey-like	✓ Spicy and clove-like
✓ Coffee type	✓ Hydrocarbon-like odor	✓ Spicy-like
✓ Cooked jasmine rice	✓ Indole-like	✓ Sulfury-like
✓ Cooked meat	✓ Lemon-like odor	✓ Sweet (dilute)-like
✓ Cooked potato	✓ Licorice type odor	✓ Sweet and cheesy-like
✓ Cooked rice-like	✓ Magnolia-like	✓ Sweet and coconut-like
✓ Cooling, minty	✓ Meaty type	✓ Sweet and floral-like
✓ Cucumber-like	✓ Medicine-like	✓ Sweet and pleasant-like
✓ Dairy type odor	✓ Metallic	✓ Sweet-like
✓ Detergent-like odor	✓ Mild alcohol-like	✓ Tallow-like
✓ Distinct odor	✓ Mild chlorine odor	✓ Terpenic type odor
✓ Earthy type odor	✓ Mild hydrocarbon	✓ Toasted
✓ Estery type odor	✓ Mild pleasant odor	✓ Unpleasant and Phenolic-like
✓ Ethereal type odor	✓ Mild sweet odor	✓ Vanilla-like
✓ Ethereal, and pungent	✓ Mild, orange blossom odor	✓ Waxy-like
✓ Ethereal-like	✓ Minty type odor	
✓ Ether-like odor	✓ Moderately strong odor	
✓ Naphthalene-like	✓ Moldy aroma	
✓ Naphthyl type odor	✓ Mothball-like	
✓ Nutty and roasted-like	✓ Mushroom-like	
✓ Nutty-like	✓ Musty aroma	

as pandan (*Pandanus amaryllifolius*)-like aroma (Laksanalamai and Ilangantileke, 1993) is due to the presence of 2-AP in rice. 2-AP is the most important and prominent aroma chemical since it was used to identify in rice cultivars (Petrov et al., 1996). Yajima et al. (1979) identified α-pyrrolidone and indole. The former is found as a key odorant during the study of volatile flavor components in cooked Kaorimai (scented rice, *O. sativa japonica*). Buttery et al. (1988) identified seven compounds, viz. (*E*)-2-decenal, (*E*)-2-nonenal, (*E, E*)-2,4-decadienal, 2-AP, decanal, nonanal, and octanal with low odor thresholds from listed 64 aroma volatile chemical compounds from rice. Later, the chemical compound 2-AP was considered as the major odorant contributor of popcorn-like rice aroma (Buttery et al., 1982; Petrov et al., 1996). This odorant contributor in rice is found at different concentration range from a minimum of 1–10 ppb to a maximum of 2 ppm level (Buttery et al., 1988). Widjaja et al. (1996b) made comparative study of the products of lipid oxidation and aroma volatile compounds, viz. (*E*)-2-decenal, (*E, E*)-2, 4-nonadienal, and (*E, E*)-2,4-decadienal from fragrant and non-fragrant rice and reported that these aroma chemical compounds are responsible for aroma in waxy rice. These three aroma compounds are also reported by Grimm et al. (2000) for contributing its distinctive aroma in glutinous or waxy rice.

1.4 CLASSIFICATION OF RICE AROMA CHEMICALS

The majority of rice volatile aroma chemicals have popcorn-like smell due to 2-AP content. Aroma similar to taste and elongation after cooking of rice is considered as desirable quality for consumer acceptability (Bergman et al., 2000; Bhattacharjee et al., 2002). Generally, rice aroma may be classified according to the flavor, fragrance, and smell as well as on the basis of their chemical structure as described in Sections 1.4.1 and 1.4.2.

1.4.1 CLASSIFICATION OF RICE AROMAS BASED ON THEIR FLAVOR, FRAGRANCE, AND SMELL

Rice aromas were classified into five major groups as shown in Table 1.3. Although any single chemical compound is not responsible for any

TABLE 1.3 Classification of Rice Volatile Aromas Based on Their Flavor, Fragrance, and Smell

S No.	Type of Rice Aroma	Responsible Chemical Compounds
1.	Green	Aldehydes, Some alcohol and Ketones, (*E*)-2,(*E*)-4-hexadienal, (*E*)-2-hexenal, (*E*)-2-octenal, (*E*)-3-octen-2-onea, 2-heptanone, 2-methyl-2-pentanol, Benzaldehyde, Decanal, Geranyl acetone, Methyl heptanoate and *n*-hexanal
2.	Fruity/Floral	(*E*)-2,(*E*)-4-hexadienal, (*E*)-3-octen-2-onea, 2-hexanone, 2-nonanone, 2-undecanone, 6-methyl-5-hepten-2-one, Heptanone, Ketones, Methyl heptanoate, *n*-heptanal, *n*-nonanal and *n*-octanol
3.	Roasty	2, 3-octanedione
4.	Nutty	(*E*,*E*)-2,4-nonadienal, 2-pentyfuran, 4-vinyl guaiacol and Benzaldehyde
5.	Bitter	Benzaldehyde and Pyridine

(Source: Adapted from Verma, D. K. and Srivastav, P. P. (2016). Extraction Technology for Rice Volatile Aroma Compounds In: Food Engineering: Emerging Issues, Modeling, and Applications (eds. Meghwal, M. and Goyal, M. R.). Used with permission from Apple Academic Press.)

specific aroma in cooked rice, a mixture of compounds in fixed proportion is responsible for specific aromas in cooked rice. This is shown very clearly in Table 1.3. For instance, fresh green or woody smell was contributed mainly by aldehydes, ketones, and some alcohols; fruity and floral smell comes due to the presence of heptanone, ketones, and 6-methyl-5-hepten-2-one, while benzaldehyde and 2-pentyfuran provided nutty aromas (Widjaja et al., 1996a).

1.4.2 BASED ON THEIR CHEMICAL STRUCTURE

Rice aroma chemicals can be classified according to their chemical structures in their families (Table 1.4). These alternative classifications could be established as a function of the chemical family of the precursor used for their production by chemical conversion.

TABLE 1.4 Classification of Rice Volatile Aromas Based on Their Chemical Structure

S No.	Family of Aroma	Aroma Chemicals
1.	Alcohols	(2*Z*)-2-Octen-1-ol; (3*Z*)-3-Hexen-1-ol; (*E*)-2-Nonen-1-ol; (*E*)-2-hexenol; (*E*)-2-Octen-1-ol; (*E*)-2-Pentenol; (*S*)-2-Methyl-1-dodecanol; 1,2-Propanediol; 10-Heptadec en-1-ol; 10-Pentadecene-1-ol; 1-Butanol; 1-Heptanol; 1-Hepten-3-ol; 1-Hexadecanol; 1-Hexanol; 1-Hexanol, 2-ethyl; 1-Nonanol; 1-Octanol; 1-Octen-3-ol; 1-Pentanol; 1-Propanol; 2-(2-Propoxyethoxy)ethanol; 2,3-Butanediol; 2,4-Hexadien-1-ol; 2-Butanol; 2-Butoxyethanol; 2-Butyl-1-octanol; 2-Decen-1-ol; 2-Ethyl-1-decanol; 2-Ethyl-1-dodecanol; 2-Ethyl-3-buten-1-ol; 2-Ethyl-4-methyl-1-pentanol; 2-Ethylhexanol; 2-Heptanol; 2-Hexadecanol; 2-Hexyl-1-decanol; 2-Hexyl-1-octanol; 2-Hexyldecanol; 2-Methyl-1-hexadecanol; 2-Methyl-undecanol; 2-Penten-1-ol; 2-Propanol; 3,4-Dimethyl-cyclo-hexanol; 3,7,11,15-Tetramethyl-2-hexadecimalen-1-ol; 3,7,11-Trimethyl-1-Dodecanol; 3,7-Dimethyl-1-octanol; 3-Methyl-1-butanol; 6,10,13-Trimethyl-tetradecanol; 7-Octen-4-ol; Anizole; Carveol; *cis*-2-Tert-butyl-cyclohexanolacetate; *cis*-Linalool oxide; Cubenol; Cyclodecanol; Dodecanol; Ethanol; Hexanol; Isobutanal; Isopentanol; Linalool; L-α-Terpineol; Menthol; Methanol; *n*-Dodecanol; *n*-Eicosanol; *n*-Heptadecanol; *n*-Heptanol; *n*-Hexadecane; *n*-Hexanol; *n*-Nonadecanol; *n*-Nonanol; *n*-Octanol; Pentacosene; Pentanol; Phytol; Tetradecanol; *trans*-Linalool oxide; Undecanol; *Z*-10-pentadecen-1-ol; α-Terpineol; δ-Cadinol
2.	Aldehydes	(4*E*)-4-Nonenal; (*E*)-2-Decenal; (*E*)-2-Hexenal; (*E*)-2-Nonenal; (*E*)-2-Octenal; (*E*)-2-Undecenal; (*E*,*E*)-2,4-Decadienal; (*E*,*E*)-2,4-Nonadienal; (*E*,*Z*)-2,6-Nonadienal; (*E*,*Z*)-Deca-2,4-dienal; (*Z*)-Dec-2-enal; (*Z*)-Hex-3-enal; (*Z*)-Non-2-enal; (*Z*,*E*)-2,4-Heptadienal; 2,3,7-Trimethyl-octanal; 2,4-Diene dodecanal; 2,4-Heptadienal; 2,4-Hexadienal; 2,4-Hexadiene aldehyde; 2,4-Octadienal; 2,4-Pentadiene aldehyde; 2-Butyl-1-octenal; 2-Butyl-2-octenal; 2-Dodecenal; 2-Ethyl-2-hexenal; 2-Ethylbenzaldehyde; 4-Ethylbenzaldehyde; 2-Ethylhexanal; 2-Heptenal; 2-Heptene aldehyde; 2-Hexenal; 2-Hydroxybenzaldehyde; 2-Methyl-2-pentenal; 2-Methylbutanal; 2-Methyl-hexadecanal; 2-Methylpentanal; 2-Methylpropanal; 2-Ocetenal (*E*); 2-Octenal; 2-Pentenal; 2-Undecenal; 3,5-Di-tert-butyl-4-hydroxybenzaldehyde; 3-Methyl-2-butyraldehyde; 4,5-Epoxy-(*E*)-dec-2-enal; 4-Methyl benzene formaldehyde; Benzaldehyde; Benzene acetaldehyde; Benzene formaldehyde; Butanal; Cinnamaldehyde; Citral; Decanal; Decyl aldehyde; Dodecanal; Dodecenal; Ethanal; Formaldehyde; Heptanal; Hexadecanal; Hexanal; Isovaleraldehyde; *m*-Tolualdehyde; Myrtenal; Nonanal; Nonnenal; Octanal; *para*-Methyl-benzaldehyde; Pentacontonal; Pentadecanal; Pentanal; Phenylacetaldehyde; *p*-Methylbenzaldehyde; Propanal; Safranal; Tetradecanal; Tridecanal; Undecanal; Undecane; α-Hexylcinnamic aldehyde; β-Cyclocitral; β-Homocyclocitral

S No.	Family of Aroma	Aroma Chemicals
3.	Ketones	(3*E*)-3-Octen-2-one; (3*E*)-6-Methyl-3,5-heptadien-2-one; (*E*)-3-Nonen-2-one; 1-(1*H*-pyrrol-2-yl)-ethanone; 1-(2-Methylphenyl)-ethanone; 1-Hydroxy-2-propanone; 1-Octen-3-one; 2,2,6-Trimethylcyclohexanone; 2,2-Dihydroxy-1-phenylethanone; 2,3-Octanedione; 2,6,6-Trimethyl-2-cyclohexene-1,4-dione; 2,6-Bis(1,1-dimethylethyl)-2,5-cyclohexadiene-1,4-dione; 2-Butanone; 2-Decanone; 2-Dodecanone; 2-Heptadecanone; 2-Heptanone; 2-Hexanone; 2-Methyl-3-octanone; 2-Methyl-5-decanone; 2-Nonanone; 2-Octanone; 2-Pentadecanone; 2-Tetradecanone; 2-Tridécanone ; 2-Undecanone; 3,5,5-Trimethyl-2-cyclopenten-1-one; 3,5-Heptadiene-2-one; 3,5-Octadien-2-one; 3-Hydroxy-2-butanone; 3-Methyl-3-buten-2-one; 3-Nonanone; 3-Nonen-2-one; 3-Octanone; 3-Octene-2-one; 3-Penten-2-one; 4-Cyclopentylidene-2-butanone; 4-Hydroxy-4-methyl-2-pentanone; 5-Ethyl-6-methyl-2-heptanone; 5-Ethyl-6-methyl-3-hepten-2-one; 5-Methy-3-hepten-2-one; 5-Methyl-2-hexanone; 6,10,14-Trimethyl pentadecanone; 6,10,14-Trimethyl-2-pentadecanone; 6,10-Dimethyl-2-undecanone; 6,10-Dimethyl-5,9-undecadien-2-one; 6,10-Dimethyl-5,9-undecandione; 6-Dodecanone; 6-Methyl-2-heptanone; 6-Methyl-3,5-heptadiene-2-one; 6-Methyl-5-ene-2-heptanone; 6-Methyl-5-heptanone; 6-Methyl-5-hepten-2-one; 7,9-Di-tert-butyl-1-oxaspiro-(4,5)deca-6,9-diene,2,8-dione; Acetone; β-Damascenone; Butan-2,3-dione; Carvone; Cyclohexanone; Diphenylketone; Farnesyl acetone; Geranyl acetone; Heptene-dione; Isophorone; Methylheptenone; Neryl acetone; Non-1-en-3-one; Nonadecanone; Nonalactone; Pentan-2-one; *p*-Menthan-3-one; Undecalactone; α/β-Ionone; β-Damascone; γ-Octalactone
4.	Esters and Fatty acids	**Esters:** (*Z*)-9-Octadecenoic acid ethyl ester; 2,4,4-Trimethylpentan-1,3-dioldi-iso-butanoate; 2-Hydroxy, 2-methyl-benzoic acid; 3-Hydroxy-2,4,4-trimethylpentyliso-butanoate; Acetic acid tetradecate; Benzenebutyrate; Benzyl acetate; Dibutyl phthalate; Diethyl carbonate; Diethyl phthalate; Diisobutyladipate; Ethyl-benzoate; Ethyl-hexadecanoate; Ethyl-hexanoate; Ethyl-linoleate; Ethyl-oleate; Ethyl-palmitate; Formic acid hexate; Hexadecanoic acid, methyl ester; Hexanoic acid dodecate; Isobutyl-salicylate; Isopropyl-myristate; Isopropyl-dodecanoate; Methyl-2-furoate; Methyl-benzoate; Methyl-linoleate; Methyl-Oleate; Methyl-palmitate; Methyl-stearate; Methylsalicylate; Octadecanoic acid, ethyl ester; Octyl-formate; Oxalic acid-cyclohexyl methyl nonate: Phenyl acetic acid-4-tridecate

TABLE 1.4 (Continued)

S No.	Family of Aroma	Aroma Chemicals
		Fatty acids: (2*E*)-2-Hexadecenoic acid; 3-Methylbutanoic acid; Acetic acid; Caprylic acid; Decanoic acid; Eicosanoic acid; Hexadecanoic acid; Lauric acid; Linoleic acid; Myristic acid; Nonadecylic acid; Nonanoic acid; Oleic acid; Palmitate; Pentadecanoic acid; Stearic acid; Tetradecanoic acid; Tridecanoic acid
5.	Heterocyclic Compounds	2-Methyl-furan; 2,3-Dihydrobenzofuran; 2-Methyl-5-isopropyl-furan; 2-Pentyl-furan; Indole; Methoxy-phenyl-oxime; Methyl-naphthalene
6.	Volatile Hydrocarbons	**Alkane Hydrocarbons:** 17-Hexadecyl-tetratriacontane; 3,5,24-Trimethyltetracontane; 4-Acetoxy-pentadecane; 6-Methylo-ctadecane; 2-Methyl decane; 2,6,10,14-Tetramethyl-hexadecane; [(1-Methylethyl)thio]cyclohexane; 2,6,10-Trimethyl-pentadecane; 2-Methyl-decane; 2-Methylheptane; 2-Methyl-tridecane; 3,5,23-Trimethyl-tetracosane; 3,5,24-Trimethyl-tetracontane; 3-Methyl-pentadecane; 3-Methyl-tetradecane; 4-Methyldecane; 5-Methyl-pentadecane; 5-Methyl-tridecane; 6-Methyl-octadecane; 9-Methyl-nonadecane; Butyl acetate; Decane; Docosane; Dodecane; Dotriacontane; Eicosane; Ethyl acetate; Geranyl acetate; Heneicosane; Heptadecane; Hexadecane; Hexatriacontane; *n*-Eicosane; Nonadecane; Nonane; Octadecane; Pentacosane; Pentadecane; Tetracosane; Tetradecane; Triacontane ; Tricosane; Tridecane; Tritetracontane
		Alkene Hydrocarbons: Propane; Undecane; (*E*)-5-Methyl-4-decene; (*Z*)-3-Undecene; 17-Pentatricontene; 1-Butene; 1-Docosene; 1-Hexacosene; 1-Tetradecene; 2-Tetradecene; 3,5-Dimethyl-1-hexene; 3-Ethyl-1,5-octadiene; 3-Tridecene; 5-Octadecene; 7-Methyl-2-decene; 7-Tetradecene; Butyl cyclopropane; Dodecene; Ethylene; Nonene; Thujopsene; α-Cadinene; δ-Cadinene
		Alkyne Hydrocarbons: 1-Tetradecyne; 4-Methyl-2-pentyne; Octadecyne

S No.	Family of Aroma	Aroma Chemicals
		Aromatic Hydrocarbons: (1*S*,*Z*)-Calamenene; 1,2,3,4-Tetramethyl-benzene; 1,2,3,5-Tetramethyl-benzene; 1,2,3-Trimethyl-benzene; 1,2,4,5-Tetramethyl-benzene; 1,2,4-Trimethyl-benzene; 1,2-Dimethyl-3-ethyl-benzene; 1,3,5-Trimethyl-benzene; 1,3-Dimethoxy-benzene; 1,3-Dimethyl-4-ethylbenzene; 1,3-Dimethyl-5-ethylbenzene; 1,4-Diethyl-benzene; 1,4-Dimethyl-2-ethylbenzene; 1,4-Dimethylnaphthalene; 1-Chloro-3,5-bis(1,1-dimethylethyl)2-(2-propenyloxy) benzene; 1-Ethyl-3-methyl-benzene; 1-Ethyl-naphthalene; 1-Methoxy-naphthalene; 1-Methyl-naphtalene; 2,3,5-Trimethylnaphthalene; 2,3,6-Trimethyl-naphthalene; 2,6-Bis(1,1-dimethylethyl)-2,5-cyclohexadiene-1,4-dione; 2,6-Dimethylnaphthalene; 2-Acetyl-naphthalene; 2-Ethyl-naphthalene; 2-Methylnaphthalene; 4-Ethyltoluene; Benzene; Carene; Decyl-benzene; Ethyl-benzene; Indene; *m*-Diethyl-benzene; *m*-Xylene; Naphthalene; *n*-Propyl-benzene; *O*-Diethyl-benzene; *O*-Xylene; *P*-Diethyl-benzene; *p*-Xylene; Styrene; β-Bisabolene
		Non-aromatic Cyclic Hydrocarbon: 4-Cyclohexyl-dodecane; Azulene; Cyclosativene; Germacrene-D; Heptyl-cyclohexane; *n*-Heptadecylcyclohexane; *n*-Octyl-Cyclohexane
		Other Volatile Hydrocarbons: 2,6-Dimethyl-decane; 2,4,6-Trimethyl-decane; 3,5-Dimethyl-octane; 3-Ethyl-2-methyl-heptane; 2,5-Dimethyl-undecane; 2-Methyl-dodecane; 2,6,10-Trimethyl-dodecane; 2,6,10-Trimethyl-tetradecane; 3-Methyl-hexadecane; 2,6-Dimethyl-heptadecane; 2,6,10,14-Tetramethyl-heptadecane; Hexacosane; Heptacosane; Octacosane; 1,1-dimethyl-2-octyl-cyclobutane; Alkyl-cyclopentane; Nonyl-cyclohexane; Undecyl-cyclohexane; Pentadecyl-cyclohexane; Heptadecyl-cyclohexane; 1-ethyl-2-methyl-benzene
7.	Organic acids	1,2-Benzenedicarboxylic acid; 1-Hexanoic acid; 2,2,4-Trimethyl-3-carboxyisopropyl, isobutyl ester pentanoic acid; 2,3-Dihydroxy-succinic acid; 2-Ethylcaproic acid; 2-Methylbutanoic acid; 3,7-Dimethyl-hexanoic acid; Benzoic acid; Butanoic acid; Ethyl myristate; Furoic acid; Hexadecyl ester, 2,6-difluro-3-methyl benzoic acid; Hexylpentadecyl ester-sulphurous acid; Isobutyl hexadecyl ester oxalic acid; Isobutyl nonyl ester oxalic acid; *n*-Heptanoic acid; Pentanoic acid; Phenylacetic acid; Propyl acid; Succinic acid
8.	Chlorine-containing	1-Chloro-3-methyl butane;1-Chloro-nonadecane; 2-Chloro-3-methyl-1-phenyl-1-butanone

TABLE 1.4 (Continued)

S No.	Family of Aroma	Aroma Chemicals
9.	Nitrogen-containing	1*H*-Indole; 1-Nitrohexane; 2,3,5-Trimethylpyrazine; 2,3-dimethyl-5-ethylpyrazine; 2,3-Dimethylpyrazine; 2,5-Dimethylpyrazine; 2,6-Dimethylpyrazine; 2-Acetopyridine; 2-Acetyl-1-pyrroline; 2-Acetyl-2-thiazoline; 2-Acetylpyrrole; 2-Amino acetophenone; 2-Butyl-1,2-azaborolidine; 2-Ethyl-3,5-dimethylpyrazine; 2-Ethyl-3-methylpyrazine; 2-Ethyl-5-methylpyrazine; 2-Ethyl-6-methylpyrazine; 2-Isoamyl-6-methylpyrazine; 2-Isobutyl-3-methoxypyrazine; 2-Methoxy-3,5-dimethylpyrazine; 2-Methylpyrazine; 2-Methylpyridine; 3-Ethyl-2,5-dimethylpyrazine; 3-Methylindole; 3-Methylpyridine; 3-Vinylpyridine; 4-Methylpyridine; 5-Amino-3,6-dihydro-3-imino-1(2*H*) pyrazine acetonitrile; 7-Chloro-4-hydroxyquinoline; Benzonitril; Benzothiazole; Ethenylpyrazine; Ethylpyrazine; Isocyanato-methylbenzene; *N*,*N*-dimethyl chloestan-7-amine; *N*,*N*-dinonyl-2-phenylthioethylamine; *N*-FurfurylPyrrole; Nicotine; N-methoxymethanamine; O-Decylhydroxamine; Propiolonitrile; Pyrazine; Pyridine; Pyrolo[3,2-d]pyrimidin-2,4(1H,3H)-dione; Pyrrole; α-Pyrrolidinone; β-Quinoline
10.	Phenol-containing	2,2-Dihydroxy-1-phenyl-ethanone; 2,6-Dimethoxy-phenol; 2,6-Dimethylaniline; 2-Methylphenol; 2-Phenoxyethanol; 2-Phenylethanol; 4-Vinylguaicol; 4-Vinylphenol; 5-Ethyl-4-methyl-2-phenyl-1,3-dioxane; Acetophenone; Benzyl alcohol; Biphenyl; Butylatedhydroxytoluene; Guaiacol; Isoeugenol; *m*-Cresol; p-Cresol; Phenol; Toluene; Vanillin
11.	Sulphur-containing	[(1-Methylethyl)thio] cyclohexane; 1-Propene-1-thiol; 2-Methyl-3-furanthiol; 3-Dimethyl-2-(4-chlorphenyl)-thioacrylamide; 3-Methyl-2-butene-1-thiol; Butanethiol; Dimethyl disulfide; Dimethyl sulphide; Dimethyl trisulfide; Hydrogen sulfide; Methanethiol;Methional; Prenylthiol
12.	Terpene	**Sesquiterpenes:** Camphene; *d*-limonene; Eucalyptol; L-Limonene; Menthone; *p*-Cymene; α-Phellandrene; α-Pinene **Monoterpene:** (E,E)-Farnesol; Aromadendrene; Isolongifolene; Longifolene; Turmerone; Valencen; α-Farnesene; β-Caryophyllene; β-Elemene

1.5 FACTORS AFFECTING RICE AROMA, FLAVOR, AND FRAGRANCE

Many factors such as genetic factor, stickiness/glutinousness, pre-harvesting, harvesting time, moisture content at harvesting, storage conditions, degree of milling, storage temperature and time, washing, cooking method, and serving temperature of cooked rice affect the development of aroma, flavor, and fragrance in rice at different stages of growth and development. Some of them are described as follows.

1.5.1 GENETIC FACTOR

Genetic factor is the main important source of variability for the development of aroma, flavor, and fragrance in rice through crop improvement. Lorieux et al. (1996), Jin et al. (2003), and Chen et al. (2006) have been reported that this is due to an eight-base pair deletion in exon 7 of a gene. This base pair deletion occurs at chromosome 8. Bradbury et al. (2005b) reported that the putative gene for the development of fragrance genotyping in rice is coded by a putative enzyme betaine aldehyde dehydrogenase 2 (*BAD2*). After the deletion, the encoded enzyme loses its function and, subsequently, the accumulation of 2-AP takes place in aromatic rice cultivars. In 2008, Fitzgerald et al. (2008) studied 464 samples collected from the Centre of Genetic Resource of International Rice Research Institute (IRRI) Manila, Philippines, in the search of the second fragrance gene in rice. In the report of Fitzgerald et al. (2008), the majority of rice cultivars belonged to South, and rice cultivars from Southeast Asia had 2-AP, but did not carry 8-bp deletion, whereas Champagne et al. (2008) suggested that the 8-bp deletion in the fragrance allele is also a cause of mutation that drives the accumulation of 2-AP in addition to contributing the aroma in rice cultivars.

1.5.2 STICKINESS/GLUTINOUSNESS

Stickiness/Glutinousness is an important physical characteristic in addition to other characteristics, based on which consumers prefer overall

acceptability of rice grain quality (Bhonsle and Krishnan, 2010). Among the glutinous rice cultivars, quality and environmental adaptations are considered to vary widely; some of them are aromatic, from white to purple and black in color, and with diverse grain size. These glutinous rice cultivars are the staple food for the peoples of Lao PDR and northeast Thailand since ancient times (Almanac, 2012). These rice cultivars have very unique characteristics such as being opaque (somewhat translucent) when raw; most nonglutinous rice varieties (Chaudhary, 2003) have 2.6–4.8% amylose content, which is lower than that (10–30%) found in nonglutinous rice varieties (KBIRRI, 2016). Glutinous rice cultivars have high amylopectin content, which is responsible for glue-like stickiness but does not contain dietary gluten (i.e., it does not contain glutenin and gliadin), and due to this reason, such rice cultivars are considered as safe for gluten-free diets (Chaudhary, 2003).

1.5.3 PRE-HARVESTING

Quality traits of rice cultivars, like aroma, amylose and protein content, etc., are affected by cultural practices and environmental conditions. Rice samples with low protein content are found to have more aroma than those with high protein content (Juliano et al., 1965). Champagne et al. (2007) grew five diverse rice cultivars with aroma and flavor conventionally with typical use of nitrogen at 50% and 100%, and chicken litter was used as organic management for comparison. Rice samples were found to have lower protein content of 7.7% and 7.5% with organic management and 50% N rate, respectively. The result concluded that rice samples showed no difference in aroma or flavor from those with higher protein content (mean 9.2% with 100% N rate). Similarly, Terao et al. (2005) reported that in the rice cultivar Akitakomachi grown under elevated CO_2 concentration, the protein content will decrease, but it did not change the sensory properties to a level that could be detected by taste panel evaluation. The concentration of 2-AP varies with environmental conditions. Itani et al. (2004) reported higher concentration of 2-AP in brown rice ripened at low temperature (day 25°C; night 20°C) than that ripened at high temperature (35°C in day; 30°C at night).

1.5.4 HARVESTING TIME

For harvesting at the proper stage, some physiological parameters (such as maturity of crop, moisture content, and meteorological conditions) must be considered that permit farmers to foster conditions for high recovery of head rice yield. Champagne et al. (2005) studied the effects of drain and harvest dates on rice sensory and reported that a predominant variety, M-202 produced in California, was found to be the representative of stable flavor with 14-day span timing of field draining and harvesting of 32−48 days after flowering. Tamaki et al. (1989) reported that rice flavor declines with maturity. In immature rice, flavor was deliberated to be rich but was found to be poor in over-ripened rice. In an early-heading cultivar of brown rice, the concentration of 2-AP during grain development stage was increased at four or five weeks after heading (WAH) and thereafter observed decreased rapidly with 20% at the maximum of seven or eight WAH. However, it was found increase at four WAH and then steadily decreased with 40% at the maximum of eight WAH (Itani et al., 2004).

1.5.5 STORAGE TEMPERATURE AND TIME

Storage temperature and time are also very important factor that affects the aroma quality of the milled rice. Lipase is a pancreatic enzyme that catalyzes the breakdown of fats to fatty acids and glycerol or other alcohols. This pancreatic enzyme in the residual bran is present on the surface of milled rice which form free fatty acid during the period of rice storage. On hydrolysis, the surface lipids form free fatty acids that are susceptible to oxidation (Yasumatsu and Moritaka, 1964). There are a number of secondary oxidation products (viz., acids, alcohols, aldehydes, furanones, ketones, and lactones), and hydrocarbons are formed by oxidation of unsaturated fatty acids; particularly, linoleic and linolenic acids were reported for the development of off-flavors and odors (Yamamatsu et al., 1966; Grosch, 1987). Champagne et al. (2005) observed based on aroma values (AV) that hexanal (grassy flavor) and 2-pentylfuran (beany) probably contributed more to flavor change in milled rice early in storage rather than at later period. 2-Nonenal (rancid flavor) and octanal (fatty flavor) contributed more to the overall flavor of milled rice during long-term storage.

1.5.6 SOAKING

Many countries over the globe, such as Japan, Korea, and other Asian countries, pre-soak rice for >30 min as a traditional practice. This pre-soaking traditional practice helps in shortening of gelatinization time and facilitates uniform cooking. Whereas the chemical changes have altered the rice flavor and aroma in the grain by soaking.

1.5.7 COOKING METHOD

The method of cooking also affects the flavor in rice, i.e., a consumer panel found rice cooked by the Pilaf method had more acceptable flavor than the excess cooking method (Crowhurst and Creed, 2001). Possible flavor compounds were lost during draining following cooking in the excess cooking method.

1.5.8 SERVING TEMPERATURE OF COOKED RICE

Serving temperature affects the contents of certain compounds of individual cultivars differently, which affect the aroma of rice. For example, Liu et al. (1996) reported that aroma of cooked rice samples rated higher in sweetness at 18°C, whereas samples evaluated at 60°C scored higher in burnt rice and rice with earthy, moldy, rancid, and sulfur aromas.

1.6 CONCLUSION

Rice is an important food crop that sustains to the daily food requirement of the people throughout the world, including Asia, South and North America, Africa, and parts of Europe. The rice-the food of daily life is preferred on the basis of aroma, flavor, and fragrance after cooking that is also considered as an important quality trait preferred by most people. The goal of this chapter is to offer a brief overview of what is known about aroma compounds in rice, addressing and discussing especially on the importance of rice aroma, flavor, and fragrance, and what are the factors that affect the aroma quality of rice.

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KEYWORDS

- **2-acetyl-1-pyrroline**
- **aroma chemicals**
- **aroma compounds**
- ***Pandanus amaryllifolius***
- **rice-rice aroma**
- **rice quality**
- **volatile aroma**

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