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Effects of variety on quality and taste of spontaneous fermented dried radish

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Abstract

Dried radish is a kind of pickled vegetable product with a unique taste made from radish via traditional solid-state spontaneous fermentation. In this study, the effects of variety on physicochemical indexes, texture properties, and taste substances of spontaneous fermented dried radish were investigated. As a result, processing and fermentation had similar trends for all radish varieties. The pH value decreased slightly, soluble solid increased with the decrease of moisture content, the hardness and chewiness decreased, while the content of organic acids and free amino acids increased. Furthermore, the variety of raw material is the key to affecting product quality and taste. The dried radish processed by the variety P21-25 presents the best texture, the highest content of sweet amino acids, the most abundant component of organic acids, while having the lowest salinity. These results indicated that radish varieties could significantly influence the quality and taste of dried radishes under the same processing and fermentation conditions. These findings reveal the importance of variety selection for the quality and taste of spontaneous fermented dried radish, and provide theoretical support for the processing and application of green radish varieties.

Keywords: variety; dried radish; spontaneous fermentation; physicochemical indexes; taste substances.

Practical Application: In this study, the quality and taste of dried radish processed from five different radish varieties with different colors were compared and analyzed. The results showed that the quality and taste of spontaneous fermented dried radish were significantly affected by radish varieties. Importantly, green radish was more suitable for processing into dried radish.

1 Introduction

Radish, known as *Raphanus sativus L.*, is a species belonging to the genus Raphanus in the Brassicaceae family (Gamba et al., 2021), which is greatly consumed in Asia, Europe, America, and North Africa due to its availability in local markets, cheapness, and consumer preference (Khadivi et al., 2022). Radish is usually eaten directly, but placed too long prone to cause hollowness and mildew. In Asia, radish is processed into paocai or dried radish for further storage (Manivannan et al., 2019). To reduce the growth of putrefying microorganisms in semi-solid fermentation such as paocai, drying radish to dried radish is considered a good way to store vegetables (Coogan & Wills, 2002; Oliveira et al., 2022).

At present, the main drying methods of radish are sun-drying, air-drying, and salt-dehydration. So far, most of the dried radishes in the market are dried using salt dehydration. The salting process can promote the fermentation and maturation by the metabolic effects of beneficial microorganisms, resulting in a unique taste and nutrition of dried radish (Liu et al., 2017). However, the dried radish with salt dehydration has higher moisture content and salinity, the higher moisture is not conducive to storage, and long-term intake of high salt might lead to diseases such as hypertension (Liu et al., 2017).

Generally, dried radish product is made by traditional solid-state spontaneous fermentation, whose moisture content after processing and fermentation is controlled at 60-70% (Tang, 2020). The quality and taste of dried radish are affected by many factors, such as raw materials, fermentation methods, and processing technologies. In recent years, most studies have focused on the effects of microbial communities, fermentation periods and processing technologies on the quality and flavor of fermented vegetables (Alan & Yildiz, 2022; Zhang et al., 2022; Kumakura et al., 2017). To the best of our knowledge, the effects of different raw materials on the quality and taste of the final products are still unclear. Furthermore, variety is a crucial factor affecting the quality and taste of the fermented products, such as chili peppers (Ye et al., 2022) and sauerkraut (Satora et al., 2021). In particular, white radish is the most commonly eaten in most countries (Gamba et al., 2021), and green radish is reported to have better value than red and white radishes (Cai et al., 2022). Nevertheless, research on the quality of radishes with different colors and types (e.g., fresh-eating, processing) lacks a systematic investigation, especially comparative studies on their subsequent processing and utilization.

To fulfill the above gaps, in this study, dry salt was used for salt dehydration, desalting through washing and soaking, and hot air drying instead of sun-drying was used to speed up the formation of dried radish, thus, providing a theoretical basis for industrial production of dried radish (Ye et al., 2013). This study aims to unveil the influence of different radish varieties on the quality and taste of spontaneous fermented dried radishes by measuring the physicochemical indexes, texture properties, organic acids, and free amino acids.

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2 Materials and methods

2.1 Samples and preparation of spontaneous fermented dried radish

Five varieties of radishes (*Raphanus sativus* L.) including P21-1, P21-13, P21-22, P21-25, and P21-27 were provided by the Academy of Agricultural Sciences in Sichuan. Especially, P21-22 is round radish, P21-25 and P21-27 are green radishes. The specific information is shown in Table 1. In the following, RM means raw material, and SF means spontaneous fermented dried radish. The numbers (1, 13, 22, 25, 27) after the letter RM and SF represent varieties P21-1, P21-13, P21-22, P21-25, and P21-27, respectively.

The preparation process of spontaneous fermented dried radish is shown in Figure 1. Raw materials were cleaned and cut into strips (6 cm × 1 cm × 1 cm). Ten percentage of dry salt by weight of radish was mixed with radish strips for salt dehydration in the jar for 2 days and turned the jar at the 24th hour. After salting, the radish strips were washed and soaked to desalt. The radish strips were dehydrated for 20 min by dehydrator and dried by oven at 40 °C for 11h to reach a relatively dry degree. Then, the radish strips were sealed and fermented at 20 ± 2 °C for 9 days to obtain spontaneous fermented dried radishes. All raw materials and spontaneous fermented dried radishes were stored at -80 °C for subsequent experiments.

2.2 Physicochemical analysis

The pH value, moisture content, soluble solid, salinity, and nitrite of RM and SF were measured. According to existing research methods, the pH value was measured by a pH meter (PHS-3E, INESA, Shanghai, China) (Tang et al., 2022). The moisture content and nitrite were tested according to GB 5009.3-2016 and GB 5009.33-2016 (Chinese National Standard, 2016a, b), respectively. The soluble solid was analyzed by a hand-held refractometer (TDA-45, JINKELIDA, Beijing, China) (Yu et al., 2022). The salinity was measured by a salt meter (ES-421, ATAGO, Tokyo, Japan) (Yang et al., 2021). All samples were determined in triplicate.

2.3 Texture analysis

Hardness and chewiness were analyzed using a texture analyzer with a P/2N probe (TA.XT Plus, SMS, UK), and the parameters were set according to the reported method (Ye et al., 2020). Before analysis, the radish strips and dried radish samples with uniform thickness were selected, and all samples were tested 5 times in parallel from the skin to the center of the pulp.

The surface microstructure of RM and SF was observed by scanning electron microscopy (SEM) using the method described by Llorca et al. (2001) with some adjustments. Before the test, the samples were cut into cubes (5 mm × 5 mm × 2 mm) and fixed

Table 1. Introduction of different varieties of raw materials.

Sample	Name	Color	Type	Source
P21-1	Jiexiamei45	White	Fresh-eating	The Academy of Agricultural Sciences in Sichuan
P21-13	C04023Guanzhuang	White	Table and processing	
P21-22	Zaocuixiaoye	White	Fresh-eating	
P21-25	Regular fruit radish	Green	Table and processing	
P21-27	Xiucui *No.1*	Green	Fresh-eating	

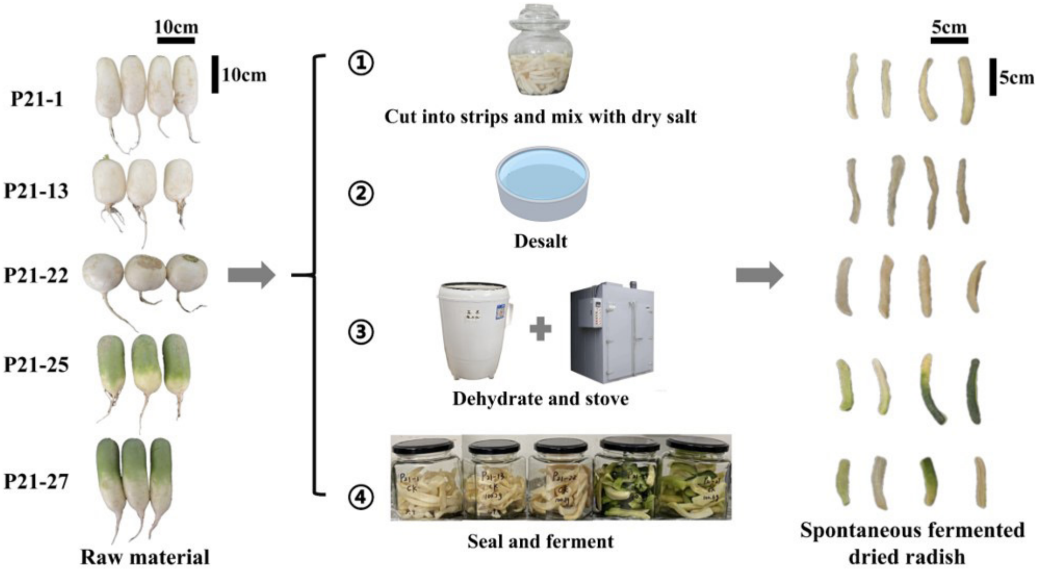

Figure 1. Visual appearance of different varieties of RM and SF and the preparation process of spontaneous fermented dried radish.

with 4% glutaraldehyde for 24 h. After rinsing with phosphate buffer of pH 7.2, the samples were freeze-dried to observe.

2.4 Organic acids analysis

Organic acids were determined by HPLC according to the previous study (Yu et al., 2022). The separation was performed on an Amethyst C18-H column (4.6 mm × 250 mm, 5 μm) with a wavelength of 210 nm and column temperature of 30 °C. The mobile phases were formic acid/water (0.1:100, *v/v*) and methanol. Before detection, 2 g samples were weighed, and 50 mL of 75 °C water were added. After being bathed at 75 °C for 20 min, the filtrate was filtered by 0.22 μm membrane filter and then injected for analysis.

2.5 Free amino acids analysis

All samples were analyzed using an automatic amino acid analyzer (A300, MembraPure GmbH, Germany) according to the previous method (Luo et al., 2021). Usually, a mixture of the chopped samples (2 g) and boiling water (8 mL) was heated in a water bath at 95 °C for 10 min. After filtration and constant volume, ten percent of sulfosalicylic acid was added to the filtrate at a ratio of 1:4 (*v/v*). The mixture was refrigerated overnight at 4 °C and then filtered through a 0.22 μm membrane filter for analysis.

2.6 Data processing and statistical analysis

One-way ANOVA (Duncan's multiple test) and independent *t*-test were applied to investigate the significant differences by using IBM SPSS Statistical 22 software (SPSS Inc., Chicago, IL, USA). The graphs were drawn by Origin Software Version 2019 (OriginLab Corporation, Hampton, MA, USA) and orthogonal partial least squares-discriminant analysis (OPLS-DA) was generated using SIMCA-P software (Version 14.1, Umetrics, Umea, Sweden). The data were presented as mean ± standard deviation and all analyses were tested three times or more.

3 Results

3.1 Physicochemical indexes

Physicochemical indexes of different varieties of RM and SF were determined. As shown in Figure 2A, there was no significant difference in pH value in the RM group. pH values decreased after processing and fermentation, and SF22 had the lowest pH value. After processing and fermentation, the moisture content of dried radish varied greatly (Figure 2B), and SF13 had the lowest moisture content, while the highest moisture content was detected in SF22 and SF27. Additionally, the content of soluble solid increased with different degrees after processing and fermentation (Figure 2C), SF13 and SF25 had the highest soluble solid content, while SF22 had the lowest. The highest salinity was observed in SF1, while SF25 had the lowest salinity (Figure 2D). Meanwhile, the nitrite concentrations of all dried radishes were much lower than the concentrations specified (20 mg/kg) according to the Chinese National Standard (2017). These results suggested that the slight differences among raw materials were significantly amplified after processing and fermentation, revealing that different varieties had varying processing characteristics.

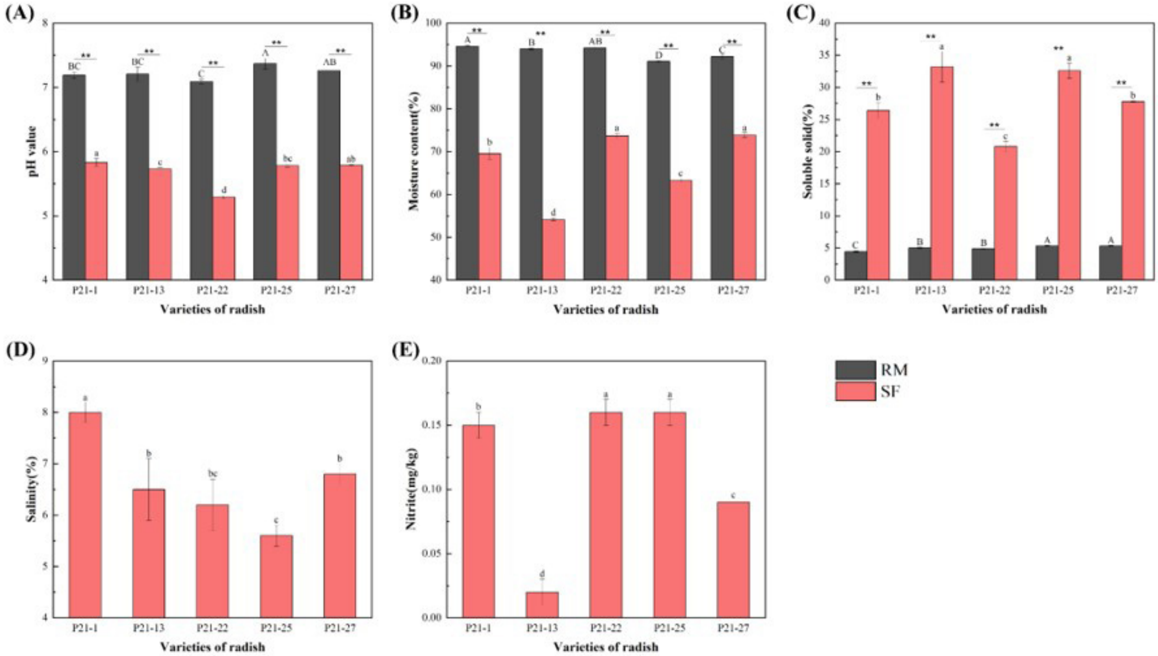

Figure 2. Physicochemical indexes of different varieties of RM and SF. (A) pH value; (B) Moisture content; (C) Soluble solid; (D) Salinity; (E) Nitrite. Different capital letters (A-D) indicate significant differences in the RM group ($p < 0.05$); different lowercase letters (a-d) indicate significant differences in the SF group ($p < 0.05$); **indicate extremely significant differences in RM and SF of the same variety (**$p < 0.01$).

3.2 Texture properties

The texture is one of the crucial factors affecting the quality and consumer acceptability of pickled vegetables (Ye et al., 2020), and hardness and chewiness are important indicators of the texture (Dong et al., 2020). As shown in Figure 3A, after processing and fermentation, the hardness of all varieties showed a significant decrease except for the variety P21-22. In the RM group, RM25 exhibited the highest hardness, while RM22 presented the lowest hardness. In the SF group, SF1 and SF22 had the lowest hardness. The result of chewiness was shown in Figure 3B, and there was no significant difference between the RM and SF groups of all varieties.

SEM was performed to show the microstructures of the samples, and the results were shown in Figure 3C. Obviously, different varieties showed distinct microstructures, after processing and fermentation, the cell wall structures of all varieties showed a certain degree of shrinkage and rupture, which corresponded to the results of the texture.

3.3 Organic acids

In total, the results of organic acids analysis were shown in Figure 4A and Table S1. After processing and fermentation, the content and types of organic acids increased, and the degree of increase was different. In the RM group, oxalic acid and succinic acid were the main organic acids. In the SF group, the dried radishes mainly contained oxalic acid, succinic acid, malic acid, and citric acid, and a little lactic acid was produced except for SF1. Especially, SF25 had more acetic acid than SF27. The organic acid content of SF13 was the highest, followed by SF25. Besides, the organic acid content of SF1 was the lowest. Furthermore, the largest increase of organic acids was determined in SF25, representing increases of 3.20-fold compared to RM25. Therefore, the variety had a great influence on the content and composition of organic acids in dried radishes.

3.4 Free amino acids

The content of sixteen free amino acids was measured, and the results were summarized in Figure 4B-C and Table S2. Through processing and fermentation, the differences of varieties resulted in different rising trends of total free amino acids (TFAAs) and free amino acids (FAAs). As a result, RM27 had the highest TFAAs content in the RM group, which mainly benefited from the most umami FAAs content. SF22 exhibited the highest content in the SF group, but its bitter FAAs occupied the majority. In addition, in the SF group, SF1 had the highest umami FAAs content, SF25 presented the highest content of sweet FAAs, while SF27 exhibited the highest total content of sweet and umami FAAs.

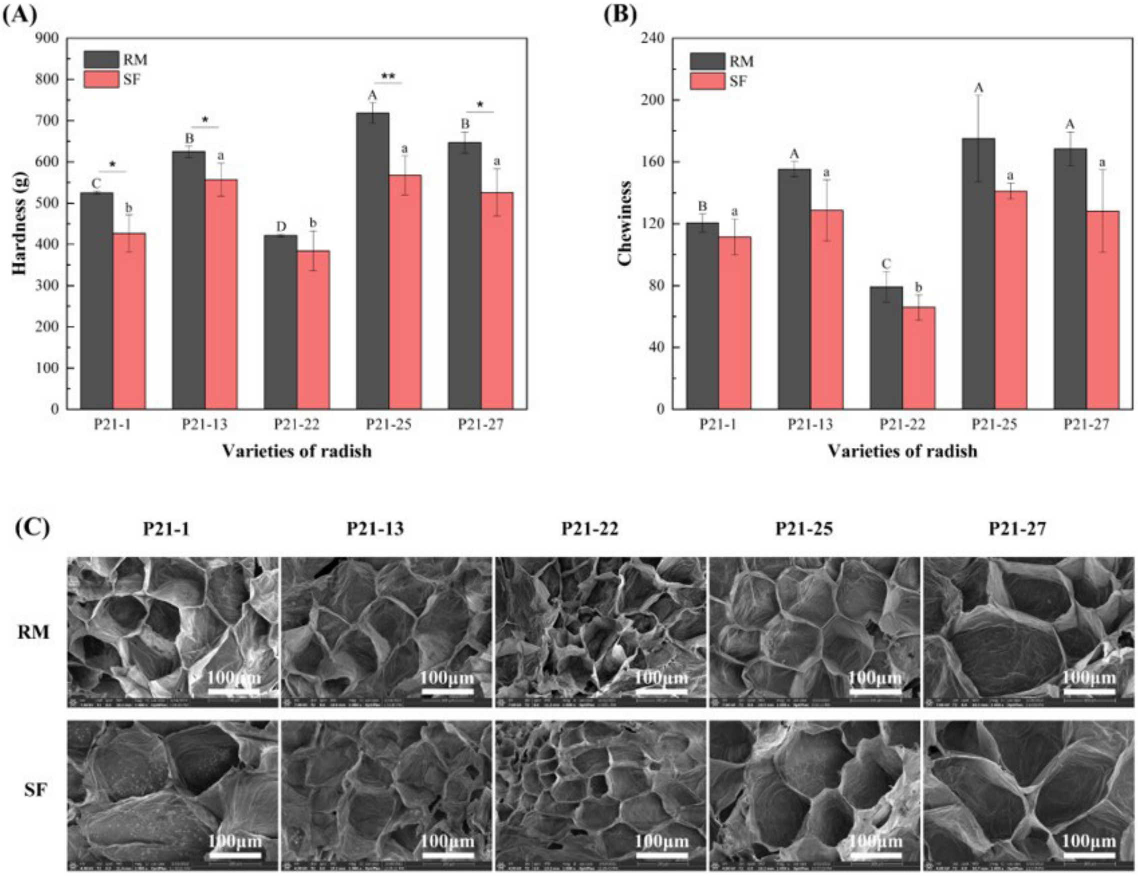

Figure 3. Hardness (A), chewiness (B) and microstructure (C) of different varieties of RM and SF. Different capital letters (A-D) indicate significant differences in the RM group ($p < 0.05$); different lowercase letters (a-b) indicate significant differences in the SF group ($p < 0.05$); *indicate significant differences in RM and SF of the same variety (*$p < 0.05$, **$p < 0.01$). Magnification was × 1000 for RM and SF.

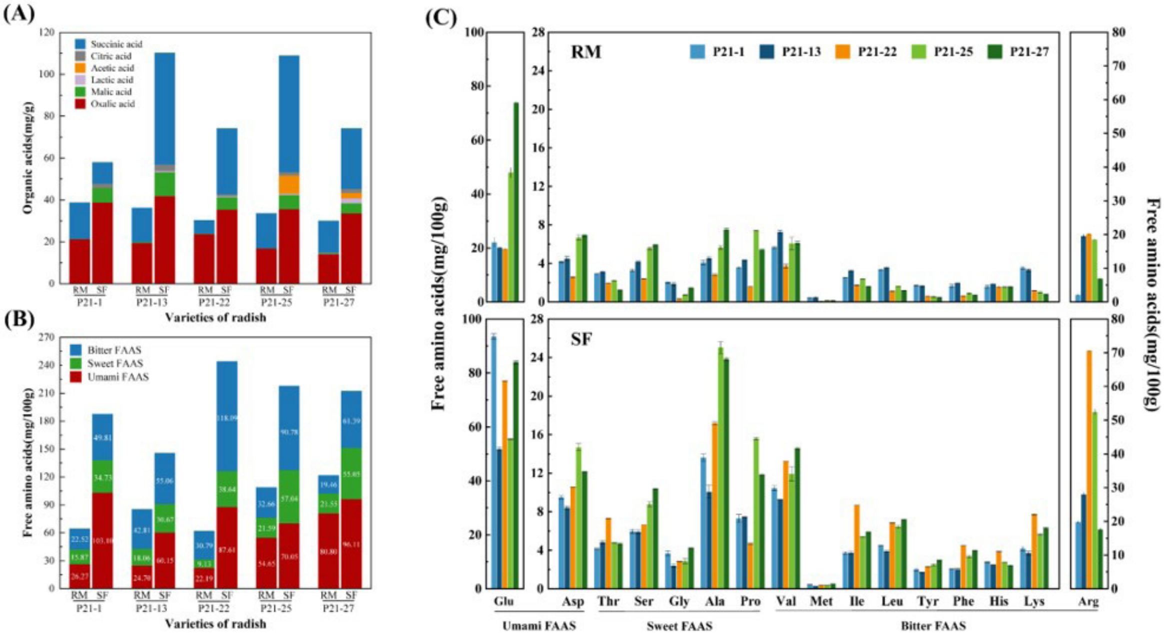

Figure 4. Organic acids (A) and free amino acids (B-C) of different varieties of RM and SF.

Among these FAAs, Glu was dominant in all tested samples (Figure 4C). In the RM group, the highest content of Glu was detected in RM27, followed by RM25. Through the processing and fermentation, the Glu content in SF1 increased the most by 4.23 times, while the Glu content had a 1.14 times higher increase in SF27. Besides, Arg exhibited the second highest FAA in all samples, and SF22 had the highest Arg content, followed by SF25 in the SF group. It also could be found that Ala was the main sweet FAA in the SF group, and the highest content of Ala was in SF25, followed by SF27. These results revealed that the different varieties of radishes presented different processing performances.

3.5 Correlation analysis of different varieties

To expound on the physicochemical indexes and texture properties relationship between different varieties, redundancy analysis (RDA) was performed. The distribution between environmental factors and samples was shown visually in Figure 5A. The angle between the lines symbolizes the correlation between indicators. The large distance between groups and samples indicated that the processing and variety had a great influence on quality. RM was positively correlated with moisture content, pH value, hardness, and chewiness, while SF was positively correlated with nitrite, salinity, and soluble solid. As could be seen from the angle, there was a positive association between hardness and chewiness, while hardness and chewiness were negatively correlated with salinity according to the obtuse angle. In addition, the obvious negative relationship between moisture content and soluble solid was detected.

The orthogonal partial least squares discriminant analysis (OPLS-DA) model was employed to evaluate the differences in taste substances among different varieties, and the date separation of taste substances of different varieties was shown in Figure 5B. The R^2X, R^2Y, and Q^2 of OPLS-DA were 0.999, 0.987, and 0.972, respectively. The SF and RM groups were distributed on the left and right side, respectively, emphasizing that processing and fermentation resulted in considerable differences in taste. After processing and fermentation, a closer separation distance was observed between SF1 and SF13, SF25 and SF27. Further, the heatmap between the contents of taste substances and varieties was presented in Figure 5C. In the RM group, there was little difference in taste substances between different varieties. In the SF group, SF1 and SF13 contained similar taste substances, and SF25 and SF27 clustered together, which were consistent with the results shown by OPLS-DA. Collectively, the effect of variety on the taste was enlarged after processing and fermentation.

4 Discussion

In this study, five different radishes, cultivated in the same environmental condition, were manufactured into dried radishes through the same processing procedure (Figure 1), and the quality of raw materials and their products was evaluated and compared. The physicochemical analyses revealed that the different varieties of radishes had different physicochemical qualities including pH value, moisture content, and soluble solid, thereby exhibiting different physicochemical qualities of dried radishes. For instance, a significant decrease in pH value and moisture content was observed after processing and fermentation among all the radishes, while soluble solid significantly increased after being processed. The decrease in pH value (Figure 2A) might be associated with the increase of organic acids (Figure 4A), because microorganisms could convert reducing sugars into organic acids during fermentation (Tang, 2020), resulting in the increase in organic acids and the decrease in pH value. In the SF group, the pH value of all samples was maintained in the range

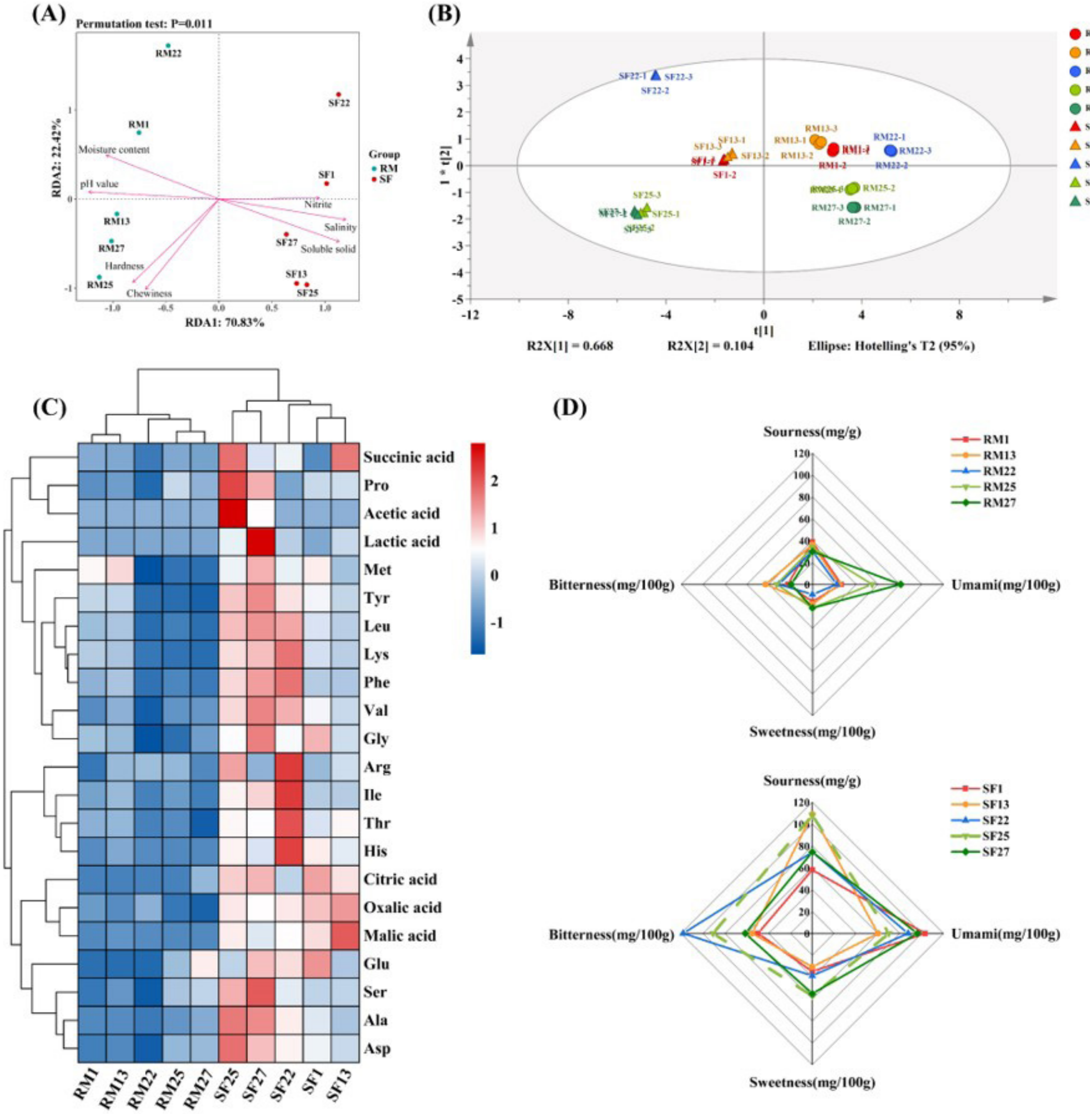

Figure 5. RDA of basic indicators in different varieties of RM and SF (A), OPLS-DA of taste substances in different varieties of RM and SF (B) (n=3), heatmap between different varieties and taste substances (C), and radar map of overall taste characteristics of different varieties of RM and SF(D).

of 5-6 (Figure 2A), indicating a weak degree of fermentation. This result was consistent with the previous report (Tang et al., 2022), which might be related to the low moisture content in the dried radishes and slow microbial growth and metabolism. The results of the correlation analysis demonstrated that the decrease in moisture content was positively related to the increase in soluble solid (Figure 2B-C & Figure 5A). For example, in the SF group, SF13 had the lowest moisture content and highest soluble solid, while SF22 showed the opposite results, probably because the moisture content decreased after dehydration and the soluble solid in the remaining dry matter increased, so that the nutrients were well retained.

Additionally, salinity and nitrite content represent the safety of the final products. In this study, the salinity of SF25 was 5.6%, lower than 6%, which was more likely to develop into a low-salt healthy product. Besides, the nitrite content of dried radish products was far lower than the Chinese national standard level (20 mg/kg). The above results indicated that the dried radishes made by the method in our study (Figure 1) had good safety and quality.

The texture is one of the important indexes to evaluate the quality of pickled vegetables, and the changes in texture were closely related to the changes in cell wall structure and composition (Dong et al., 2020; Toivonen & Brummell, 2008). After processing and fermentation, the hardness decreased to some extent and the cell wall structure showed different degree of shrinkage and turgor loss (Figure 3), like other pickled vegetables such as pickled peppers (Ye et al., 2022). Notably, higher salinity also led to softening of the tissue, possibly due to an increase in osmotic pressure (Satora et al., 2021), explaining that the better texture properties of SF25 (Figure 3) were associated with the lowest salinity (Figure 2D).

The content and composition of organic acids are crucial for the quality and taste of dried radishes (Zhou et al., 2022). Cai et al. (2021) reported that there were different organic acids metabolism during the fermentation of zha-chili prepared with the different rice varieties, and a similar result was found in this study. Soluble solid represents the sugar content index, which can be decomposed as carbohydrates to organic acids under the action of microorganisms, in the SF group, SF13 and SF25 had the highest organic acid content, which might be related to their highest content of soluble solid. In the SF group, oxalic acid, succinic acid, and malic acid were the main organic acids (Figure 4A), Tang et al. (2022) concluded that succinic acid and malic acid were typically detected in dry-salted vegetables, and they were mainly derived from root vegetable materials (Chen et al., 2019). Additionally, lactic acid and acetic acid were mainly produced by microbial metabolism during fermentation (Tang, 2020). In this study, the low content of lactic acid in dried radishes indicated that the degree of solid-state fermentation was weak. Meanwhile, acetic acid was only found in green dried radishes, and SF25 (8.51 mg/g) had more than SF27 (2.66 mg/g), which could enhance the taste of dried radishes (Wang et al., 2019).

The increase of FAAs in the dried radishes might be due to the decomposition of proteins by endogenous enzymes and proteases secreted by microorganisms (Wang et al., 2020), and it was demonstrated that the salting process could also lead to an increase in FAAs (Tang et al., 2022), showing that dried radish is a better source of FAAs, which were in accordance with the report of fermented pickled peppers (Ye et al., 2022). As shown in Figure 4B-C, umami was one of the characteristics taste of dried radishes, the TAV of Glu was greater than 1 in all dried radishes according to the reported threshold values of FAAs (Zhang et al., 2021), indicating that Glu had an important effect on the taste of dried radishes. In addition, NaCl could mask the metallic taste and bitterness, and increase the umami taste (Zhao et al., 2016; Sheng, 2020; Cai et al., 2021). Our results showed that the highest content of Glu (96.3 mg/100 g) and salinity (8%) resulted in the strongest umami taste of SF1. Zou et al. (2022) reported that citric acid could promote the production of sweet FAAs in a low-salt environment, this might be related to the fact that SF25 contained the lowest salinity and the highest sweet FAAs.

Due to the formation of metabolites such as organic acids and amino acids, dried radishes prepared by processing exhibited enhanced nutritional value and quality. And the differences in raw materials and the role of microorganisms during processing and fermentation led to a large difference in the quality and taste of the final products (Cai et al., 2021; Zhao et al., 2016). For instance, RM27 had the highest umami taste in the RM group (Figure 5D). In the SF group, SF22 presented the most bitterness, SF1 showed the richest umami taste, while SF25 exhibited the best overall taste in all tested dried radishes (Figure 5D). So, these results suggested that the variety P21-25 was more suitable for making dried radish and had a better quality and taste of the final product.

5 Conclusion

In this study, the effects of variety on the quality and taste of the dried radish products were systematically investigated by determining the physicochemical indexes, texture properties, and taste substances. After processing and fermentation, the pH value and texture decreased slightly, and the content of organic acids and free amino acids increased in all dried radishes. Importantly, SF25 was rich in organic acids and sweet FAAs, and showed good texture properties and the lowest salinity, thus, it exhibited the characteristics of low-salt, healthy, crisp mouthfeel, and unique taste. The obtained results in this study demonstrated that the selection of an appropriate variety of radish is crucial for dried radish product with satisfying quality and taste, and the green radishes have better excellent processing characteristics and development prospects.

Conflict of interest

The authors declare that they have no conflict of interest.

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Supplementary material

Supplementary material accompanies this paper.

Table S1. Organic acids content in different varieties of RM and SF.

Table S2. Free amino acids content in different varieties of RM and SF.

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