Indonesian Food Science and Technology Journal
IFSTJ : Vol 9 No 1, Dec 2025 (PP:54-60)
ISSN : 2615-367X, DOI. 10.22437/ifstj.v9i1.41456

INDONESIAN FOOD SCIENCE AND TECHNOLOGY JOURNAL (IFSTJ)

Journal homepage : online-journal.unja.ac.id/ifstj/issue/archive

Profile of Nonvolatile Compounds and Their Correlation to the Flavor of Fried Shallots

Olivia Yofananda[1,2], Christofora Hanny Wijaya[1#], Hanifah Nuryani Lioe[1], Sobir[3]

[1]*Department of Food Science and Technology, Faculty of Agricultural Engineering and Technology, IPB University, IPB Campus Dramaga, Bogor, 16680, Indonesia*

[2]*Department of Fisheries, Faculty of Agriculture, Universitas Gadjah Mada, Sleman, Yogyakarta, 55281, Indonesia*

[3]*Department of Agronomy and Horticulture, Faculty of Agriculture, IPB University, IPB Campus Dramaga, Bogor, 16680, Indonesia*

[#]*Corresponding author: E-mail: channywijaya@apps.ipb.ac.id*

***Abstract*—This study aimed to evaluate the relationship between the nonvolatile compounds detected in fried shallots and their sensory characteristics. Six shallot varieties were used: Bima Brebes, Bauji, Tajuk, Super Philip, Batu Ijo, and Rubaru. Each variety was assessed using the rate-all-that-apply (RATA) and hedonic rating tests for the taste and aroma of fried shallots. All fried shallots were prepared in a laboratory under homogeneous frying conditions. The chemical compounds in the water extracts of the six fried shallots with molecular weights less than 3 kDa were identified using LC-MS/MS instrument. Additionally, the correlation between the chromatographic peak intensities of the chemical compounds and sensory intensities was examined through multivariate orthogonal partial least squares (OPLS) analysis. The PCA result revealed two distinct groups of samples. Batu Ijo fried shallot, which received the highest overall hedonic score and showed a strong correlation between its fragrant sulfury aroma and savory taste, was categorized separately from the others. Although 18 compounds were identified in fried shallots, a significant correlation was observed only with salty taste, primarily due to glutamyl-phenylalanine, a known kokumi compound.**

***Keywords*— allium, cultivar, fried shallot, sensory analysis, taste chemistry**

Manuscript received Jan 25, 2025; revised Aug 02, 2025; accepted Oct 21, 2025. Available online Dec 17, 2025

I. INTRODUCTION

Fried shallots are the primary processed product derived from shallots, acknowledged on the Indonesian market. These products can be purchased in both traditional and modern markets. Their popularity stems from their distinctive flavor, making them a prevalent condiment in many dishes. Previous research indicated that consumers favored specific sensory characteristics of fried shallots, notably their savory taste, fragrant sulfury aroma, and crispness [1]. Various cultivars within specific species, such as artichoke and bitter orange, yield unique sensory characteristics [2]. We also observed that fried shallots from various varieties clustered by their sensory attributes [3]. The unique sensory attributes are derived from the chemical composition of their constituents, as evidenced in commodities such as kiwifruit [4], mango [5], and almond [6].

The volatile compounds responsible for the aroma in fried shallots, including alkyl pyrazines, which impart the characteristic scent of deep-fried foods, and hexanal, as well as (E,E) and (E,Z)-decadienal, associated with the rancid odor that occurs during storage, have been examined using the GC-MS instrument [7]. The volatile compounds responsible for the aroma during onion processing have also been analyzed using the GC-O instrument [8]. The identification of volatile compounds contributing to the aroma of fried shallots has also been investigated using GC-MS and multivariate analysis [9]. To date, there have been no recent articles on the nonvolatile compounds in fried shallots and their sensory attributes, especially taste. At the same time, fried shallots have become highly desirable due to their distinctive aroma.

In addition to aroma, taste contributes an essential part of the overall flavor. The compounds that contribute to taste are typically water-soluble. Water extraction is effective for investigating umami compounds [10-12], bitter compounds [13-14], and even sweet modulator compounds [15]. In other *Allium* species, such as garlic and onion, compounds responsible for kokumi were also identified and extracted using water [16-17]. Kokumi is a mouthfeel perception associated with savory taste, which can be described by γ-glutamyl-peptides compounds [18]. At garlic and onion, kokumi compounds were sulfur-containing compounds, such as alliin, (+)-S-methyl-L-cysteine sulfoxide, γ- L-glutamyl-S-allyl- L-cysteine [16], trans-(+)-S-propenyl-L-cysteine sulfoxide, cycloalliin [17], γ-glutamyl-γ-glutamyl-S-methylcysteine, γ-glutamyl-γ-glutamyl-S-allylcysteine, and γ-glutamyl-γ-glutamyl-S-1-propenylcysteine [19].

The aqueous extract was then tested using specific instruments to identify the compounds contained. Toelstede and Hofmann [14], tested the aqueous extract of Gouda cheese using LC-MS. Wakamatsu et al. [20] identified the compound responsible for kokumi in roasted garlic using LC-MS/MS. The identified compounds can then be correlated with a product's sensory characteristics using multivariate analysis, as has been done by Sung et al., Tian et al., and Intelmann et al. [5, 9, 21].

The present investigation aimed to examine the nonvolatile profiles of the water-soluble extract of fried shallots using an LC-MS-MS instrument and to identify the chemicals associated with their sensory attributes. This work offers foundational insights for plant breeding researchers in developing shallot varieties suitable for fried shallot production, while also providing early data for food science researchers examining the flavor precursors that characterize fried shallot flavor.

II. Materials and Methods

A. Materials

The six varieties of fresh shallots (Bima Brebes, Tajuk, Super Philip, Bauji, Batu Ijo, Rubaru) used in this study were obtained from planting at the Experimental Garden of IPB, Bogor, in September-November 2019. Sunco brand palm cooking oil (Mikie Oleo Nabati Industri Corp., Bekasi, Indonesia) and Refina brand table salt (UnichemCandi Corp., Sidoarjo, Indonesia) were obtained from local markets. Other materials will be explained further in the following subsection.

B. Method

Sample preparation

The fried shallot production process is as outlined by Yofananda et al. (2021). [3]. The homogenous process was applied to each fresh shallot sample to produce fried shallots. The process entails slicing the tubers using a slicer (Tupperware, USA) to a thickness of 1-2 mm, followed by soaking in water and a 2% salt solution (w/w sample) before draining. Shallots are sautéed in palm oil at 105-110°C for 4-5 minutes, until they develop a golden-brown hue. The fried shallot samples are subsequently preserved in an airtight container (Tupperware, USA) until they are prepared for further analysis.

Sensory profile evaluation of fried shallots of six varieties

The sensory analysis was performed in accordance with the Statement of Ethical Approval Number 128/IT3.KEPMSM-IPB/SK/2018, by the Research Ethics Commission Involving Human Subjects, LPPM IPB University. Fried shallots were evaluated using the rate-all-that-apply (RATA) descriptive method, as outlined in a prior study [3]. The sensory characteristics of six varieties of fried shallots were assessed using a rate-all-that-apply sensory descriptive test, conducted with 103 untrained panelists (aged 18-54 years, 84 females and 19 males). The sensory attributes evaluated included fragrant sulfury aroma, sweet aroma, rancid aroma, savory taste, salty taste, sweet taste, and bitter taste. The scores for each attribute were analyzed using one-way analysis of variance (ANOVA) and presented in a spider web chart to highlight differences in the sensory profiles of each fried shallot.

Preferences for six varieties of fried shallots were assessed using a hedonic rating test, following the research of Yofananda et al. (2020) [1]. In this test, panelists rated their preference for each sample on a 7-point scale, where 1 indicated “very dislike” and 7 indicated “very much like.” The attributes evaluated included taste, aroma, and overall acceptance. Preference scores were analyzed using one-way ANOVA, followed by Tukey's test for further comparison. Additionally, to explore the relationship between sensory attributes and hedonic preferences, a Pearson correlation test was conducted using SPSS 22 software (IBM, USA).

Profiles of water-soluble extract compounds of fried shallots. The compounds were extracted using a water extraction method. Initially, a 5-gram sample was homogenized with 50 mL of deionized water. The mixture was then heated to 70°C and stirred for 30 min in a water bath. Afterward, the mixture of fried shallots and water was filtered under vacuum through Whatman No. 1 paper for 20 min. The resulting extract was further filtered through Whatman No. 42. In the final step, filtration was performed using a regenerated cellulose membrane with a 0.45 µm pore size on a vacuum filter. The filtrate was then subjected to ultrafiltration at 3 kDa, 1811 × g at 28°C for 15 min. The <3 kDa filtrate was stored in a 5 mL dark vial for analysis via LC-MS/MS instrument. We exclusively utilize constituents under 3 kDa, as the molecules responsible for taste are often minuscule.

Fried shallot filtrate <3 kDa was analyzed using UHPLC Vanquish Tandem Q Exactive Plus Orbitrap HRMS ThermoScientific. A 250 µL of the sample was mixed with 750 µL of methanol, and 10 µL aliquots were injected into the column. The separation was performed on an Accucore C18 column (100 × 2.1 mm, 1.5 µm, Thermo Scientific) at 40°C. The mobile phases were H_2O with 0.1 % formic acid (A), and acetonitrile with 0.1% formic acid (B), and the flow rate was set at 0.2 mL/min. The gradient elution was programmed as follows: 0-0.5 min, 95 % A and 5 % B; 0.5-6 min, 95-50 % A and 5-50 % B; 6-7 min, 50 % A and 50 % B; 7-8 min, 50-5 % A and 50-95 % B; 8-10 min, 5 % A and 95 % B; 10-13 min, 95 % A and 5 % B. The analysis was performed in negative Electrospray Ionization (ESI) mode $(M-H)^-$, with a mass range of 100-1500 m/z and an ionization voltage of 3.5 kV. MS_1 detection was performed using the complete scan method at a resolution of 70,000, while MS_2 (orbitrap) used dependent MS_2 ($ddMS_2$) detection with a resolution of 17,500 and window isolation of 4.0 m/z. The identification of compounds followed

the methodology outlined by Sittipod et al. [22], adapted from the Advanced Research Laboratory at IPB University, Bogor.
In the Compound Discoverer, the detected compounds are restricted to a maximum molecular formula of C90 H190 N10 O30 S6. The compound databases employed included NIST, Nature Chemistry, Nature Chemical Biology, and MassBank. The chromatograms, based on total ion current (TIC), were manually annotated by comparing the compounds and MS data using X-Calibur. The compounds identified manually were verified by matching them with the data from the database. The delta mass of the exact mass for compound identification was also set to 10 ppm (mass difference up to 0.00001).

Correlation of identified compounds with sensory characteristics of fried shallots
The compounds identified in the six fried shallot extracts were analyzed using multivariate principal component analysis (PCA). This analysis aimed to determine the characteristic metabolite compounds in each fried shallot. Additionally, a correlation between the sensory descriptive characteristics and the compounds detected by LC-MS/MS was examined through multivariate orthogonal partial least squares (OPLS) analysis. Both multivariate analyses were performed using SIMCA 14 software (Sartorius, Germany).

III. RESULTS AND DISCUSSION

A. Sensory Profile of Six Varieties of Fried Shallots
According to Yofananda et al. [1], desirable sensory attributes in fried shallots include a savory taste, fragrant sulfury aroma, and crispness, while bitter taste and rancid aroma are considered undesirable. Aroma is the first sensory attribute that can influence consumers' impressions before they even taste the product. Consumers typically preferred a strong sulfury aroma in fried shallots. As shown in **Figure 1**, Super Philip's fried shallots exhibited the highest intensity of this aroma, while Tajuk's fried shallots had the lowest. In this study, fresh shallots were fried at approximately 100°C for 4-5 minutes. According to Villière et al. 2015 [8], onions fried at 100°C for 25 minutes produce a distinctive sulfur aroma, whereas those fried at 130°C for 18 minutes develop a Maillard reaction aroma. Further research is needed to investigate the specific cause of the aroma in the fried shallots used in this study.

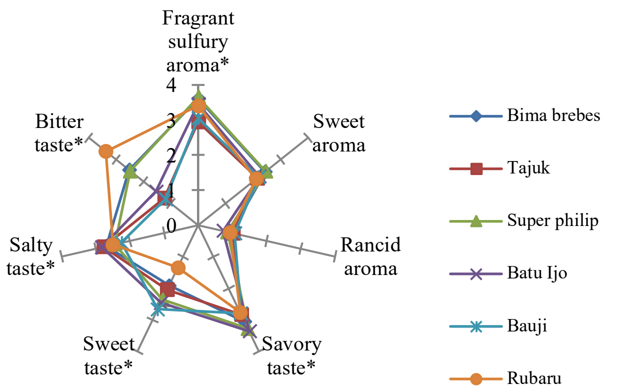

Fig. 1 Sensory profile of six fried shallots from different varieties based on a rate-all-that-apply test (*: p value less than 0.05)

The favored flavor in fried shallots is a strong umami taste. Batu Ijo fried shallots demonstrated a high level of umami. This outcome aligns with the hedonic test results (**Table 1**), indicating that Super Phillip has the highest value for taste attributes. Conversely, a bitter taste is an unfavorable quality for consumers. This investigation revealed that Rubaru fried shallots possess a pronounced bitter taste, characterized by high intensity, as demonstrated by the RATA test (Figure 1). Rubaru fried shallots, often known as Sumenep fried shallots, are widely considered to possess superior quality compared to other varieties of fried shallots. In this study, the predominance of the bitter flavor led to a diminished preference for Rubaru fried shallots for taste (**Table 1**). The results in Table 2 could be described by those in Table 1 and Figure 1.

TABLE 1.
HEDONIC RATING (1 VERY DISLIKE TO 7 VERY LIKE) OF FRIED SHALLOTS FROM DIFFERENT SHALLOT VARIETIES BASED ON THE HEDONIC OF 101 PANELISTS

Varieties	Aroma	Taste	Overall
Bima Brebes	5.28 ± 1.102[bc]	4.70 ± 1.420[b]	5.13 ± 1.105[bc]
Batu Ijo	5.52 ±1.078[c]	5.58 ± 1.112[c]	5.54 ± 0.941[c]
Rubaru	5.23 ± 1.356[abc]	3.94 ± 1.658[a]	4.68 ± 1.415[ab]
Bauji	4.95 ± 1.269[ab]	4.84 ± 1.272[b]	4.55 ± 1.224[a]
Tajuk	4.79 ± 1.292[a]	4.89 ± 1.304[b]	4.29 ± 1.287[a]
Super Philip	5.31 ± 1.177[bc]	5.06 ± 1.281[bc]	5.26 ± 1.033[c]

Note: Numbers followed by different letters show a significant difference at the 5% level with Tukey's test.

TABLE 2.
PEARSON CORRELATION COEFFICIENT BETWEEN THE SENSORY DESCRIPTION SCORES OF RATA AND THE HEDONIC RATING OF FRIED SHALLOTS

Variables	Aroma liking	Taste liking	Overall liking
Fragrant sulfury aroma	**0.888**	0.114	**0.856**
Sweet aroma	0.297	0.331	0.492
Rancid aroma	**-0.866**	-0.252	**-0.797**
Savory taste	0.834	0.716	**0.960**
Sweet taste	0.031	**0.812**	0.293
Salty taste	0.183	0.296	0.213
Bitter taste	0.435	-0.679	0.193

Note: a correlation coefficient value more than 0.80 or less than -0.80 (written in bold) is considered a strong correlation at the 5% level. RATA is a rate-all-that-apply descriptive method, referring to a previous study [1]

According to **Table 2**, which shows the Pearson correlation coefficient, aroma liking is strongly positively correlated with fragrant sulfury aroma and strongly negatively correlated with rancid aroma. In contrast, taste preference has a strong positive correlation with sweet taste intensity. Overall, the findings reveal that fragrant sulfury aroma and savory taste are strongly positively correlated, while rancid aroma shows a strong negative correlation. These results align with those of

Yofananda et al. [1], who reported that, according to consumer perception, the appealing qualities of fried shallots are driven by their fragrant sulfury aroma and savory taste. An interesting observation in this study is that, among hedonic preferences for taste qualities, sweet taste showed a stronger positive association than savory flavor. This suggests that the sweet taste of fried shallots enhances their taste preference. Bolhuis et al. [23] and Miyagi et al. [24] found that sweetness can influence meal consumption and overall preference for fried foods. Although in this study, sweet taste correlated solely with taste preference, rather than overall preference. Notably, Bauji fried shallots received the highest rating for sweet taste. The increased sweetness intensity may result from the presence of sugar molecules, sweet-tasting amino acids, and compounds produced during the Maillard reaction throughout processing [25]. The characteristics of fried shallots from these different varieties can serve as a useful reference for selecting the most suitable shallots for specific dishes. Further research could explore the mechanism behind the exceptional sweetness of Bauji shallots compared to other varieties.

B. LC-MS/MS nonvolatile profiles and the compounds detected in fried shallot extracts

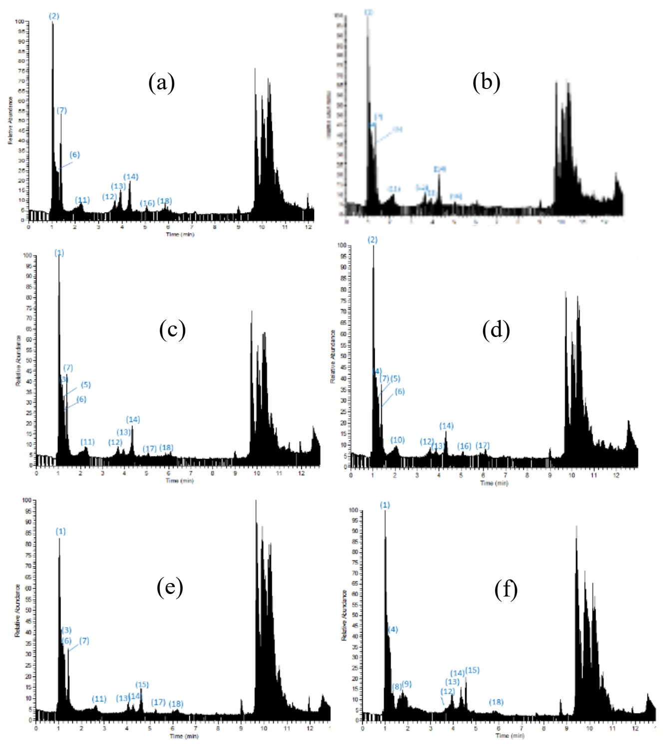

Fig. 2 Chromatograms of water extract fried shallot varieties a) Rubaru, b) Tajuk, c) Super Philip, d) Bima Brebes, e) Bauji, f) Batu Ijo, obtained by LC-MS/MS

The fried shallot extract revealed 28 peaks (**Figure 2**) during the retention time range of 0 to 13 minutes. However, 10 peaks identified between 9 and 13 minutes of retention time may contain compounds not originating from fried shallot samples, as indicated by their presence in the blank injection result. Therefore, 18 compounds associated with 18 peaks in LC-MS/MS chromatograms were evaluated for their presence in fried shallots and their correlation to sensory results.

TABLE 3.
PUTATIVE COMPOUNDS DETECTED IN FRIED SHALLOT WATER EXTRACTS BY LC-MS/MS INSTRUMENT

Peak	RT	Compound	Ion precursor (m/z) (M-H)	Ion fragment (m/z) (M-H)	Formula	MW (g/mol)	Sample
1	1.01	Malic acid	133.0133	115.00272 71.01281	$C_4H_6O_5$	134.0206	TAJ, SUP, BAU, BAI
2	1.04	2-Furoic acid	111.00783	67.01791	$C_5H_4O_3$	112.0151	RUB, BBR
3	1.13	α, α -Trehalosa	341.10910	59.01284 179.05550	$C_{12}H_{22}O_{11}$	342.1164	SUP, BAU
4	1.14	Unknown	131.04552	-	-	132.0528	TAJ, BBR, BAI
5	1.18	Oxoproline	128.03444	82.02877	$C_5H_7NO_3$	129.0417	SUP, BBR
6	1.27	Citric acid	191.0190	111.00783 87.00776	$C_6H_8O_7$	192.0264	RUB, TAJ, SUP, BBR, BAU
7	1.39	Aconitic acid	173.00850	111.00785 85.02850	$C_6H_6O_6$	174.0158	RUB, TAJ, SUP, BBR, BAU
8	1.76	Galactose	179.05556	59.01283	$C_6H_{12}O_6$	180.0628	BAI
9	1.85	Fumaric acid	115,00276	71.01282	$C_4H_4O_4$	116.0100	BAI
10	2.06	γ-L-Glutamyl-(S)-2-carboxipropile-L-cysteinyl-glicine	392.11392	143.04541 272.08902	$C_{14}H_{23}N_3O_8S$	393.1212	BBR
11	2.25	γ-L-Glutamyl-(S)-2-carboxipropile-L-cysteinyl-glicine	392.11392	143.04541 272.08902	$C_{14}H_{23}N_3O_8S$	393.1212	RUB, TAJ, SUP, BAU
12	3,66	L-γ -Glutamyl-L-leucine	259.13019	128.03442	$C_{11}H_{20}N_2O_5$	260.1373	RUB, TAJ, SUP, BBR, BAI
13	3.96	γ-L-Glutamyl-(S)-allyl-L-cisteine	289.09		$C_{11}H_{18}N_2O_5S$	290.0940	RUB, TAJ, SUP, BBR, BAU, BAI
14	4.34	Glutamyl-phenylalanine	293.1145	128.03436 164.07092	$C_{14}H_{18}N_2O_5$	294.1218	RUB, TAJ, SUP, BBR, BAU, BAI
15	4.54	Unknown	350.03	-	-	-	BAU, BAI
16	5.05	Unknown	625.1424	301.03510 151.00273	$C_{28}H_{26}N_4O_{13}$	626.1497	RUB, TAJ
17	5.08	Leucine	130.08662	128.03439 88.03936	$C_6H_{13}NO_2$	131.0939	SUP, BBR, BAU
18	5.88	N-Acetoacetylphenylalanine	248.0930	164.07098 82.02882	$C_{13}H_{15}NO_4$	249.1003	RUB, SUP, BBR, BAU, BAI

Note: Fried shallot products: RUB: Rubaru fried shallot; TAJ: Tajuk fried shallots; SUP: Super Philip fried shallots; BBR: Bima Brebes fried shallots; BAU: Bauji fried shallots; and BAI: Batu Ijo fried shallots.

The identification of chemicals in the <3 kDa fraction of fried shallot water extract is presented in **Table 3**. The detected compounds comprised organic acids, sugars, amino acids, amino acid derivatives, peptides, peptide derivatives, and several inexplicable molecules. Organic acids, including malic acid, 2-furoic acid, fumaric acid, citric acid, and aconitic acid, were determined. The discovered sugars were trehalose and galactose, while the amino acid leucine was also identified. The detected amino acid derivative was oxoproline. The detected peptides comprised glutamyl-phenylalanine, γ-L-Glutamyl-(S)-2-carboxypropyl-L-cysteinyl-glycine, L-γ-Glutamyl-L-leucine, and γ-L-Glutamyl-(S)-allyl-L-cysteine, three of which were γ-glutamyl peptides. Notably, 33.33% of the identified chemicals were peptides containing the glutamyl group, known for their contribution to umami (kokumi) flavor, which is associated with savory and salty tastes [26].

The chromatogram data (relative areas of 18 peaks across 6 chromatograms of 6 fried shallots) were analyzed by PCA, with the results illustrated in **Figure 3**. The R^2X value for the initial two primary components was 0.676, while the Q^2 value was -0.21. The PCA model accounts for 67.6% of the data variation; however, the low Q^2 value suggests limited predictive capability. This may result from insufficient replication in the test or the impact of outliers in the data. The investigation found two distinct groups of fried shallots based on the chemicals detected. The first group comprised fried shallots from the Bauji, Super Philip, Bima Brebes, Rubaru, and Tajuk varieties. The second group comprised exclusively Batu Ijo fried shallots, which earned the highest hedonic score for overall preference and showed a strong correlation with a fragrant, sulfury aroma and a savory taste.

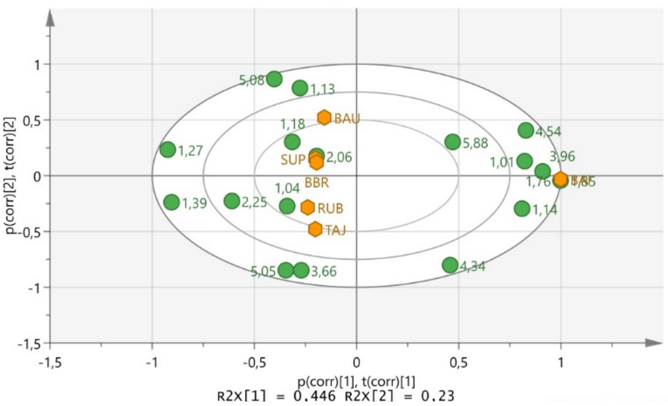

Fig. 3 PCA biplot based on LC-MS/MS chromatogram peak height ratio. Fried shallot products: RUB: Rubaru fried shallot; TAJ: Tajuk fried shallots; SUP: Super Philip fried shallots; BBR: Bima Brebes fried shallots; BAU: Bauji fried shallots; and BAI: Batu Ijo fried shallots

C. Correlation of sensory characteristics and their constituent compounds

The relationship between sensory attributes and nonvolatile compounds detected by LC-MS/MS was examined using multivariate analysis with the OPLS method. The OPLS analysis result revealed that sensory qualities, including fragrant sulfury aroma, sweet aroma, rancid aroma, savory taste, sweet taste, and bitter taste, exhibited a lack of correlation with the compounds (data not shown). As shown in Figure 4, a substantial association was observed between the salty taste and the compounds identified in Table 2. **Figure 4** illustrates the score plot for the two principal components of the salty taste, with a R^2X value of 0.65, a R^2Y value of 0.957, and a Q^2 value of 0.687. This figure shows that 65% of the variation in the identified compounds accounts for 95.7% of the variation in the salty taste data. The elevated Q^2 value indicates that the model developed in this study can accurately predict the correlation. The sample on the far left, Bauji fried shallots, possesses the least salty flavor, whilst the sample on the far right, Batu Ijo, demonstrates the highest level of salty taste.

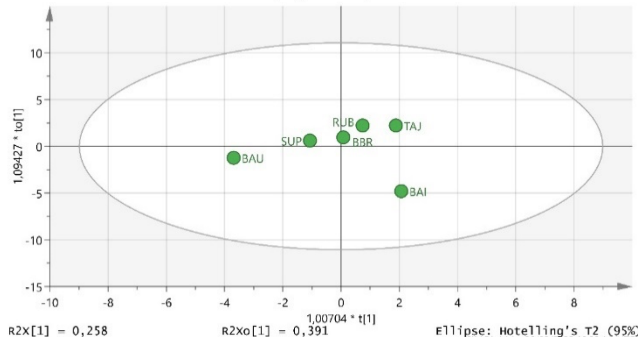

Fig. 4 OPLS score plot of salty taste of fried shallots based on compounds detected by LC-MS/MS. The fried shallot products: RUB: Rubaru fried shallot; TAJ: Tajuk fried shallots; SUP: Super Philip fried shallots; BBR: Bima Brebes fried shallots; BAU: Bauji fried shallots; and BAI: Batu Ijo fried shallots

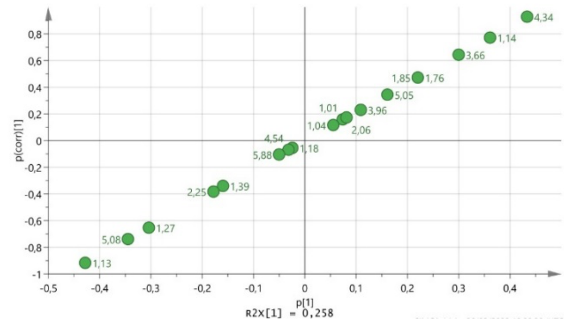

Fig. 5 S-plot correlation of compounds detected by LC-MS/MS and descriptive sensory characteristics of salty taste

An S-plot is a graphical representation of the contribution of variable X to variable Y, commonly used in partial least squares (PLS) analysis, with the VIP value generally indicating this association. In this study, variable X denotes the compounds identified by LC-MS/MS analysis, whereas variable Y denotes the sensory attributes of fried shallots. Compounds associated with each sensory characteristic are represented as points in the upper right quadrant of the figure, positioned on the positive x and y axes (**Figure 5**). The compound that exhibited a positive correlation with the salty taste was glutamyl-phenylalanine, with a retention time of 4.34 minutes and a correlation coefficient of 0.927. This peptide is probably associated with the umami taste or kokumi sensations. A previous study has indicated that γ-glutamyl-phenylalanine serves a role in the kokumi experience in food [27]. Kokumi compounds have been shown to affect the perception of sweetness, saltiness, and umami via the calcium-sensing receptor (CaSR), thereby improving food mouthfeel and richness [28]. Additional peptide molecules, like arginine dipeptides present in fermented fish sauce [29] and methionine-glycine [30], have demonstrated the ability to augment salty tastes. Moreover, peptides derived from the Maillard reaction and γ-glutamyl peptides can enhance both salty and umami tastes [26]. This study, however, examined only savory, salty, sweet, and bitter tastes, thereby precluding a comprehensive assessment of glutamyl-phenylalanine's potential to elicit umami or kokumi sensations. The finding is noteworthy, as the kokumi sensation component was identified in the water extract of the fried product.

IV. CONCLUSION

Based on the sensory attributes analysis results, it was revealed that a strong sulfury fragrance and savory flavor, as well as a sweet taste, were key factors in the preference for fried shallots. Fried shallots from the Batu Ijo variety had the highest overall preference rating. These results indicated that different shallot varieties had distinct chemical compositions, which affected the sensory attributes of fried shallots.

Application of LC-MS/MS analysis on fried shallots in this study mentioned 18 nonvolatile compounds in their water-soluble extracts (with molecular weights under 3 kDa). Among the putative identified compounds, glutamyl-phenylalanine was significantly associated with the salty taste. This compound also potentially contributes to both umami taste and kokumi sensation according to the literature on the compound.

For future studies, validating the potential role of glutamyl-phenylalanine as a kokumi-active compound in fried shallots could lead to optimized processing strategies or natural flavor enhancers for savory foods.

ACKNOWLEDGMENT

This research was funded by the Ministry of Research, Technology, and Higher Education in accordance with the PMDSU Scholarship. Grant Number 129/SP2H/PTNBH/DRPM/2018.

CONFLICT OF INTEREST

The authors declare no conflict of interest to disclose.

REFERENCES

[1] O. Yofananda, C. H. Wijaya, and H. N. Lioe, "Current Research in Nutrition and Food Science Fried Shallot Quality : Perception and Differentiation," vol. 08, no. 1, 2020, doi: http://dx.doi.org/10.12944/CRNFSJ.8.1.09.

[2] D. De Santis and M. T. Frangipane, "Citrus aurantium L.: Cultivar impact on sensory profile," *Int. J. Gastron. Food Sci.*, vol. 20, p. 100203, 2020, doi: 10.1016/j.ijgfs.2020.100203.

[3] O. Yofananda, C. H. Wijaya, and H. N. Lioe, "Variability and relationship of six Indonesian shallots (Allium cepa var . ascalonicum) cultivars based on amino acid profiles and fried shallot ' s sensory characteristics," *Biodiversitas*, vol. 22, no. 8, pp. 3327–3332, 2021, doi: 10.13057/biodiv/d220828.

[4] V. J. Paterson, E. A. Macrae, and H. Young, "Relationships between sensory properties and chemical composition of kiwifruit (Actinidia deliciosa)," *J. Sci. Food Agric.*, vol. 57, no. 2, pp. 235–251, 1991, doi: 10.1002/jsfa.2740570208.

[5] J. Sung, J. H. Suh, A. H. Chambers, J. Crane, and Y. Wang, "Relationship between Sensory Attributes and Chemical Composition of Different Mango Cultivars," *J. Agric. Food Chem.*, vol. 67, no. 18, pp. 5177–5188, 2019, doi: 10.1021/acs.jafc.9b01018.

[6] L. M. Franklin and A. E. Mitchell, "Review of the Sensory and Chemical Characteristics of Almond (Prunus dulcis) Flavor," *J. Agric. Food Chem.*, vol. 67, no. 10, pp. 2743–2753, 2019, doi: 10.1021/acs.jafc.8b06606.

[7] C. C. Chyau and J. L. Mau, "Effects of various oils on volatile compounds of deep-fried shallot flavouring," *Food Chem.*, vol. 74, no. 1, pp. 41–46, 2001, doi: 10.1016/S0308-8146(00)00336-8.

[8] A. Villière *et al.*, "Evaluation of aroma profile differences between sué, sautéed, and pan-fried onions using an innovative olfactometric approach," *Flavour*, vol. 4, no. 1, 2015, doi: 10.1186/s13411-015-0034-0.

[9] P. Tian *et al.*, "Analysis of volatile compound changes in fried shallot (Allium cepa L. var. aggregatum) oil at different frying temperatures by GC–MS, OAV, and multivariate analysis," *Food Chem.*, vol. 345, no. December 2020, p. 128748, 2021, doi: 10.1016/j.foodchem.2020.128748.

[10] S. N. Andayani, H. N. Lioe, C. H. Wijaya, and M. Ogawa, "Umami fractions obtained from water-soluble extracts of red oncom and black oncom—Indonesian fermented soybean and peanut products," *J. Food Sci.*, vol. 85, no. 3, pp. 657–665, 2020, doi: 10.1111/1750-3841.14942.

[11] A. Istiqamah, H. N. Lioe, and D. R. Adawiyah, "Umami compounds present in low molecular umami fractions of asam sunti – A fermented fruit of Averrhoa bilimbi L.," *Food Chem.*, vol. 270, no. January 2018, pp. 338–343, 2019, doi: 10.1016/j.foodchem.2018.06.131.

[12] M. M. Poojary, V. Orlien, P. Passamonti, and K. Olsen, "Improved extraction methods for simultaneous recovery of umami compounds from six different mushrooms," *J. Food Compos. Anal.*, vol. 63, no. August, pp. 171–183, 2017, doi: 10.1016/j.jfca.2017.08.004.

[13] G. Haseleu, A. Lagemann, A. Stephan, D. Intelmann, A. Dunkel, and T. Hofmann, "Quantitative sensomics profiling of hop-derived bitter compounds throughout a full-scale beer manufacturing process," *J. Agric. Food Chem.*, vol. 58, no. 13, pp. 7930–7939, 2010, doi: 10.1021/jf101326v.

[14] S. Toelstede and T. Hofmann, "Sensomics mapping and identification of the key bitter metabolites in Gouda cheese," *J. Agric. Food Chem.*, vol. 56, no. 8, pp. 2795–2804, 2008, doi: 10.1021/jf7036533.

[15] H. Hillmann, J. Mattes, A. Brockhoff, A. Dunkel, W. Meyerhof, and T. Hofmann, "Sensomics analysis of taste compounds in balsamic vinegar and discovery of 5-acetoxymethyl-2-furaldehyde as a novel sweet taste modulator," *J. Agric. Food Chem.*, vol. 60, no. 40, pp. 9974–9990, 2012, doi: 10.1021/jf3033705.

[16] Y. Ueda, M. Sakaguchi, K. Hirayama, R. Miyajima, and A. Kimizuka, "Characteristic flavor constituents in water extract of garlic," *Agric. Biol. Chem.*, vol. 54, no. 1, pp. 163–169, 1990, doi: 10.1080/00021369.1990.10869909.

[17] Y. Ueda, T. Tsubuku, and R. Miyajima, "Composition of Sulfur-Containing Components in Onion and Their Flavor Characters," *Biosci. Biotechnol. Biochem.*, vol. 58, no. 1, pp. 108–110, 1994, doi: 10.1271/bbb.58.108.

[18] J. Yang, W. Bai, X. Zeng, and C. Cui, "Gamma glutamyl peptides: The food source, enzymatic synthesis, kokumi-active and the potential functional properties – A review," *Trends Food Sci. Technol.*, vol. 91, no. May, pp. 339–346, 2019, doi: 10.1016/j.tifs.2019.07.022.

[19] M. Nakamoto, T. Fujii, T. Matsutomo, and Y. Kodera, "Isolation and Identification of Three γ-Glutamyl Tripeptides and Their Putative Production Mechanism in Aged Garlic Extract," *J. Agric. Food Chem.*, vol. 66, no. 11, pp. 2891–2899, 2018, doi: 10.1021/acs.jafc.7b05480.

[20] J. Wakamatsu, T. D. Stark, and T. Hofmann, "Taste-Active Maillard Reaction Products in Roasted Garlic (Allium sativum)," *J. Agric. Food Chem.*, vol. 64, no. 29, pp. 5845–5854, 2016, doi: 10.1021/acs.jafc.6b02396.

[21] D. Intelmann, G. Haseleu, A. Dunkel, A. Lagemann, A. Stephan, and T. Hofmann, "Comprehensive sensomics analysis of hop-derived bitter compounds during storage of beer," *J. Agric. Food Chem.*, vol. 59, no. 5, pp. 1939–1953, 2011, doi: 10.1021/jf104392y.

[22] S. Sittipod, E. Schwartz, L. Paravisini, E. Tello, and D. G. Peterson, "Identification of Compounds that Negatively Impact Coffee Flavor Quality Using Untargeted Liquid Chromatography/Mass Spectrometry Analysis," *J. Agric. Food Chem.*, vol. 68, no. 38, pp. 10424–10431, 2020, doi: 10.1021/acs.jafc.0c01479.

[23] D. P. Bolhuis, A. Costanzo, and R. S. J. Keast, "Preference and perception of fat in salty and sweet foods," *Food Qual. Prefer.*, vol. 64, no. September 2017, pp. 131–137, 2018, doi: 10.1016/j.foodqual.2017.09.016.

[24] A. Miyagi and Y. Ogaki, "Sensory preferences among general Japanese consumers and physicochemical evaluation of deep-fried peanuts," *J. Sci. Food Agric.*, vol. 94, no. 10, pp. 2030–2039, 2014, doi: 10.1002/jsfa.6521.

[25] K. Hu *et al.*, "The Effects of Fructose and Glucose on the Flavor of Vacuum Fried Hawk Claw Shrimp," *J. Chinese Inst. Food Sci. Technol.*, vol. 23, no. 1, pp. 216–227, 2023, [Online]. Available: 10.16429/j.1009-7848.2023.01.021%0A

[26] M. R. Rhyu *et al.*, "Kokumi taste active peptides modulate salt and umami taste," *Nutrients*, vol. 12, no. 4, pp. 1–19, 2020, doi: 10.3390/nu12041198.

[27] M. C. Chi, H. F. Lo, M. G. Lin, Y. Y. Chen, L. L. Lin, and T. F. Wang, "Application of Bacillus licheniformis γ-glutamyltranspeptidase to the biocatalytic synthesis of γ-glutamyl-phenylalanine," *Biocatal. Agric. Biotechnol.*, vol. 10, no. February, pp. 278–284, 2017, doi: 10.1016/j.bcab.2017.04.005.

[28] M. M. Ramesh, A. H. Venkatappa, and R. Bhat, "Natural sources, mechanisms, and sensory evaluation of umami and kokumi flavour compounds in food," *Eur. Food Res. Technol.*, 2025, doi: 10.1007/s00217-025-04729-7.

[29] A. Schindler *et al.*, "Discovery of salt taste enhancing arginyl dipeptides in protein digests and fermented fish sauces by means of a sensomics approach," *J. Agric. Food Chem.*, vol. 59, no. 23, pp. 12578–12588, 2011, doi: 10.1021/jf2041593.

[30] H. Kino and K. Kino, "Alteration of the substrate specificity of L-amino acid ligase and selective synthesis of Met-Gly as a salt taste enhancer," *Biosci. Biotechnol. Biochem.*, vol. 79, no. 11, pp. 1827–1832, 2015, doi: 10.1080/09168451.2015.1056511.