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The characterization of sensory properties, aroma profile and antioxidant capacity of noodles incorporated with asparagus tea ultra-micro powder

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ABSTRACT

Asparagus tea enhances the taste and flavor of processed foods when used as an ingredient during preparation. In this study, asparagus tea ultra-micro powder was incorporated into wheat flour during the mixing process before noodle formation at levels of 5 %, 10 % and 20 %. Flavor analysis using electric nose (E-nose) and gas chromatography–mass spectrometry (GC–MS) revealed clear distinctions among 100 % wheat flour noodle, green asparagus tea ultra-micro powder noodles (GATUPNs) and white asparagus tea ultra-micro powder noodles (WATUPNs). Based on principal component analysis (PCA) of the volatiles using GC–MS, with a threshold of VIP > 1 and $P < 0.05$, the key flavor components of GATUPNs were 1-octen-3-ol, hexanal, (E)-2-octenal, pyrazine and 3,5-diethyl-2-methyl-(8Cl, 9Cl). In contrast, the key flavor components of WATUPNs were hexanal and (+)-dipentene. The antioxidant capacity of the noodles exhibited a dose-dependent relationship with the ATUP content, with GATUPNs showing the highest antioxidant activity.

1. Introduction

Asparagus (*Asparagus officinalis* L.) is a vegetable species known for its with high nutritional values, favorable taste and fine texture (Zhou et al., 2023). The primary components responsible for the biological activity of asparagus are phenols and saponins (Fuentes-Alventosa & Moreno-Rojas, 2015). Due to the high contents of these metabolites, asparagus also has significant pharmacological functions, such as being used as supplements of antioxidants (Oli, Chauhan, Bisht, Agnihotri, & Dobhal, 2023), anti-tumor and anticancer with regulation of the immune system (Guo et al., 2020) and for the treatment of cough, rheumatism, diabetes mellitus, and other chronical diseases (Velmani, Maruthupandian, Santhosh, & Viji, 2019). Asparagus comes in different color, with the most common types being white, green, and purple. The contents of nutrients and bioactive components of asparagus spears are mainly affected by the cultivation systems and cultivars. There are no biological differences between, white and green asparagus spears. The color of the tender shoots and their bioactive components are mainly linked to the exposure to light during growth (Cuppett, Deleon, Parkhurst, & Hodges, 1997).

The tender asparagus spears have a very short shelf life due to the high respiration rate (Tzoumaki, Biliaderis, & Vasilakakis, 2009). During the harvest process alone, approximately one-third of asparagus is typically discarded (Xue, Zhang, Cheng, Sun, & Yang, 2022). To improve the economic value and extend shelf-life, asparagus shoots are prepared as canned asparagus (Zafiriou et al., 2012), asparagus tea (Zhang et al., 2024), asparagus juice (Sun, Tang, & Powers, 2005), and many other types of processed products.

Noodles are indeed a major staple food in Asia and many parts of the world with multiple choices of texture and taste, affordable price and great convenience (Baik & Donelson, 2018). The market of noodles is growing rapidly. Noodles prepared using wheat flour normally do not contain certain nutrients and biologically active substances (Wang et al., 2024). The addition of an appropriate proportion of asparagus tea ultra-micro powder (ATUP) into wheat flour can be a solution to effectively address this issue. However, raw asparagus contains a significant

Abbreviations: ATUP, asparagus tea ultra-micro powder; ATUPNs, asparagus tea ultra-micro powder noodles; GATUPNs, green asparagus tea ultra-micro powder noodles; WATUPNs, white asparagus tea ultra-micro powder noodles.

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amount of hexanal, which produces a soybean-like odor (Kong et al., 2023), negatively impacting the flavor of asparagus-based products. Related research has demonstrated that heat treatment can alter the chemical composition of food, leading to the development of new flavors (Pegiou, Mumm, & Hall, 2023).

Previously, we have optimized the preparation process of asparagus tea using blanching technology. The products have significantly enhanced the strong and sweet aroma while improving the milder taste by reducing the sourness, astringency, and bitterness of the original tea. (Zhang et al., 2024). In this study, asparagus tea ultra-micro powder of asparagus tea were added into wheat flour at different proportions. The taste color, texture, compounds and antioxidant capacity of the noodles were analyzed. This study has provided new insights for improving noodle quality and developing asparagus tea ultra-micro powder noodles (ATUMPNs) with added nutritional value.

2. Materials and methods

2.1. Preparation of asparagus tea ultra-micro powder (ATUP)

Fresh shoots of green asparagus ('No. 7') and white asparagus ('Guanjun') were harvested from an asparagus plantation in Weifang, Shandong Province, China. The asparagus tea was prepared following the method of Zhang et al. (2024). The asparagus tea ultra-micro powder (ATUP) was collected after passing through a 100-mesh standard sieve and stored at 4 °C until analysis.

2.2. Manufacture of noodles

The ATUP derived from green and white asparagus shoots, at a ratio of 0 % (control), 5 %, 10 %, and 20 % (weight/weight), was mixed into wheat flour, (Yihai Kerry Arawana Holdings Co., Ltd., China). The dough was prepared by evenly stirring the required amount of water into the flour mixture. It was then pressed into sheets approximately 2 mm thick and then cut into strips to form noodles using a pasta machine (Longkou Fuxing Machinery Co., Ltd., China). The noodles were air-dried until water content reached 9.0 %. The final dry noodle products were placed in polyethylene bags and stored in a refrigerator at 4 °C until analysis. A picture of the noodles was provided in Fig. S1.

2.3. Assessment of noodle color

The color of the cooked noodles was assessed using a colorimeter (Konica Minolta Holdings, Inc., Japan) following the method of Cavazza et al. (2012). Noodles were boilt in water (water: noodles; 5:1, w/w) at 100 °C for 5 min. After transferring onto a transparent glass plate, the surface color of the cooked noodles was recorded three times. The average values were recorded as L^*, a^*, and b^*, where L*, representing black to white (0 to 100), a* representing red to green (positive to negative scale), and b* representing yellow to blue (positive to negative scale), respectively. ΔE represents the degree of color difference between samples (Rayas-Duarate et al., 2009).

2.4. Sensory evaluation

The sensory evaluation was conducted following the method of Wang et al. (2023) with minor modification. Ten professional semi-trained assessors (5 men and 5 women) were recruited from the graduate students and teachers in Qingdao Agricultural University (China) to participate in the sensory evaluation. After being arranged in a random order, all samples were prepared by cooking 100 g of each of the seven types of noodles in 500 mL of boiling water for 5 min. All the assessors were required to rinse their mouth with double distilled water before the evaluation began. Noodles were assessed for color, appearance, taste, palatability, consistency, smoothness, and toughness. Scoring was done through a nine-point hedonic scale (1: very dislike, 5: neither like nor dislike, 9: very like). The final grade was given as the average value of all the rating scores, excluding the highest and lowest values.

2.5. Analysis of texture using texture profile analysis (TPA)

Texture profile analysis (TPA) was determined following the method of Rayas-Duarate et al. (2009) with minor modification. Cooked noodles were placed on the test platform of a texture analyzer (AMETEK Brookfield Corp, America). Each sample was measured three times. The TPA cyclic deformation test was performed with a cylindrical probe at a speed of 1.0 mm/s. The trigger force was set at 0.1 N and the compression ratio at 80 %, when measuring the cohesiveness, resilience, hardness, and firmness of the steamed noodles.

2.6. Electronic-nose (E-nose) analysis

E-nose analysis was performed following the method of Li et al. (2013) with minor modification. The cooked noodle samples, weighing 50 g each, were divided into three equal portions and placed in separate bottles. The bottles were immediately sealed with cling film and left at room temperature for 10 min to measure aroma using an electronic nose (Airsense Analytics GmbH, Germany). Each sample was measured three times. The PEN3 electronic nose is equipped with sensors that detect various aroma compounds, including the W1C (R1, aromatic), W5S (R2, broadrange), W3C (R3, ammonia and aromatic molecules), W6S (R4, hydrogen), W5C (R5, arom-aliph), W1S (R6, broad-methane), W1W (R7, sulfur-organic), W2S (R8, broad-ethanol), W2W (R9, sulf-chlor) and W3S (R10, methane-aliph).

2.7. Analysis of volatile compounds by headspace solid-phase microextraction/gas chromatography–mass spectrometry (HS-SPME/GC–MS)

GC–MS Analysis was performed following the method of Zhang et al. (2024). One gram of cooked noodles was placed into a 100 mL solid-phase microextraction vial. After the addition of the internal standard 3-nonanone, the vial was preheated for 5 min at 60 °C. Volatiles were then extracted and adsorbed for 50 min. Each sample was extracted six times for GC–MS analysis.

2.8. Identification and quantification of volatile compounds

Raw data collected by GC–MS were deconvolved using Agilent Mass Hunter Qualitative Analysis software (Agilent technology, USA). Volatile compounds were identified by comparing the obtained mass spectrometry data and real retention index (RI) with information from the National Institute of Standards and technology (NIST). RI values were calculated from a linear formula for n-alkanes under the same conditions, and the experimental conditions were based on published literature (Dool & Kratz, 1963). The relative content of the identified volatile compounds is expressed as the peak area ratio of the target volatile compound to the total volatile compounds.

2.9. Antioxidant properties

Antioxidants were extracted from the noodles following the method of Shen, Zhang, Bhandari, and Guo (2018) with minor modifications. Aliquots of 1 g of cooked noodles was soaked in 25 mL of 60 % ethanol followed by ultrasonication at 300 W and 40 °C for 1 h. After centrifugation at 5000 r/min for 20 min, supernatants were collected for antioxidant assay.

2.9.1. Assay of 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging rate

The antioxidant activity of the noodle extract was evaluated using the DPPH (2,2-diphenyl-1-picrylhydrazyl) method, as described in

Sadek and Hamidah (2023) with minor modifications. The reaction mixture contained 0.1 mL of the antioxidant supernatant, 0.4 mL of 0.25 mmol/L DPPH solution and 0.3 mL of 60 % ethanol solution. The control solution was added with 0.1 mL of 60 % anhydrous ethanol. After incubation for 30 min in darkness, the absorbance at 517 nm was recorded. Data were collected in triplicates for each sample.

2.9.2. Measurement of reducing power (RP)

The reducing power of the antioxidant supernatant was assayed using the potassium ferricyanide method (Oyaizu, 1986) with minor modifications. A specified amount of antioxidant solution (e.g., 0.1 mL) was mixed with 0.2 mL of phosphate buffer (0.2 mol/L, pH 6.6), followed by the addition of 0.5 mL of ferric potassium cyanide solution (0.01 g/mL). After incubation in a water bath at 50 °C for 20 min, the reaction solution was removed and cooled to room temperature. Then, 1 mL of trichloroacetic acid (0.1 g/mL) was added and mixed thoroughly. After centrifugation at 5000 r/min for 5 min, the supernatant (1.5 mL) was mixed with 3 mL of distilled water and 0.2 mL of ferric chloride solution (1 g/L). After thorough shaking, the mixture was left to stand for 5 min and the absorbance at 700 nm was recorded. Three measurements were taken for every sample.

2.10. Data analysis

Principal component analysis (PCA) and orthogonal partial least squares discriminant analysis (OPLS-DA) were performed using SIMCA-P software. Analysis of Variance (ANOVA) was conducted using SPSS software version 25.0 to determine the significance of differences among the means ($P < 0.05$).

3. Results and discussion

3.1. Color analysis

The indices of ΔL, Δa, and ΔE all decreased, while Δb increased, as a higher proportion of ATUP was added into the wheat flour (Table S1). The color of the noodles is influenced by factors such as the natural pigment of wheat grain, wheat flour quality, protein content, polyphenol oxidase activity, ash content, and the color of exogenous additives (Morris, 2018). ATUP has a deep brownish color, and its addition to the wheat flour resulted in darker-colored noodles. The noodles became less greenish and more yellowish after the addition of both GATUPNs and WATUPNs. During the 'heating' process in the production of asparagus tea, pheophytinization occurs in the asparagus shoots (Schwartz & Von Elbe, 1983), which causes the tender asparagus stems to change from bright green to olive color (Lau, Tang, & Swanson, 2000). Our data are consistent with those previous studies. The significant increases in the ΔE value indicates that the addition of ATUP indeed improved the color of the noodles.

3.2. Sensory evaluation

The sensory evaluation results are presented in Table S2 and Fig. 1. The evaluation revealed that ATUP affected the sensory characteristics of the noodles. Compared with the control, the addition of ATUPNs led to reduced scores in color, viscosity, slipperiness, palatability, appearance and overall sensory quality. Among the ATUPNs, the 10 % GATUPNs had the highest total score, with excellent taste and palatability. However, when the ATUPNs ratio was increased to 20 %, the total score decreased rapidly, as reflected in the TPA results. Similar findings were reported in previous studies, where incorporating 7 % negatively affected the sensory quality of the noodles (Dhull & Sandhu, 2018).

3.3. Textural analysis

TPA simulates the chewing process of food and is a key criterion for assessing the overall quality of food (Smewing, 1997). Compared with control, the addition of ATUP had an obvious effect on the texture of GATUPNs and WATUPNs, mainly reflected in the decrease of hardness, resilience, cohesiveness and chewiness. The chewiness was negatively related to the amount of ATUP added in the wheat flour (Fig. 2). Meanwhile, GATUPNs scored higher than WATUPNs in all the texture indices described above. Redondo-Cuenca et al. (2023) reported that both green and white asparagus contain cellulose, arabinose, and xylan. According to Wang et al. (2020), cellulose and arabinoxylan are the

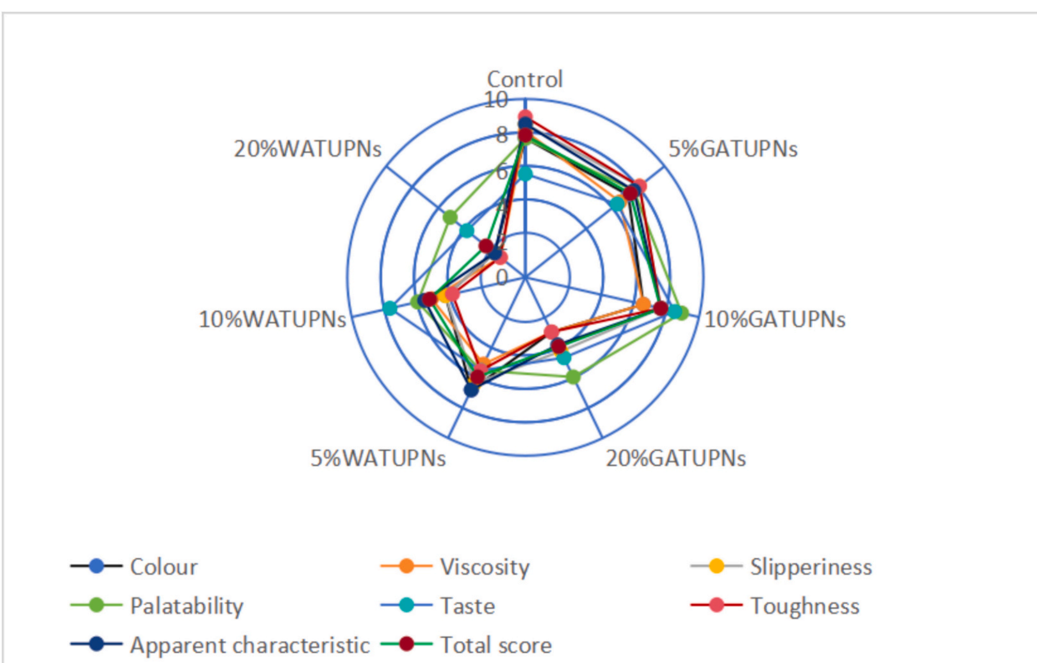

Fig. 1. Radar chart of sensory score of different kinds of noodles. Each value in the figure was presented as the mean ± standard deviation of three replicates ($n = 3$).

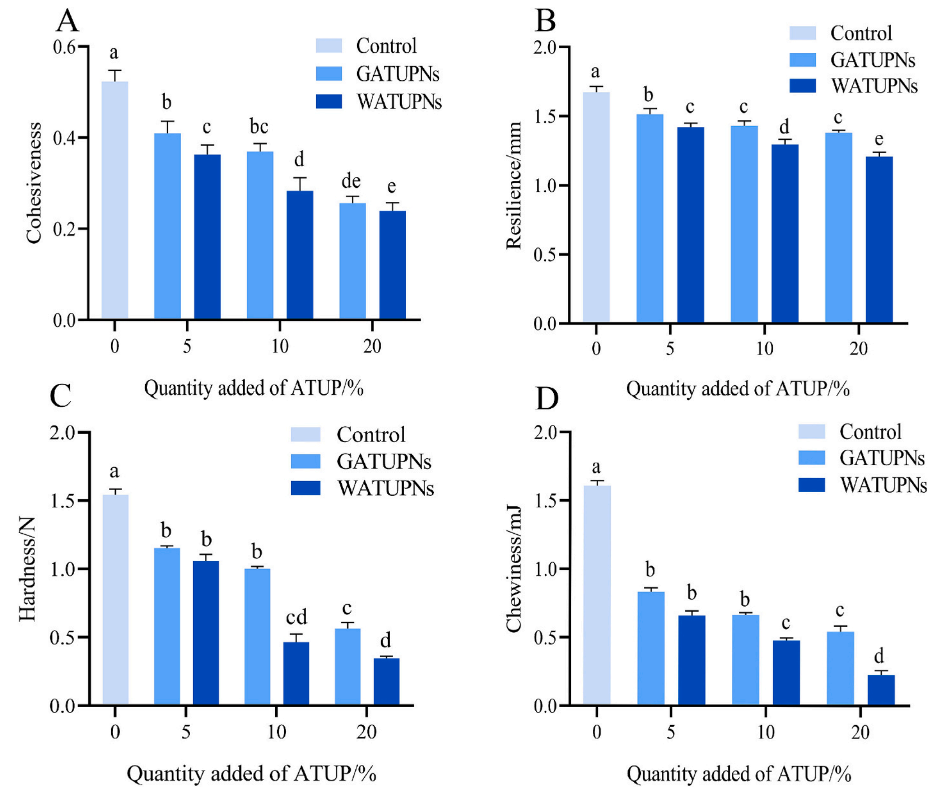

Fig. 2. The influence of different quantity added of asparagus tea ultra-micro powder (ATUP) on the textural of cooked noodles (A: Hardness, B: Cohesiveness, C: Resilience, D: Chewiness). Data are reported as the mean ± SD of three replicates (n = 3). Bars with different superscripts are significantly different ($P < 0.05$).

main components of bran, which play a significant role in interfering with the formation of gluten in bread dough, resulting in reduced cohesiveness and resilience (Hazard et al., 2015; Wang et al., 2020). Related studies have reported that the hardness of cooked instant noodles is positively correlated with the content of amylose in starch (Park & Baik, 2004). However, the main carbohydrates in asparagus are fructose, glucose and a small amount of sucrose (Bhowmik, Matsui, & Kawada, 2000), therefore the addition of ATUP may have contributed to the decline in the hardness of the noodles.

Chewiness refers to the resistance and duration of food breakdown during the chewing process, so it is positively correlated with the hardness of the noodles (Hong et al., 2024). A study of Elleuch et al. (2011) has shown that the fiber content in vegetable flour is responsible for the weakening of the quality of pasta. Padalino, Mastromatteo, Lecce, Cozzolino, and Del Nobile (2013) also reported that the addition of various vegetable powders, including asparagus powder, led to a decrease in the resilience, hardness, and adhesiveness of pasta.

3.4. E-nose analysis

The E-nose is sensitive to odor within its measurable range and is used to detect the content of volatile odor (Huang et al., 2023). The results of volatile odor analysis in different types of noodles are shown in Fig. 3A. The contribution rate of the first principal component (PC1) was 89.04 %, and the contribution rate of the second principal component (PC2) was 8.26 %. Sensor No. 2 had the highest contribution rate to the first principal component, followed by the sensor No. 10 and No. 4, while sensor No. 6 had the highest contribution rate to the second principal component. The volatile component W5S corresponding to the sensor No. 2, detects a broad range of compounds, while W1S, corresponding to sensor No. 6, is specific to broad-methane. The specific component with the highest contribution rate to the principal component were not detected by sensor No. 2. However, reports on sensor No. 6 indicated that the contents of broad-methane varied among different types of noodles.

LDA analysis indicated that the contribution rate of the first principal component (PC1) was 92.08 %, the contribution rate of the second principal component (PC2) was 2.82 %, and the total contribution rate was 94.9 %. As shown in Fig. 3B, the control, GATUPNs, and WATUPNs were clearly separated into distinct regions with no overlap, indicating that LDA analysis effectively distinguishes between GATUPNs and WATUPNs.

The E-nose was employed to analyze the volatile organic compounds (VOCs) in the noodle samples; however, it lacks the capability to identify specific types of VOCs. Therefore GC–MS analysis was subsequently conducted to further quantitatively analyze the VOCs present in ATUP noodles,.

3.5. Analysis and identification of volatile components in ATUPNs by HS-SPME/GC–MS

HS-SPME/GC–MS analysis was performed to examine the volatile profiles of the noodles, aiming to identify differences in aroma components among the control, GATUPNs and WATUPNs. Sensory evaluation indicated that noodles made with wheat flour supplemented with 10 % ATUPNs were the most preferred, so the same formula containing 10 % of GATUPNs and WATUPNs were used in GC–MS analysis. The 69 volatile aroma components (VOCs) and their contents in the control, 10 % GATUPNs and 10 % WATUPNs were shown in Table 1. The detected VOCs were categorized based on their primary functional groups, which include 7 alcohols, 11 aldehydes, 4 ketones, 1 acid, 13 esters, 1 ether, 12 alkanes, 1 alkene, 1 terpene, 8 aromatic hydrocarbons, 1 haloalkan, 9 heterocyclics aromatic substances. The total content of heterocyclic aromatic substances was the highest among the detected VOCs, followed by aldehydes, esters, and aromatic hydrocarbons.

Compared to the control, the ATUPNs-noodles were detected with a higher abundance of aroma components. The contents of alcohols, aldehydes and heterocyclic volatile substances increased, whereas the

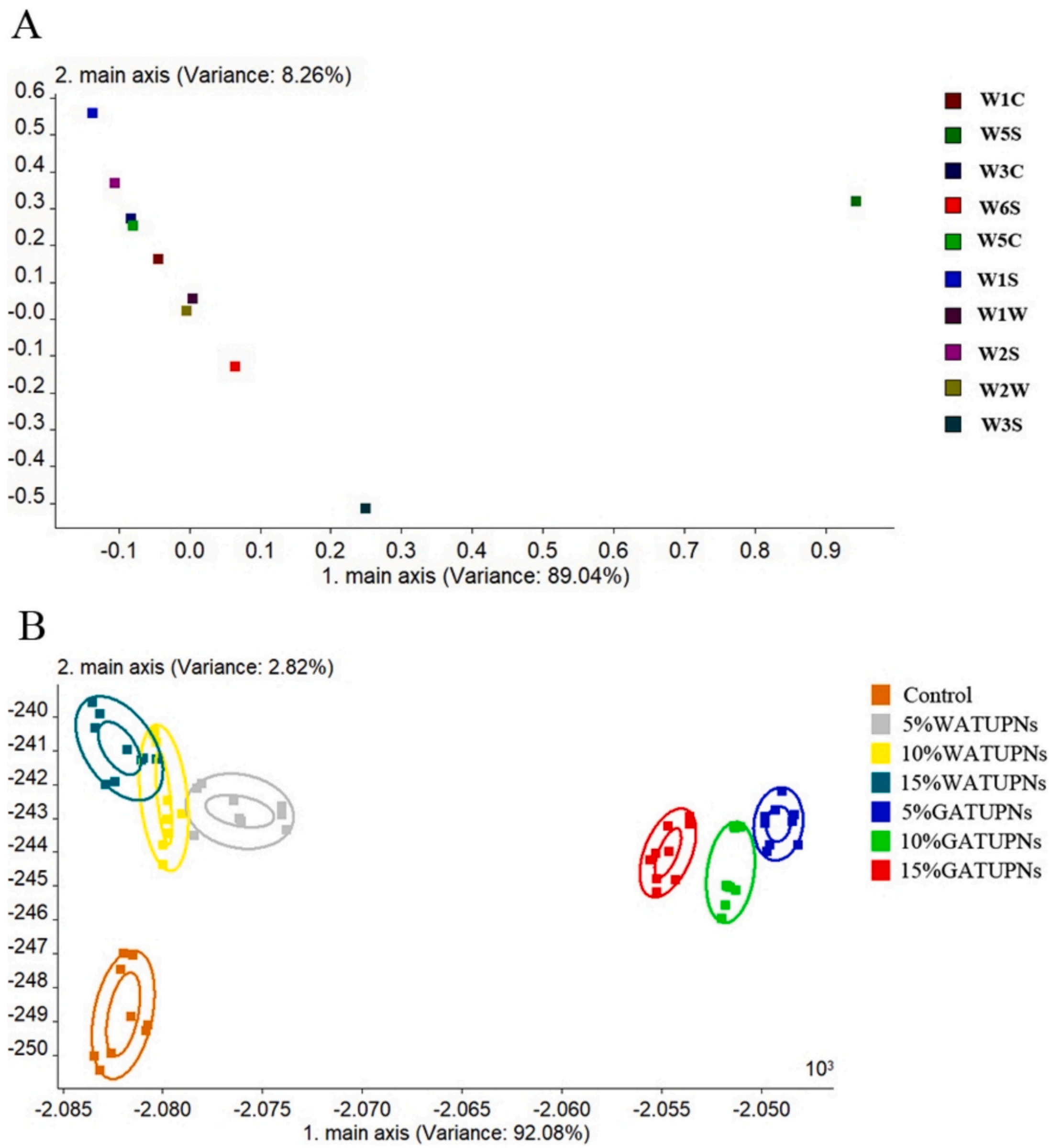

Fig. 3. E-nose analysis of noodles of wheat flour supplemented with asparagus tea ultra-micro powder. (A: Loadings analysis of different noodles, B: Linear Discriminant Analysis of different noodles). Each value in the figure was presented as the mean ± standard deviation of three replicates (n = 3). GATUPNs: green asparagus tea ultra-micro powder noodles; WATUPNs: white asparagus tea ultra-micro powder noodles. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

contents of aromatic hydrocarbons and ketones decreased in ATUPNs. GATUPNs were primarily dominated by alcohols and esters, with 1-octen-3-ol being the most abundant aroma compound. In contrast, WATUPNs were characterized by heterocyclic and aldehyde aromatic substances, with 2-ethylpyrrole showing the highest content ($P < 0.05$).

In this study, the effect of ATUP on the flavor of noodles was identified. Our results concur with a previous study showing that ultra-finely ground large-leaf yellow tea powder improves promotes the development of noodle flavor (Wang et al., 2023). In addition, the reduction or formation of different classes of volatiles can be attributed to the Melad reaction, glycoside hydrolysis, and the release of volatile compounds from carotenoids or lipids degradation during processing (Ho, Zheng, & Li, 2015). Ketones play a key role in the formation of tea aroma, often contributing fruity, floral and woody taste (Yang et al., 2018). In this study, the addition of ATUP actually reduced ketone contents in the noodles, which may be due to the decomposition of ketones at high temperatures.

Pyrrole is a product of the Maillard reaction, which contributes to the characteristic baking flavor in foods. In our results, the content of pyrrole in ATUPNs was higher than that in the control, which may enhance the baked aroma of the noodles. However, the increase in aldehydes, such as benzaldehyde with a bitter almond odor (Guo et al., 1998) and hexanal with beany flavor (Bott & Chambers IV, 2006) can lead to the formation of undesirable flavors. This observation leads us to speculate that the treatment and analysis of aldehydes could be a critical approach to addressing the off-flavors in ATUPNs.

3.6. *Characteristic of volatile compounds of ATUPNs*

3.6.1. *PCA on the volatile components*

To verify the reliability of the results, PCA was carried out using SIMCA 14.0. As shown in Fig. 4A, the principal component 1 (PC1) and principal component 2 (PC2) explained 54.70 % and 3.26 % of the total variation in ATUPNs (57.96 %), respectively. In the model, the seven

Table 1
Volatile components and relative contents of different types of ATUPNs.

Number	RI/s[1]	CAS	Compounds	Relative Content (%)[2]			VIP
				Control	10 % GATUPNs	10 % WATUPNs	
Alcohol							
1	661	107–98-2	1-methoxy-2-propanol	0.87 ± 0.12[a]	0.82 ± 0.06[a]	0.88 ± 0.11[a]	0.34
2	980	3391-86-4	1-Octen-3-ol	1.34 ± 0.11[c]	8.64 ± 0.10[a]	4.63 ± 0.31[b]	1.01
3	1030	104–76-7	2-Ethyl-1-Hexanol	–	–	1.24 ± 0.54[a]	1.05
4	1036	100–51-6	Benzyl alcohol	–	1.38 ± 0.31[a]	–	1.01
5	1038	69,668–82-2	3,5-Octadien-2-ol	2.25 ± 0.15[a]	–	–	1.06
6	1225	122–99-6	2-phenoxy-Ethanol	0.30 ± 0.15[a]	–	0.26 ± 0.02[a]	0.91
7	1598	77–53-2	Cedrol	0.34 ± 0.12[a]	–	–	1.03
Total content				5.10 ± 0.65[c]	10.84 ± 0.47[a]	7.01 ± 0.98[b]	0.92
Aldehyde							
8	652	590–86-3	3-methyl-Butanal	–	0.98 ± 0.02[a]	0.64 ± 0.04[b]	1.02
9	699	110–62-3	Pentanal	–	0.88 ± 0.02[a]	0.35 ± 0.05[b]	1.01
10	800	66–25-1	Hexanal	–	5.59 ± 0.07[a]	4.35 ± 0.29[b]	1.02
11	832	498–60-2	3-Furaldehyde	–	0.15 ± 0.01[a]	0.14 ± 0.01[a]	1.04
12	901	111–71-7	Heptanal	0.60 ± 0.18[a]	–	0.45 ± 0.04[b]	0.98
13	1003	124–13-0	Octanal	0.58 ± 0.05[a]	–	–	1.05
14	1040	36,431–60-4	1-Cyclopentene-1-carboxaldehyde, 5-ethyl-	0.36 ± 0.08[a]	–	–	1.06
15	1060	2548-87-0	(E)-2-Octenal	–	2.20 ± 0.57[a]	–	1.13
16	1104	124–19-6	Nonenal	–	–	–	1.04
17	1162	18,829–56-6	Trans-2-nonenal	–	7.00 ± 0.08[a]	5.07 ± 0.10[b]	1.08
18	1508	18,127–01-0	Bourgeonal	–	0.21 ± 0.07[a]	–	1.01
Total content				1.54 ± 0.31[c]	17.01 ± 0.84[a]	11.00 ± 0.53[b]	1.04
Ketone							
19	986	110–93-0	6-Methyl-5-hepten-2-one	0.56 ± 0.04[a]	–	–	1.06
20	1471	719–22-2	2,6-Di-tert-butyl-p-benzoquinone	0.22 ± 0.06[a]	–	–	1.01
21	1486	79–77-6	β-Lonone	–	0.50 ± 0.02[a]	–	1.04
22	1635	119–61-9	Benzophenone	0.13 ± 0.12[a]	0.13 ± 0.01[a]	0.12 ± 0.00[a]	0.70
Total content				0.91 ± 0.22[a]	0.63 ± 0.03[b]	0.12 ± 0.00[c]	0.95
Acid							
23	610	64–19-7	Acetic acid	–	3.30 ± 0.08[b]	4.05 ± 0.20[a]	1.08
Total content				–	3.30 ± 0.08[b]	4.05 ± 0.20[a]	1.08
Ester							
24	751	2155-30-8	methyl (±)-lactate	–	–	0.15 ± 0.01[a]	1.15
25	773	556–24-1	Methyl isovalerate	–	0.66 ± 0.03[a]	–	1.04
26	861	141–32-2	Butyl acrylate	–	0.51 ± 0.18[a]	–	0.97
27	925	106–70-7	Methyl hexanoate	–	–	2.92 ± 0.15[a]	1.14
28	1178	101–41-7	Methyl phenylacetate	–	0.42 ± 0.07[a]	–	1.03
29	1225	1731-84-6	Methyl Nonanoate	–	0.43 ± 0.03[a]	–	1.04
30	1725	124–10-7	Methyl Myristate	–	6.54 ± 3.84[a]	0.89 ± 0.52[b]	0.86
31	1820	7132-64-1	Methyl Pentadecanoate	1.26 ± 0.96[b]	1.51 ± 0.85[a]	–	0.98
32	1904	10,030–74-7	Palmitelaidic acid methyl ester	2.54 ± 2.02[a]	–	–	0.89
33	1926	112–39-0	Methyl palmitate	–	7.16 ± 1.91[a]	2.20 ± 0.62[b]	0.92
34	1965	84–74-2	Dibutyl phthalate	0.33 ± 0.10[a]	0.33 ± 0.09[a]	0.34 ± 0.09[a]	0.12
35	1993	628–97-7	Palmitic acid ethyl ester	–	0.61 ± 0.2[a]	–	0.85
36	2126	1,000,333–58-3	Orthodenticle-related protein (Hemicentrotus pulcherrimus clone 10 gene Otx N-terminal fragment)	0.46 ± 0.27[a]	–	–	0.96
Total content				4.59 ± 3.35[c]	18.17 ± 7.20[a]	6.50 ± 1.39[b]	0.92
Ether							
37	746	624–92-0	Dimethyl disulfide	–	0.19 ± 0.03[a]	–	1.03
Total content				–	0.19 ± 0.03[a]	–	1.03
Alkane							
38	1071	13,151–34-3	3-Methyldecane	0.71 ± 0.52[a]	–	–	0.79
39	1106	2801-84-5	2,4-dimethyldecane	–	0.47 ± 0.19[a]	–	0.98

(continued on next page)

Table 1 (*continued*)

Number	RI/s[1]	CAS	Compounds	Relative Content (%)[2]			VIP
				Control	10 % GATUPNs	10 % WATUPNs	
40	1125	17,312–54-8	3,7-dimethyldecane	0.79 ± 0.26[a]	–	–	0.96
41	1138	17,312–55-9	Decane,3,8-dimethyl	–	0.76 ± 0.28[a]	–	0.99
42	1156	1632-70-8	Undecane, 5-methyl-	0.52 ± 0.12[b]	1.01 ± 0.05[a]	–	1.09
43	1160	2980-69-0	Undecane, 4-methyl-	0.39 ± 0.08[a]	–	–	1.05
44	1181	71,138–64-2	Undecane,3-methylene-	–	–	0.73 ± 0.05[a]	1.15
45	1229	17,312–66-2	3-Ethyl-3-methyldecane	–	0.42 ± 0.08[a]	0.40 ± 0.04[a]	1.03
46	1348	25,117–31-1	5-Methyltridecane	0.39 ± 0.08[a]	–	–	1.05
47	1548	55,045–14-2	4-Ethyl-tetradecane	0.33 ± 0.04[a]	–	–	1.03
48	1600	544–76-3	N-hexadecane-D34	0.88 ± 0.05[b]	–	1.05 ± 0.22[a]	1.04
49	1811	104–66-5	Ethylene glycol diphenyl ether	–	–	0.55 ± 0.11[a]	0.15
Total content				4.01 ± 1.15[a]	2.66 ± 0.60[c]	2.73 ± 0.42[b]	0.94
Alkene							
50	893	100–42-5	Styrene	2.09 ± 0.24[b]	3.85 ± 0.22[a]	2.15 ± 0.16[b]	1.02
Total content				2.09 ± 0.24[b]	3.85 ± 0.22[a]	2.15 ± 0.16[b]	1.02
Terpene							
51	1018	5989-27-5	(+)-Dipentene	–	2.50 ± 0.00[a]	1.46 ± 0.31[b]	1.01
Total content				–	2.50 ± 0.00[a]	1.46 ± 0.31[b]	1.01
Aromatic hydrocarbon							
52	763	108–88-3	Toluene	1.16 ± 0.16[b]	1.54 ± 0.05[a]	0.92 ± 0.11[c]	1.02
53	855	100–41-4	Ethylbenzene	1.54 ± 0.18[a]	0.88 ± 0.04[b]	–	1.14
54	866	108–38-3	m-Xylene	8.97 ± 1.47[a]	5.58 ± 0.22[b]	5.08 ± 0.45[c]	1.03
55	1022	527–84-4	O-Cymene	–	0.45 ± 0.12[a]	–	1.01
56	1182	91–20-3	Naphthalene	0.58 ± 0.16[a]	–	–	1.04
57	1298	91–57-6	2-Methylnaphthalene	–	0.25 ± 0.06[a]	–	1.01
58	1552	148,145–44-2	1H-Cyclopenta[*def*]phenanthrene, 2,3,3a,4,4a,5,6,7-octahydro-	–	–	0.22 ± 0.01[a]	1.15
59	1663	3075-84-1	2,2′,5,5'-Tetramethylbiphenyl	–	–	0.13 ± 0.02[a]	1.03
Total content				12.25 ± 1.97[a]	8.70 ± 0.49[b]	6.35 ± 0.59[c]	1.05
Haloalkane							
60	700	1979-1-6	Trichloroethylene	–	0.16 ± 0.01[a]	–	1.04
Total content				–	0.16 ± 0.01[a]	–	1.04
Heterocyclic							
61	917	123–32-0	2,5-Dimethyl pyrazine	–	0.46 ± 0.12[a]	–	1.00
62	965	620–02-0	5-Methyl furfural	–	0.52 ± 0.08[b]	0.38 ± 0.08[a]	1.00
63	993	3777–69-3	2-Pentylfuran	2.61 ± 0.69[a]	1.87 ± 0.04[b]	1.60 ± 0.23[c]	0.93
64	1064	1072-83-9	2-Acetyl pyrrole	–	–	12.79 ± 0.41[a]	1.09
65	1084	13,067–27-1	2,6-Diethylpyrazine	–	2.18 ± 0.02[a]	–	1.04
66	1151	28,564–83-2	2,3-Dihydro-3,5-dihydroxy-6-methyl-4(H)-pyran-4-one	–	–	7.04 ± 1.46[a]	1.13
67	1158	18,138–04-0	2,3-Diethyl-5-methylpyrazine	–	0.18 ± 0.04[a]	–	1.02
68	1162	18,138–05-1	Pyrazine,3,5-diethyl-2-methyl- (8Cl,9Cl)	–	0.73 ± 0.02[a]	–	1.04
69	1314	18,433–98-2	isopentyldimethylpyrazine,2-isopentyl-3,6-dimethylpyrazine	–	0.50 ± 0.05[a]	–	1.04
Total content				2.61 ± 0.69[c]	6.44 ± 0.37[b]	21.81 ± 2.18[a]	1.03
Total **amount**				33.10 ± 8.58[c]	74.45 ± 10.34[a]	63.18 ± 6.76[b]	1.00

Note:[1]RI, retention index is consistent with the NIST spectral library. [2]Relative percentage content of each component was calculated by dividing the single peak area by the total peak area. The content of volatile compounds was expressed as mean value ± standard deviation ($n = 3$). Means followed by the same lowercase letters are not significantly different, and different letters indicating significant differences ($P < 0.05$, VIP > 1). "–"not perceived.

types of noodles were clustered into three distinct sets of quadrants. WATUPNs in the first quadrant, the control in the second quadrant, and GATUPNs in the third quadrant. This distribution indicates significant differences between the samples, suggesting that each type of noodles has a distinct aroma profile, as revealed by the analysis.

3.6.2. OPLS-DA on the volatile components

In order to further verify the accuracy of the model and effectively differentiate between different types of noodles, the OPLS-DA model analysis was again carried out using SIMCA 14.0. As shown in Fig. 4B, the fitting index of the independent variable (R^2x) was 0.873, while the fitting index of the dependent variable (R^2y) was 0.991. Additionally,

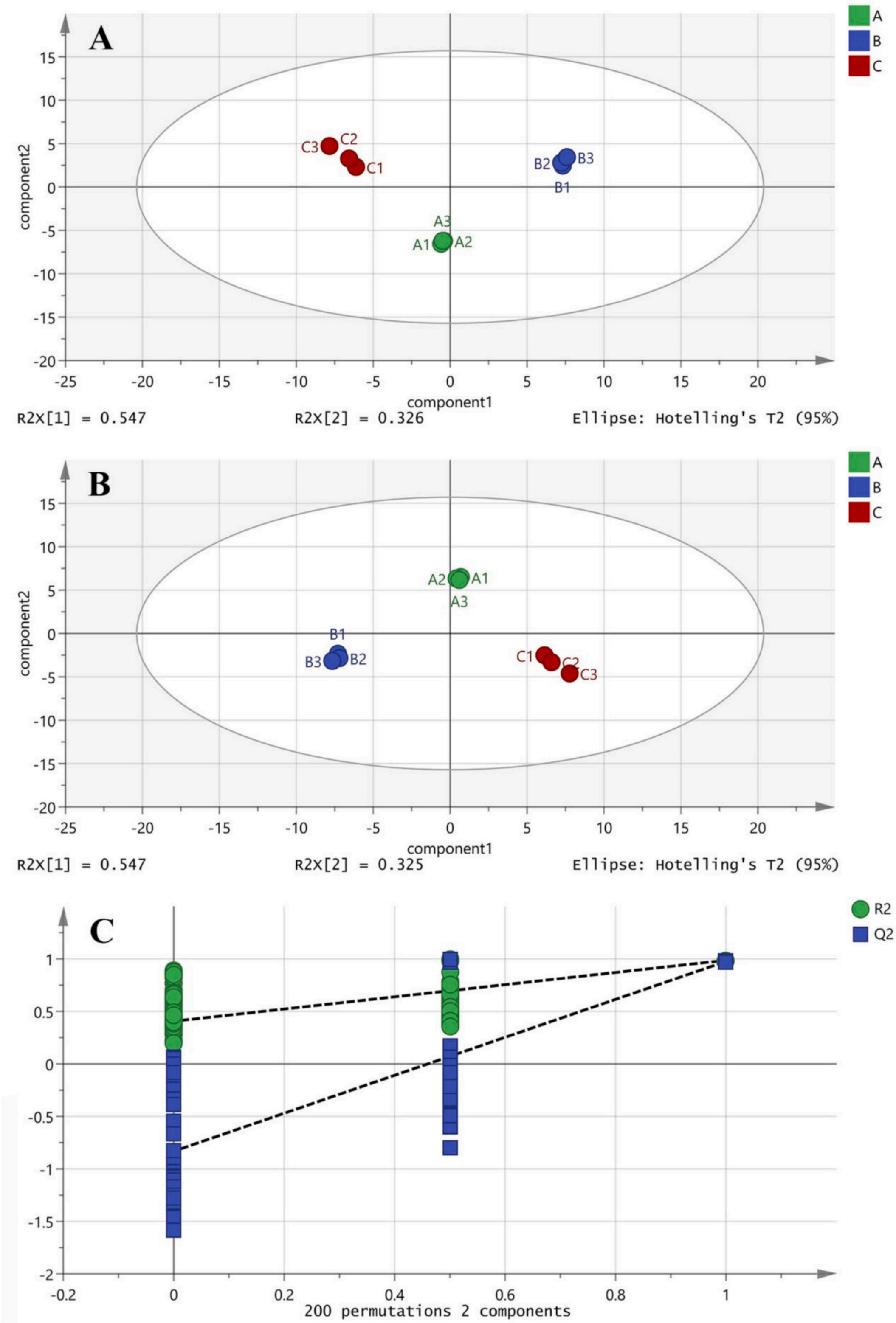

Fig. 4. Score plot of volatile compounds. (A: PCA score plot of different noodles, B: OPLS-DA score plot of different noodles, C: Permutation Test of different noodles). Each value in the figure was presented as the mean ± standard deviation of three replicates (n = 3).

the model's prediction index (Q^2) was 0.983. Since both $R^2 > 0.5$ and $Q^2 > 0.5$, the fitted model is considered acceptable, indicating a strong and reliable relationship between the variables and a high predictive accuracy (Yun et al., 2021). The model cross-substitution experiment was performed 200 times to obtain the results shown in Fig. 4C. It is evident that Q^2 reached a high value, with all other points positioned to the left of this peak. Additionally, the intersection of the Q^2 regression line with the y-axis is below zero, indicating the absence of overfitting phenomenon. This validates that the results can reliably be used to analyze the differences in aroma substances among all the noodle samples.

3.6.3. Variation of key volatile compounds of ATUPNs

Key distinct volatiles of the noodle samples were further identified based on the criteria VIP > 1 and $P < 0.05$ (Fig. 5). The changes in the content of these key volatile compounds were pivotal in distinguishing differences among the control, 10 % WATUPNs and 10 % GATUPNs. To visualize these differences, a heat map was constructed, and hierarchical cluster analysis (HCA) was performed to compare the three types of noodles.

As shown in Fig. 6A, 17 different key volatiles were identified between the control and 10 % GATUPNs, with 12 compounds showing higher content levels in GATUPNs. Among all the volatiles, 1-octen-3-ol, hexanal, (E)-2-octenal, and pyrazine, 3,5-diethyl-2-methyl-(8Cl, 9Cl) showed significantly increases in GATUPNs compared to the control noodles. Conversely, five volatile compounds decreased in GATUPNs, with Naphthalene showing a statistically significant reduction.

As shown in Fig. 6B, 20 distinct key volatiles were identified in the control and 10 % WATUPNs. In GATUPNs, 12 key volatiles increased and 8 decreased. The volatile species that showed remarkable increases in GATUPNs include hexanal, and (+)-dipentene, whereas acetic acid, 2-ethyl-1-hexanol, N-hexadecane-D34, and 2-ethyl pyrrole exhibited significant reductions.

As shown in Fig. 6C, 24 distinct key volatiles were detected in 10 % GATUPNs and 10 % WATUPNs. Among a total of 17 volatile compounds, 10 % GATUPNs exhibited higher levels than 10 % WATUPNs. Notably, 1-octen-3-ol, hexanal, (E)-2-octenal, methyl isovalerate, undecane, 5-methyl, 3,5-diethyl-2-methyl-(8Cl, 9Cl) were significantly higher in GATUPNs. Only 7 volatile compounds in 10 % GATUPNs were lower than in 10 % WATUPNs, including 2-ethyl-1-hexanol, acetic acid, methyl hexanoate, undecane, 3-methylene-, and N-hexadecane-D34, which were significantly lower in GATUPNs.

Our results showed that some key compounds such as 1-octen-3-ol, 6-methyl-5-hepten-2-one, naphthalene, methyl tetradecanoate, pyrazine, 2-pentylfuran, 3,5-diethyl-2-methyl-(8Cl, 9Cl), (E)-2-octenal, and hexanal, had important effects on the odor of ATUPNs. The analysis of key volatile compounds concluded that the addition of ATUP reduced content of these odorous volatile compounds. The 6-methyl-5-hepten-2-one has a fruity aroma and a fresh and crisp aroma (Guo et al., 2021), but this compound was not detected after the addition of ATUP. It is likely due to the decomposition of the aroma components during high temperature processing. Conclusively, the addition of ATUP improved the overall flavor of the noodles. The naphthalene (soil, moldy) components contained in control were not detected in noodles after adding ATUP (Tian et al., 2020). Compared with control, the 2-pentylfuran components that produce green and soil odor in GATUPNs and WATUPNs were significantly reduced (Zhu et al., 2018). In addition, the mushroom-like and earthy flavor and the fruity flavor of honey-coconut were improved after the addition of ATUP to the noodles, which was due to the increase in the content of 1-octen-3-ol and methyl tetradecanoate (Du, Finn, & Qian, 2010; Kang et al., 2023), and the content of GATUPNs was greater than that of WATUPNs. Pyrazine and 3,5-diethyl-2-methyl-(8Cl, 9Cl), which are typical substances with baking odor produced by the Melad reaction (Ulrich, Hoberg, Bittner, Engewald, & Meilchen, 2001), were detected in ATUPNs, and at a higher concentration in GATUPNs. (E)-2-Octenal is the most abundant volatile substance produced by lipid oxidation, and it is readily released in green tea and oolong tea (Takeo & Tsushida, 1980). And this substance was detected only in GATUPNs. Therefore, we concluded that the addition of ATUP improved the noodle aroma overall, and that GATUPNs had a better aroma composition. Hexanal produces raw oil and grassy aroma, which is the component that produces bean flavor, and the aldehydes contained in asparagus are dominated by hexanal. A previous study reported that some low-boiling aldehydes evaporate at high temperatures (Shi et al., 2021). The content of hexanal decreased during the baking process of ATUP noodles under high temperature. This suggests that adding ATUP could remove the undesirable taste associated with asparagus.

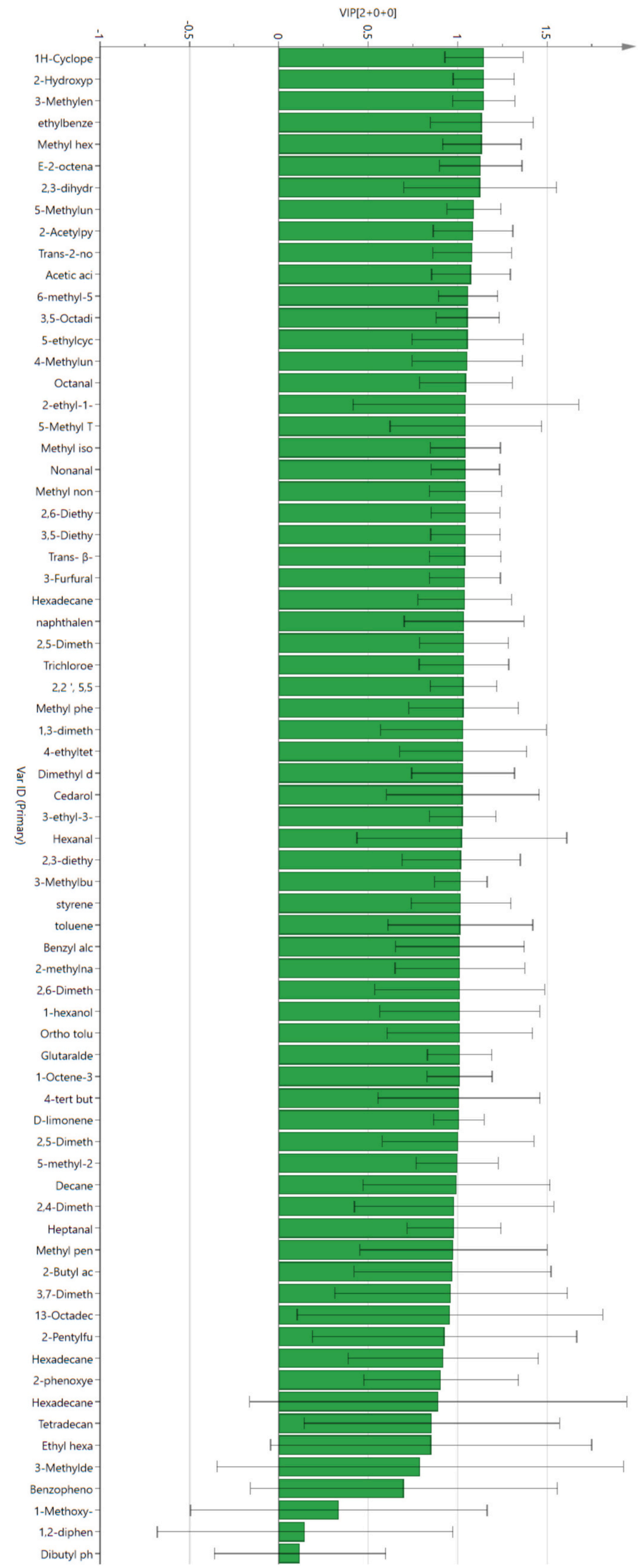

Fig. 5. VIP values of different volatile organic compounds. Each value in the figure was presented as the mean ± standard deviation of three replicates (n = 3).

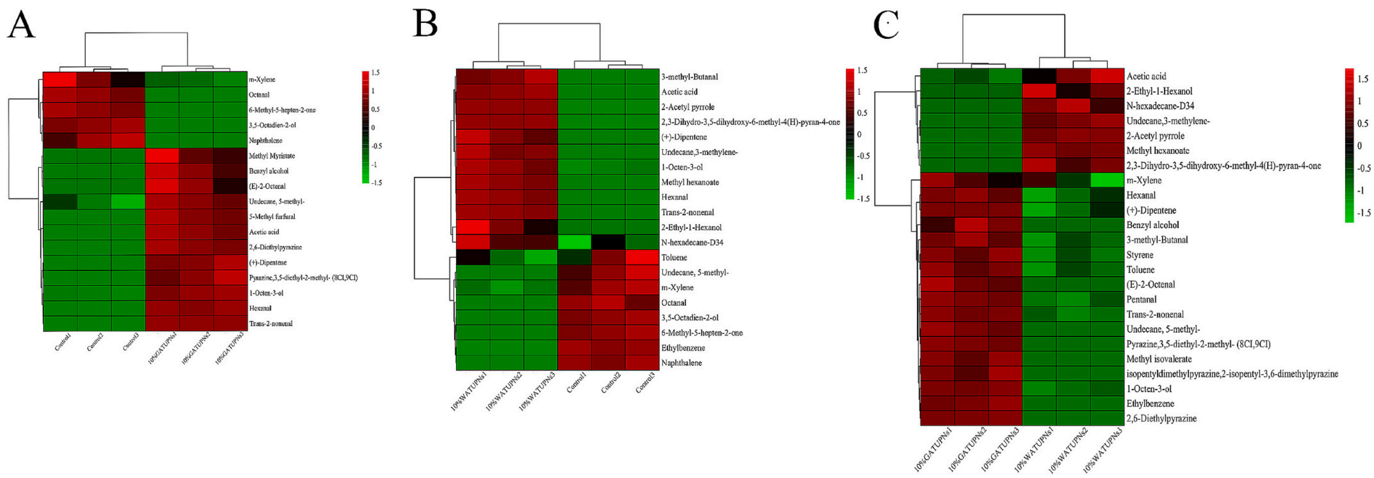

Fig. 6. Hierarchical cluster analysis (HCA) of key compounds of different types of noodles (A: Control vs GATUPNs. B: Control vs WATUPNs. C: GATUPNs vs WATUPNs). Each value in the figure was presented as the mean ± standard deviation of three replicates (n = 3).

3.7. Analysis of antioxidant capacity

The antioxidant activity of noodle extracts was characterized by DPPH free radical scavenging activity and reducing power (Fig. 7). The results showed that, compared to the control, the noodles supplemented with ATUP exhibited higher DPPH free radical scavenging activity. The scavenging activity of GATUPNs was higher than that of WATUPNs. The free radical scavenging activity of DPPH increased further as more ATUP was added to the noodles. Among them, the 20 % GATUPNs exhibited the highest scavenging rate, reaching 89.05 % ± 0.67 %, which was 79.12 % ± 2.34 % higher than that of the control.

The ATUP-noodle extract exhibited strong reducing ability toward ferrous ions, and the ferric ion reducing antioxidant power (FRAP) value was proportional to the amount of ATUP added to the wheat flour. When added in the same ratio, the ferrous ions reduction ability of GATUPNs was higher than that of WATUPNs. The reducing ability of 20 % GATUPNs was the strongest, reaching 5.80 ± 0.16 mmol/L, which was 5.47 ± 0.09 mmol/L higher than that of the control, indicating that GATUPNs exhibited strong antioxidant activity. The antioxidant capacity of GATUPNs and WATUPNs was significantly higher than that of the control ($P < 0.05$), which was due to the rich bioactive components in asparagus (Fuentes-Alventosa et al., 2013). A previous study indicated that the addition of asparagus powder can improve the antioxidant activity of noodles (Vital, Itoda, Crepaldi, Saraiva, & Matumoto-Pintro, 2020). Our results confirmed that the antioxidant capacity of GATUPNs was greater than that of WATUPNs, which is consistent with the fact that green asparagus contains a higher level of antioxidants than white asparagus, as reported by Kim et al. (2024).

4. Conclusion

Our study explored the feasibility of using ATUP to improve the quality of wheat flour noodles. The quality, aroma components and antioxidant capacity of the noodles were evaluated. As asparagus is rich in antioxidants, the antioxidant capacity of both GATUPNs and WATUPNs was significantly enhanced compared to the plain wheat flour noodles (control). According to GC–MS analysis, there was a significant difference in volatile compounds between control and ATUPNs. The addition of ATUP to the noodles generally led to a decrease in aldehydes, aromatic hydrocarbons, and ketones, while pyrazine compounds increased. We identified 17, 20, and 24 key volatiles compounds to distinguish between control and ATUPNs (control vs 10 % GATUPNs, control vs 10 % WATUPNs, 10 % GATUPNs vs 10 % WATUPNs). Notably, 1-Octen-3-ol, (E)-2-Octenal, and methyl tetradecanoate were the key compounds affecting the flavor of ATUPNs. Hexanal, a compound responsible for the undesirable smell of asparagus, was reduced. Our research confirmed that adding ATUP to wheat flour noodles can mitigate unpleasant flavor caused by asparagus. Additionally, as green asparagus grows under light conditions, the spears contain more polysaccharides, polyphenols, and other beneficial compounds, making GATUPNs more effective with higher antioxidant capacity and better aroma quality than WATUPNs.

Ethical Guidelines

The study was reviewed and approved by the Qingdao Agricultural University IRB and informed consent was obtained from each subject prior to their participation in the study.

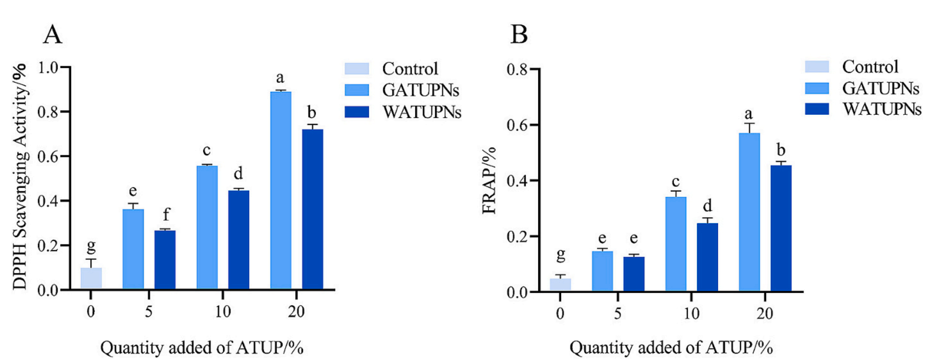

Fig. 7. Antioxidant activity of different types of noodles. (A: DPPH radical scavenging activity of different noodles, B: Ferrous reducing power of different types of noodles). Data are reported as the mean ± SD of three replicates (n = 3). Bars with different superscripts are significantly different ($P < 0.05$).

CRediT authorship contribution statement

Tengteng Li: Writing – original draft, Conceptualization. **Hao Wang:** Conceptualization. **Huaizhen Zhang:** Visualization, Resources. **Chenxia Cheng:** Investigation. **Zhongzhe Wang:** Writing – review & editing. **Suping Zhou:** Writing – review & editing. **Kexin Wang:** Methodology. **Shaolan Yang:** Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.fochx.2025.102297.

Data availability

Data supporting the findings of this study are available from the corresponding author upon official written request.

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