

Characterization of Cooked Nonglutinous Rice Cultivars Based on Flavor Volatiles and Their Change during Storage

Keishi Yamashita, Nanako Kato, Kento Sakakibara, Aki Seguchi, Asako Kobayashi, Shinobu Miyagawa, and Tomohiro Uchimura*



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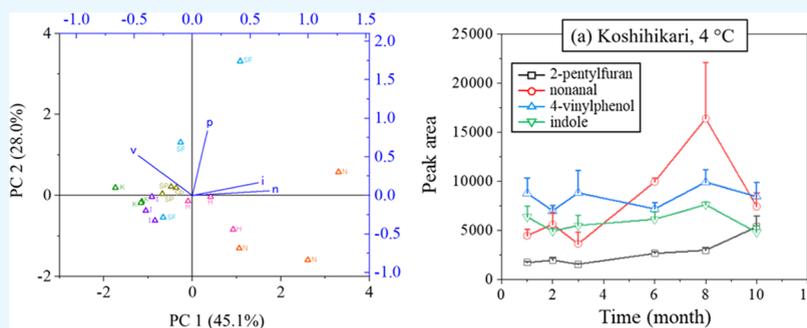
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ABSTRACT: Characterizing freshly cooked rice cultivars according to the volatile aroma compounds helps consumers select a favorite and is useful for the development of new cultivars that will have a pleasant aroma. In the present study, six Japanese nonglutinous cultivars, which were freshly harvested in 2021, were characterized based on their flavor volatiles after being freshly cooked. In order to extract the volatile compounds just after cooking, the vaporized compounds were extracted for 5 min using a solid-phase microextraction (SPME) fiber and were measured via gas chromatography/mass spectrometry (GC/MS). Multiple comparison tests statistically detected four volatile aroma compounds: 2-pentylfuran, nonanal, 4-vinylphenol, and indole. From among the six rice cultivars tested, the proportions of the latter two compounds showed significant differences, and in principal component analysis of cooked rice, these two best characterized freshly harvested and freshly cooked Japanese nonglutinous rice cultivars; indole was indicative of Nipponbare, and 4-vinylphenol was indicative of Koshihikari and Ichihomare. In the present study, changes in the volatile aroma compounds of the freshly cooked rice cultivars were found to slightly differentiate according to storage times: 2-pentylfuran tended to increase, nonanal first increased and then decreased, and 4-vinylphenol and indole either remained almost unchanged or were only slightly decreased during storage. Therefore, establishing the differences in rice cultivar types revealed that the characteristics of the flavor volatiles of freshly cooked rice after long-term storage significantly depend on how the rice cultivar is stored.

INTRODUCTION

Nonglutinous rice is a staple food in Japan; Koshihikari has been the most widely cultivated variety of rice in Japan since 1979.¹ In 2020, Koshihikari's share of the total cultivated area was 33.7%, and the top 10 varieties all are descendants of Koshihikari.² The odor of cooked rice is one of the most important qualities contributing to the pleasure of eating rice—equal even to taste and texture. However, an objective evaluation of odor is difficult, and sensory testing is common. The objective characterization of the odors of rice cultivars is possible, however, via a combination of the instrumental analysis of volatile aroma compounds and sensory testing. Such a characterization helps consumers select a favorite.

Gas chromatography/mass spectrometry (GC/MS) is generally applied to the analysis of the volatile aroma compounds in cooked rice.^{3,4} To perform GC/MS analysis of the rice consumed in Japan, a Tenax GC trap and injection

technique is used to measure the volatile compounds in cooked nonglutinous rice (Koshihikari), and it has been reported that the quantities of volatile compounds decrease when rice is milled.⁵ Recently, solid-phase microextraction (SPME) has been applied to the volatile compounds in cooked rice. Reports of the flavor volatiles released during and after the cooking of three nonglutinous rice cultivars are particularly noteworthy—Nipponbare has a higher amount of indole, while Koshihikari and Akitakomachi have higher amounts of 4-

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Figure 1. Brown rice samples. Rice cultivars: 1, Nipponbare; 2, Hanaechizen; 3, Koshihikari; 4, Ichihomare; 5, Shin-Fuku 1; and 6, Shine Pearl.

vinylphenol.⁶ In our previous study, volatile compounds from cooked rice were measured using SPME-GC/MS, where ultraviolet laser pulses were applied as an ionization method for MS that is referred to as resonance-enhanced multiphoton ionization (REMPI).⁷ In that paper, to measure the volatile compounds from rice just after cooking, a normal rice cooker was used with a short extraction time (5 min) for SPME in order to replicate the orthonasal aroma at mealtime. As a result, the amount of 4-vinylphenol proved to be large for nonglutinous rice (Ichihomare) and that of indole was large for glutinous rice (Tanchomochi).

Analysis of the volatile aroma compounds in cooked rice and descriptions of the characteristic odors of rice cultivars helps consumers select a favorite and is surely useful for the development of new rice cultivars that will have a pleasant aroma. In addition, evaluating the change in the flavor volatiles against storage time and storage conditions is also important.^{8–12} The general temperature for the storage of brown rice in Japan is 15 °C, but the behavior of the change in the amount of volatile aroma compounds is, of course, dependent on the storage temperature. Such studies offer information such as the optimal storage conditions that must be used for each rice cultivar and the maximum amount of time that the desired characteristics of odor could be expected to be preserved under a given set of storage conditions.

In the present study, six freshly harvested and freshly cooked nonglutinous rice cultivars were characterized based on the flavor volatiles measured by SPME-GC/MS. These are the main paddy rice cultivars in Fukui Prefecture, Japan, and are intended to be branded by differentiating their odor. Moreover, we monitored the time courses for the storage of the volatiles and noted any changes in their characteristics by comparison with those in freshly cooked rice. This study should help establish the optimal storage conditions of rice according to differences in cultivar type and personal preferences for odor and should also be useful for the development of new rice cultivars with a pleasant aroma.

EXPERIMENTAL SECTION

Reagents. A standard mixture of *n*-alkanes was purchased from GL Sciences, Inc. (Product No. 1021-58303) and diluted

in hexane (CAS No. 110-54-3, FUJIFILM Wako Pure Chemical Corporation). Next, 2-pentylfuran (CAS No. 3777-69-3) and nonanal (CAS No. 124-19-6) were diluted in hexane, while 4-vinylphenol (10% solution in propylene glycol, CAS No. 2628-17-3) and indole (CAS No. 120-72-9) were diluted in acetone (CAS No. 67-64-1), all of which were purchased from FUJIFILM Wako Pure Chemical Corporation. In order to identify contaminants arising from the indoor environment, the probable compounds were examined: 2,2,4-trimethyl-1,3-pentanediol diisobutyrate (TXIB, CAS No. 6846-50-0, Toronto Research Chemicals, ON, Canada) was diluted with acetone, and dibutyl phthalate (CAS No. 84-74-2, FUJIFILM Wako Pure Chemical Corporation) was diluted with hexane.

Rice and Cooking Conditions. Six Japanese nonglutinous rice cultivars were used: Nipponbare, Hanaechizen, Koshihikari,¹ Ichihomare,¹³ Shin-Fuku 1,¹⁴ and Shine Pearl; the photos of brown rice samples produced in 2022 are shown in Figure 1. All nonglutinous rice samples used in the present study were harvested at the Fukui Agricultural Experiment Station (Japan) in 2021 (Nipponbare, 21 September; Hanaechizen, 19 August; Koshihikari, 6 September; Ichihomare, 15 September; Shin-Fuku 1, 7 September; and Shine Pearl, 7 September). The first three rice cultivars are in distribution in Japan; Ichihomare is in distribution in the Fukui Prefecture, and the latter two cultivars were recently developed at the Fukui Agricultural Experiment Station. The pedigree of Nipponbare is completely different from that of the other five cultivars. Namely, Hanaechizen, Ichihomare, and Shine Pearl are descendants of Koshihikari, whereas Shin-Fuku 1 is derived from a mutant of Koshihikari, but the ancestry of Nipponbare does not include Koshihikari. Incidentally, the culm length of Koshihikari is the highest, and it is the most susceptible to lodging among these six cultivars. In the summer of 2021, Fukui experienced long rains and low temperatures, which caused the culms of Koshihikari plants to grow taller, and further heavy rains caused them to completely lodge. As a result, the Koshihikari rice grains did not fully ripen. The unripened rice was removed, resulting in low yields. Even in the sampled rice, there was a large amount of chalky rice that may have affected the odor of the Koshihikari rice.

All harvested rice grains were dried, dehulled, and stored as brown rice in a paper bag. The storage temperature was either 4 °C (in a refrigerator) or 15 °C (in storage for rice). All rice was milled using a rice milling machine (RCI-AS-B, IRIS OHYAMA Inc., Miyagi, Japan) immediately prior to measurement. The degree of milling was set at 90% so that only 10% of the outer bran layer of the brown rice was removed via milling. Each cooked batch consisted of 450 g of milled rice. The washing procedure and cooking conditions were the same as those described previously.⁷ Rice was cooked using a household induction-heated rice cooker (SR-HD103, Panasonic Corporation, Tokyo, Japan) under a fume hood for evacuation. The cooking time was 27 min.

Solid-Phase Microextraction (SPME). A 1 cm SPME fiber (57328-U, 50/30 μm thickness of divinylbenzene/carboxen/poly(dimethylsiloxane) (DVB/CAR/PDMS), Supelco/Sigma-Aldrich, St. Louis, MO) was used for extracting vaporized compounds from the cooked rice. After cooking, each sample of rice was let to stand for 5 min with the lid of the rice cooker closed. Then, air exhaustion from the fume hood was stopped, and the lid was opened. At that point, an SPME fiber was held ca. 3 cm from the cooked rice by hand for 5 min. During the process of extraction, the cooked rice was stirred twice—just after opening the lid and at 2.5 min after beginning the extraction. Before the extraction, a SPME fiber was conditioned via insertion into a piped heater (TMF-300N, AS ONE, Osaka, Japan) and into the injection port of a GC as a blank measurement. After 5–6 full extractions, the fiber was exchanged for a new one in order to exclude the possibility that components in the vapor might have adhered to it and affected the extraction efficiency.

GC/MS. A gas chromatograph/quadrupole mass spectrometer (GC/QMS, 8890GC/5977MSD, Agilent Technologies, Santa Clara, CA) was used for the measurement of vaporized compounds from cooked rice. When extraction was finished, the SPME fiber was inserted into the injection port of the GC. A splitless mode was used for injection, with the inlet temperature set at 250 °C. The purge time was 1 min.

An HP-5ms Ultra Inert capillary column (Agilent Technologies Inc., inner diameter 250 μm , film thickness 0.25 μm , length 30 m) was employed for GC separation. Helium (purity >99.99995%) was used as a carrier gas at a constant flow rate of 1.0 mL/min. The oven temperature of the GC was set at 50 °C for the first 5 min and was then raised to 280 °C at a rate of 15 °C/min. The temperature was held at 280 °C for 5 min. The temperatures of the transfer line and the ion source were 285 and 230 °C, respectively. The effluent from the column was ionized via a 70 eV electron ionization source. Mass spectra were recorded in scan mode from m/z 40 to 400. For daily system evaluation, a standard mixture solution of *n*-alkane was measured at the beginning of each measurement day, and the peak area of the quantitation ion of tetradecane (m/z 57) was routinely checked. As a result, the relative peak area for tetradecane ranged from 84 to 117% when calculated from each raw peak area divided by the average peak area throughout the present study (11 months). Therefore, the method maintained long-term quantitative accuracy. The volatile compounds detected by SPME-GC/MS were identified by each standard solution and/or were confirmed using the mass spectral library (NIST 20). The retention times and the m/z of the molecular ion peak and that of the base peak for compounds are shown in Table S1. The area of the base peak was used for quantification. As a control experiment, an SPME

fiber was placed inside a fume hood for 5 min with no rice cooking, and the residual components in the indoor environment were measured via GC/MS. All of the experiments were performed in triplicate.

Data Analysis. A Tukey–Kramer multiple comparison test was performed using the BellCurve for Excel (Social Survey Research Information Co., Ltd., Tokyo, Japan) to assess the significant differences between the peak areas of each compound from cooked rice and the indoor air. Principal component analysis (PCA) was also performed on volatile aroma compounds using data analysis software (OriginPro, LightStone Corp., Tokyo, Japan).

RESULTS AND DISCUSSION

Characterization of Nonglutinous Rice Cultivars Based on Volatile Aroma Compounds in Cooked Rice.

Figure S1 shows the extracted mass chromatograms (EIC) obtained from Koshihikari that was freshly harvested and freshly cooked. All measurements using six nonglutinous rice cultivars were performed within 1 month after the rice was harvested, dried, and dehulled. The extraction time from the freshly cooked samples was as short as 5 min, which was considered an approximation of orthonasal aromas at mealtime. As a result, the peak areas of the rice cultivars were statistically different for some or all of the four volatile aroma compounds (2-pentylfuran, nonanal, 4-vinylphenol, and indole) compared with the peak areas from indoor air (Figure 2, see also Figure S2 for confirmation of all compounds). In

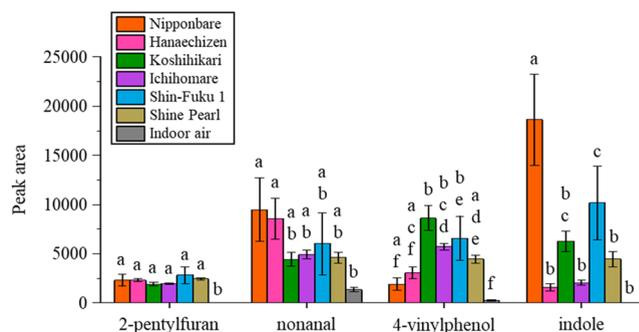


Figure 2. Comparison of peak areas for four volatile aroma compounds obtained from six different cooked rice cultivars combined with the influence of ambient indoor air. Error bars represent the standard deviation of three measurements. In each compound, vertical bars with different letters are significantly different ($p < 0.05$). See also Figure S2 for all compounds to be confirmed in the present study.

particular, the peak areas of the latter two compounds showed a significant difference among the rice cultivars; the peak area for 4-vinylphenol was relatively strong in Koshihikari, Ichihomare, and Shin-Fuku 1, and that for indole was strong, particularly in Nipponbare. Though decanal and hexadecanoic acid were reported to be vaporized from cooked nonglutinous rice,^{6,15} the peak areas showed no significant differences compared with those from indoor air under the present experimental conditions (Figure S2). Incidentally, TXIB and dibutyl phthalate were reported in the indoor air.¹⁶ The signal intensity of volatile aroma compounds is enhanced if the extraction time is prolonged. However, the temperature of a rice cooker pot generally decreases after cooking (during maintaining warmth), which gradually decreases the amount of

volatile compounds. In addition, the volatile compounds that exist just after cooking should gradually decrease, which means the amount of extraction would not be directly proportional to the extraction time. In our preliminary experiment, the above-mentioned four flavor volatiles increased 2–3 times when the extraction time was 20 min (4 times). These results suggest that the orthonasal aroma of cooked rice could change with time. Therefore, an extraction time that is as short as possible is desirable for the characterization of cooked rice according to the orthonasal aroma. In addition, there is a possibility that an increase in the extraction time could lead to the adherence of vapor components to the fiber, which would affect the extraction efficiency. Therefore, the extraction time was determined to be as short as 5 min, though the flavor volatiles studied in this paper were few in number (4).

Figure 3 features the PCA of the peak areas for the four volatile aroma compounds obtained from rice cultivars that

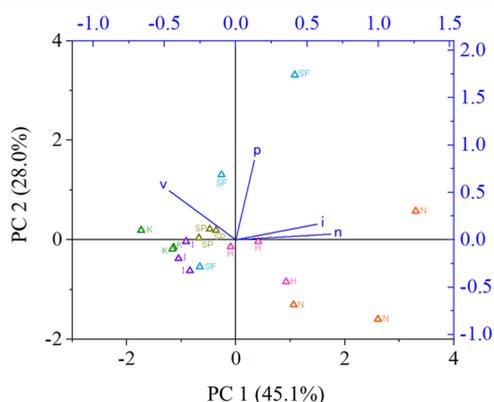


Figure 3. PCA biplots (score and loading) based on four volatile aroma compounds in cooked rice of six different rice cultivars. On each biplot, the left and bottom axes are the sample score scales, and the right and top axes are the loading vector scales. Compounds: p, 2-pentylfuran; n, nonanal; v, 4-vinylphenol; and i, indole. Rice cultivars: N, Nipponbare (orange); H, Hanaechizen (pink); K, Koshihikari (green); I, Ichihomare (purple); SF, Shin-Fuku 1 (light blue); and SP, Shine Pearl (ocher).

were freshly harvested and freshly cooked. The first and second principal components, PC 1 and PC 2, accounted for 45.1 and 28.0% of the total variation, respectively. By also taking the result of Figure 2 into account, Nipponbare showed a distinct separation from the other five rice cultivars, with, in particular, indole imparting large positive values for PC 1, which is indicative of this rice cultivar. Nipponbare is known to contain a higher amount of indole compared with Koshihikari.⁶ Indole is known to be significantly different among different cultivars; for example, cooked aromatic rice is reported to contain more indole compared with that in cooked Koshihikari.¹⁷ In our previous study using GC/REMPI-MS as an analytical method, indole was strongly detected from cooked Tanchomochi (glutinous rice) compared with cooked Ichihomare (nonglutinous rice).⁵ Indole had the odor of household insecticide when the aroma of an authentic reagent was sniffed.⁵ In lower concentrations, however, the odor of this compound has a herbaceous scent.^{18,19}

The results of Figures 2 and 3 show a tendency for nonanal to be indicative of Nipponbare and Hanaechizen, but the indole content is small in Hanaechizen compared with that in Nipponbare. Nonanal has also been detected as a compound in

cooked rice.^{15,20,21} Nonanal had a relatively strong fruity odor when an authentic reagent was sniffed in our laboratory, and it is one of the possible compounds that could be used to characterize rice that has been freshly harvested and freshly cooked. Incidentally, the amount of this compound was significantly changed during storage, as described later.

Koshihikari and Ichihomare could be distinguished from the other four rice cultivars by showing negative values for the PC 1 of 4-vinylphenol, which is indicative of these cultivars. This compound possessed a sweet odor similar to that of caramel (similar to cough syrup for children) when the aroma of an authentic reagent was sniffed.⁷

In the case of Shine Pearl, Figure 2 shows intermediate values for the peak areas of both indole and 4-vinylphenol, and PCA plots for this rice cultivar are localized centrally in Figure 3. On the other hand, the error bars of all peak areas for Shin-Fuku 1 are large in Figure 2, and the corresponding plots are indicative of dispersal, as shown in Figure 3.

As Figure 3 shows, 2-pentylfuran imparted large positive values on PC 2. This compound had a fruity odor (La France-like scent) when an authentic reagent was sniffed. However, as shown in Figure 2, there were no significant differences among the six rice cultivars just after being harvested. Moreover, this compound seemed to roughly increase with storage time, as described later. Therefore, this compound was not included in the characterizations of these nonglutinous rice cultivars.

As previously stated, 4-vinylphenol and indole are used in the present study to characterize freshly harvested and freshly cooked Japanese nonglutinous rice cultivars. Of course, this characterization reflects the use of rice cultivars harvested in 2021, and an annual study should be performed in the future in order to verify repeatability.

Changes in the Amounts of Volatile Aroma Compounds during Storage. The changes in the volatile aroma compounds of freshly cooked rice cultivars are shown in Figure 4 according to storage time; the significant differences among the different months appear in Figure S3. Koshihikari was stored at 4 °C, Ichihomare was stored at both 4 and 15 °C, and Hanaechizen and Nipponbare were stored at 15 °C. Koshihikari, Ichihomare, and Hanaechizen were monitored at the same intervals during storage over a half-year period: 1, 2, 3, and 6 months. Koshihikari and Ichihomare were further monitored at 8 and 10 months, while Hanaechizen was checked at 9 and 11 months. Hanaechizen was harvested 1 month earlier than the others, and therefore, the above three rice cultivars were monitored in the same months after half a year: May and July, 2022. On the other hand, Nipponbare's share of the total cultivated area is small in Japan, and this rice cultivar was peripheralized at first. Therefore, the amount of cultivation (i.e., storage) is small, and as a result, only two plots were obtained.

Herein, the obtained behaviors are discussed as a rough tendency during storage, though some data are not necessarily applicable when significant differences are considered. As shown in Figure 4a,b, Koshihikari and Ichihomare, which had similar characteristics of volatile aroma compounds just after harvest, showed similar signal behaviors under the same storage temperature of 4 °C. In those cultivars, nonanal changed drastically during storage, and the amount had increased 6–8 months after harvest, at which point it tended to decrease. This compound is produced by oleate hydroperoxide decomposition, and during storage, it is known to increase and then decrease when it is stored at 25 °C in the

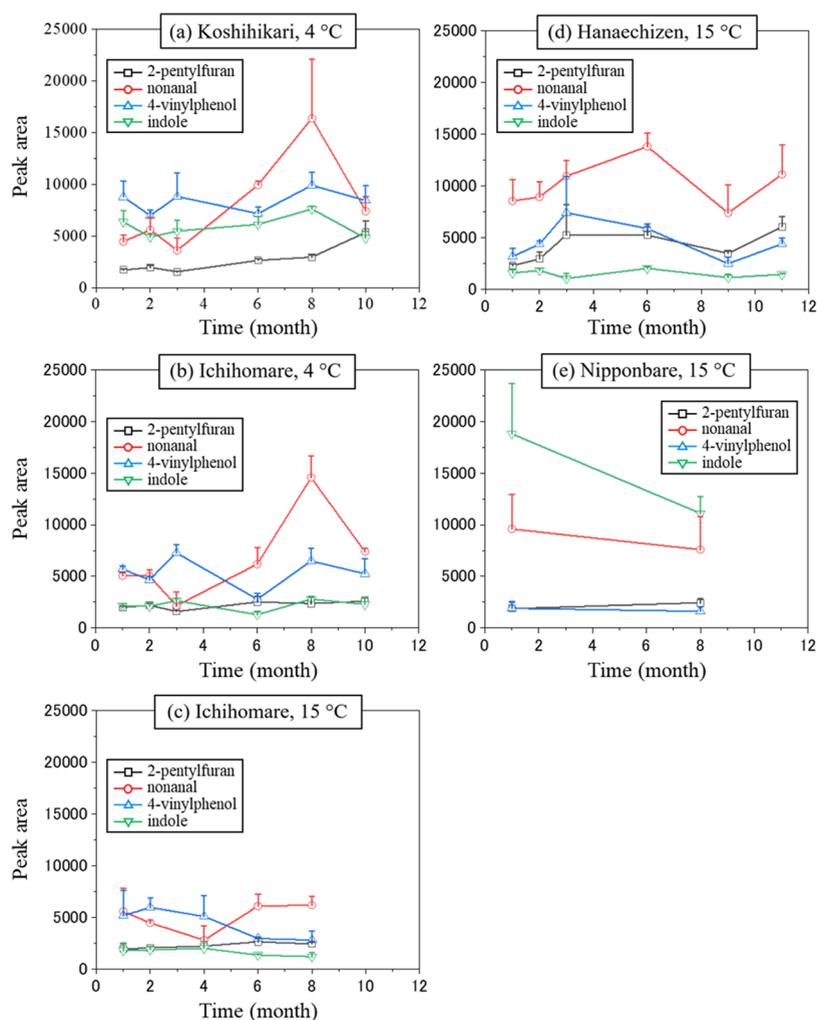


Figure 4. Changes in the peak area of four volatile aroma compounds with storage time. Error bars represent the standard deviation of three measurements; only the upper error bars are illustrated for better visibility. Rice cultivars: Koshihikari (a); Ichihomare (b, c); Hanaechizen (d); and Nipponbare (e). Storage temperatures: 4 °C (a, b); 15 °C (c–e). The abscissa indicates the storage time (month); e.g., the value of 2 means that three measurements were performed ranging from 1 to 2 months after harvest, following drying and dehulling. The significant differences among the different months appear in Figure S3.

form of unmilled black rice.²¹ Another noteworthy change has been reported for 2-pentylfuran, which is an oxidation product of linoleic and linolenic acid and is formed in a lipoxygenase reaction along with 1-pentanol.¹² The amount of 2-pentylfuran also has been known to increase with storage time,⁶ and in the present study, an increase was noted 6 months after harvest of Koshihikari, and Ichihomare also showed a slight increase at the same time. The behaviors of these compounds could be the result of a balance between an increase caused by decomposition and a decrease caused by vaporization during storage. The other compounds, 4-vinylphenol and indole, which were significantly different between freshly harvested rice cultivars, were not significantly changed throughout the present storage time, although the amounts did fluctuate. By contrast, a different result was confirmed for Ichihomare when stored at 15 °C (Figure 4c); the peak area of nonanal was roughly unchanged, whereas the peak areas for 4-vinylphenol and indole were slightly decreased after half a year. Most of the flavor components in rice are produced in low amounts at the onset of lipid oxidation, and some of them are produced by thermal decomposition of the nonvolatile constituents existing in rice.¹⁹ Though 4-vinylphenol is considered to be formed by

thermal decomposition during cooking,¹⁷ to the best of our knowledge, no papers have reported the formation mechanism of indole. The amounts of 4-vinylphenol and indole in cooked rice were almost unchanged, or perhaps had been slightly decreased, after long periods of storage, but these compounds did not seem to increase in the same manner as 2-pentylfuran and nonanal.

The amounts of the four volatile aroma compounds in Hanaechizen stored at 15 °C (Figure 4d) were relatively unchanged 2 months after harvest, which mirrored the tendency shown in Figure 4a–c. Nonanal, which is a characteristic compound in freshly harvested Hanaechizen, maintained a high amount, although there was a degree of fluctuation. The amount of 2-pentylfuran had increased 3 months after harvest. Such differences in signal behavior against those appearing in Figure 4c could have been due either to the differences in rice cultivars or to rather higher temperatures due to drying following harvest because this was the only rice cultivar that was harvested and dried in August.

As shown in Figures 2 and 3, indole and nonanal were characteristic compounds for Nipponbare. Although only scant data are available (Figure 4e), the peak area of the former was

decreased after 8 months of storage following harvest, while the latter maintained a high amount.

The PCA of the peak areas for the four volatile aroma compounds shown in Figure 4 appears in Figure 5. The

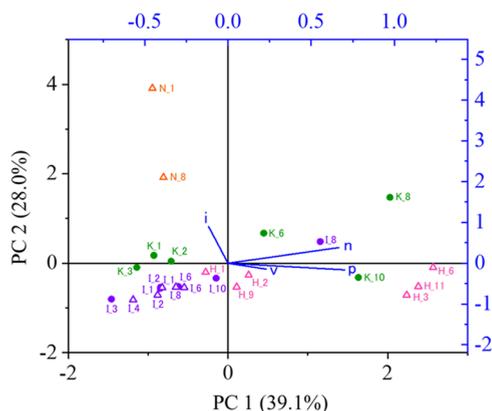


Figure 5. PCA biplots (score and loading) based on four volatile aroma compounds in freshly cooked rice. On each biplot, the left and bottom axes are the sample score scales, and the right and top axes are the loading vector scales. Compounds: p, 2-pentylfuran; n, nonanal; v, 4-vinylphenol; and i, indole. Rice cultivars: N, Nipponbare (orange); H, Hanaechizen (pink); K, Koshihikari (green); and I, Ichihomare (purple). Storage temperatures: 4 °C (filled circle); 15 °C (open triangle). The number following the underscore indicates the storage time (month).

direction of the four eigenvectors approximated one another, compared with the calculations shown in Figure 3, which was based on the four compounds from the six freshly harvested rice cultivars. This was probably due to the small peak areas for all compounds in Ichihomare stored at 15 °C, and, in fact, corresponding plots were localized in the quadrant without eigenvectors, as shown in Figure 5. In this PCA, the plots for Nipponbare showed a distinct separation from those for the other rice cultivars, and those for Koshihikari and Ichihomare stored at 4 °C were similarly changed due to the significant change in the peak area for nonanal, as shown in Figure 4a,b. It is noteworthy that under all experimental conditions, the changes in the peak areas for the first few months were small, and this is confirmed in Figure 4.

Although rice is harvested from July to November in Japan, harvest peaks in September in most areas. Herein, our findings of the changes in the odors of freshly cooked nonglutinous rice cultivars against time have been described based on the results of Koshihikari and Ichihomare during a normal harvesting season. Japan is located in the northern hemisphere, and after harvest, the season changes from autumn to winter, and therefore, stored rice grains seldom experience higher temperatures for several months. As shown in Figure 4, the amounts of the four volatile aroma compounds tested in the present study were almost unchanged for the first few months of storage either at 4 or 15 °C, and there is a possibility that other trace volatile aroma compounds would also remain unchanged for the same period. Therefore, the odors and characteristics of each freshly cooked rice cultivar could be considered stable for a few months after harvest, which typically means the end of autumn or the beginning of winter. Subsequently, the amount and the ratio of volatile aroma compounds are assumed to be gradually changed roughly from December to the beginning of

the following year, which would probably result in a change in the odor.

Because all rice cultivars used in the present study were stored at low temperatures, it is difficult to predict the change in the odor of freshly cooked rice after long-term storage that might last until spring or the hot summer months in Japan. The results of the present study suggest that the amounts of 4-vinylphenol, which is produced by thermal decomposition, and indole significantly characterize freshly harvested and freshly cooked rice cultivars, and these would be either unchanged or slightly decreased by longer storage time. The amount of 2-pentylfuran and nonanal, however, would be likely to increase during storage due to lipid oxidation. Based on these assumptions, following long-term storage, the features found in freshly harvested rice that arise from 4-vinylphenol and indole are expected to gradually disappear, and the odor is expected to gradually be influenced by 2-pentylfuran and nonanal. Therefore, the characteristics of the flavor volatiles, and perhaps the characteristics of the odor itself, of freshly cooked rice after long-term storage significantly depends on how the rice cultivar is stored, in addition to any differences in rice cultivar type. As a matter of course, the change in the odor according to time does not necessarily represent deterioration; the alteration could be attributed to additional ripening—ultimately, the preference for odor will always be a personal matter. In addition, the odor of cooked rice is affected by factors that include the degree of milling, the washing and cooking conditions, and cultivation conditions/area/year. In future studies, correlations between the preferences for odor and the results of volatile aroma compounds will be explored. The accumulation of such data should help establish the optimal storage conditions for the selection and marketing of rice according to differences in cultivar type and personal preferences for odor.

CONCLUSIONS

In the present study, the vaporized compounds of freshly cooked Japanese nonglutinous rice cultivars were extracted using SPME over a short period of time and were then measured via GC/MS. From freshly harvested rice cultivars, four volatile aroma compounds, 2-pentylfuran, nonanal, 4-vinylphenol, and indole, were detected in significant portions, and the latter two compounds, in particular, could logically be used to characterize freshly harvested and freshly cooked Japanese nonglutinous rice cultivars. Based on the results of changes in the compounds during storage, the former two compounds tended to increase, and the latter two remained almost unchanged or were slightly decreased. Therefore, the characteristics of the flavor volatiles, and perhaps the characteristics of the odor itself, of freshly cooked rice after long-term storage significantly depends on the storage conditions, in addition to the rice cultivar type. The compounds studied in this paper were few in number (four), and in the future, highly effective extraction methods for orthonasal aroma compounds from cooked rice should be verified. A highly sensitive GC/MS instrument is also useful; GC/REMPI-MS combined with a high repetition-rate laser as an ionization source would be one of the best choices.²² With a combination of instrumental analysis and sensory testing, the odor of cooked rice could be accurately characterized.

■ ASSOCIATED CONTENT

SI Supporting Information

The Supporting Information is available free of charge at <https://pubs.acs.org/doi/10.1021/acsomega.3c01276>.

Retention time and m/z for compounds obtained by SPME-GC/MS; extracted mass chromatograms obtained from an extract of freshly cooked Koshihikari; comparison of peak areas for compounds obtained from cooked rice of six different rice cultivars; and analysis of variance for experimental data of Figure 4 (PDF)

■ AUTHOR INFORMATION

Corresponding Author

Tomohiro Uchimura – Department of Materials Science and Engineering, Graduate School of Engineering, University of Fukui, Fukui 910-8507, Japan; orcid.org/0000-0003-4816-6328; Phone: +81-776-27-8610; Email: uchimura@u-fukui.ac.jp

Authors

Keishi Yamashita – Department of Materials Science and Engineering, Graduate School of Engineering, University of Fukui, Fukui 910-8507, Japan

Nanako Kato – Department of Materials Science and Engineering, Graduate School of Engineering, University of Fukui, Fukui 910-8507, Japan

Kento Sakakibara – Department of Materials Science and Engineering, Graduate School of Engineering, University of Fukui, Fukui 910-8507, Japan

Aki Seguchi – Department of Materials Science and Biotechnology, School of Engineering, University of Fukui, Fukui 910-8507, Japan

Asako Kobayashi – Fukui Agricultural Experiment Station, Fukui 918-8215, Japan

Shinobu Miyagawa – Department of Materials Science and Engineering, Graduate School of Engineering, University of Fukui, Fukui 910-8507, Japan

Complete contact information is available at: <https://pubs.acs.org/10.1021/acsomega.3c01276>

Notes

The authors declare no competing financial interest.

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