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The effect of instant tea on the aroma of duck meat

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ABSTRACT

Tea products, such as instant tea, have been shown to improve the aroma of meat products. However, the mechanisms by which tea products enhance meat aroma have not been adequately explained. In this study, we analyzed the impact of instant tea on the aroma of duck meat. Our results showed that treatment with instant tea led to increases in floral, baked, and grassy notes while reducing fishy and fatty notes. Several alcohols, aldehydes, ketones, indole and dihydroactinidiolide exhibited significantly increased OAVs. Conversely, certain saturated aldehydes, unsaturated aldehydes and alcohols displayed significantly decreased OAVs. The enhanced floral, baked and grassy notes were attributed to volatile compounds present in instant tea. The reduction in fishy and fatty notes was linked to polyphenols in instant tea interacting with nonanal, undecanal, (E)-2-octenal, (E)-2-nonenal, (E)-2-decenal, and 2,4-decadienal through hydrophobic interactions and electronic effects. This study enhances our understanding of how tea products improve meat aromas.

1. Introduction

The desirable flavor is an essential indicator of the quality of meat (Li, Al-Dalali, Wang, Xu, & Zhou, 2022). Currently, various techniques, including fermentation, irradiation, curing and cooking have been proposed to improve the overall aroma of meat products (Flores, 2018). Cured meat products have been shown to have spicy, savory and toasted notes compared with raw meat (Flores, 2018; Li, Belloch, & Flores, 2023), but the curing process could result in nitrites that are harmful to human health (Shakil et al., 2022). Fermentation with *Saccharomyces cerevisiae* or *Lactobacillus* could give a fruit, fatty note to meat products (Flores, Corral, Cano-Garcia, Salvador, & Belloch, 2015), but the fermentation could reduce the amount of nutrients due to microorganism metabolisms. Cooking can enhance savory, cooked meaty and roasted notes, it is not easy to control Maillard reaction (Bleicher, Ebner, & Bak, 2022). Thus, it is very attractive to develop an easy-practice process to improve the aroma of meat.

Instant tea is a soluble tea extract that is made from tea leaves through hot water extraction, centrifugal separation, concentration and drying. Instant tea is extensively applied to food processing due to enriched tea polyphenols, desirable flavor, easy storage and good solubility (Kong et al., 2022). In recent years, tea polyphenols have been shown to improve food qualities effectively, including reducing the fishy note of seafood, promoting the antioxidant activity of foods, and improving the aroma of instant rice (Alghazeer, Saeed, & Howell, 2008; Fu, Niu, Tu, & Xiao, 2021; Jiang et al., 2022; Sugimoto et al., 2021), indicating that instant tea is a practicable candidate for improving the aroma and enhancing the bioactivities of meat products. However, the effects of instant tea on the aroma of meat products have not been sufficiently illustrated.

Gas chromatography-mass spectrometry (GC–MS), gas chromatography–olfactometry-mass spectrometry (GC-O-MS), gas chromatography-ion mobility spectrometry (GC-IMS) and *E*-nose detection are often used to analyze and identify the aromatic compounds of foods (Li et al., 2022). By using these analysis technologies, the aromatic compounds, including aldehydes, ketones and esters have been identified to generate meaty, fatty and fishy notes (Cui et al., 2023; Jin et al., 2021; Man et al., 2023; Sohail et al., 2022; Soncin, Chiesa, Cantoni, & Biondi, 2007). In addition, a series of biochemical reactions, including the Maillard reaction, Strecker, thiamine degradation and lipid degradation have been shown to be involved in the aroma formation of meat (Jin et al., 2021). In this context, duck meat which has a great number of consumers was used to investigate the effect of instant tea on the aroma of meat product (Cai et al., 2020; Tabak, Yılmaz, &

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Table 1
Quantitative descriptive evaluation standard.

Aroma properties	fishy	fatty	floral	baked	grassy
Standards	(*E*)-2-nonenal (μg/L)	(E,E)-2,4-heptadienal (μg/L)	Geraniol (μg/L)	3-ethyl-2,5-dimethylpyrazine (μg/L)	(E)-2-hexenal (μg/L)
1 point	0.4	5.0	7.5	2.2	17.0
3 points	1.2	15.0	22.5	6.6	51.0
5 points	2.0	25.0	37.5	11.0	85.0

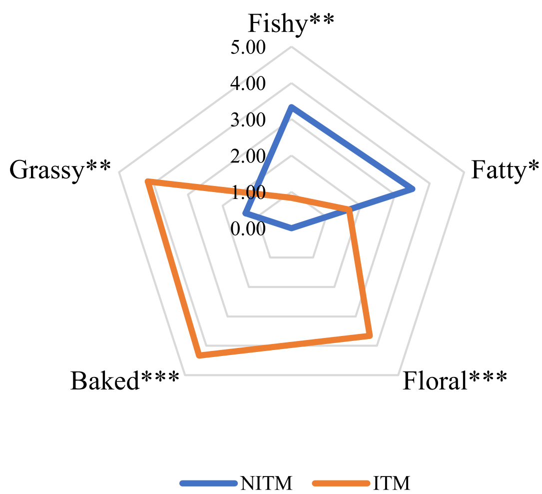

Fig. 1. Sensory evaluation of the duck meat with (ITM) and without (NITM) the instant tea treatment.
Note: *** means highly very significant differences (P<0.001), ** indicates a very significant difference (P<0.01), * indicates a significant difference (P<0.05).

Tekiner, 2021), via sensory evaluation, GC–MS and OAV analysis. This study would not only illustrate the effect of instant tea on the aroma of duck meat, but also enhance the knowledge of how instant teas affect the aroma of meat products.

2. Materials and methods

2.1. Materials and chemicals

Duck leg meat that was purchased from a local market (Xiamen, China) was stored at −20 °C in a refrigerator. Instant Oolong tea powder containing 25.07% (label provision) of tea polyphenols was purchased from Fujian Da Ming Co., Ltd. (Zhangzhou, China). A standard series of C_8-C_{20} alkanes for retention index (RI) determination and the internal standard 2,4,6-trimethylpyridine (≥98%) and ethyl decanoate (≥98%) were purchased from Sigma-Aldrich Co., Ltd. (St. Louis, USA). The standards, including 1-pentanol (≥98%), (Z)-3-hexen-1-ol (≥90%), benzaldehyde (≥97%), furfural (≥95%), (*E*)-2-hexenal (≥98%), benzeneacetaldehyde (≥98%), (E)-linalool oxide (≥96%), linalool (≥95%), phenylethyl alcohol (≥90%), 1-octen-3-ol (98%), (E)-2-nonenal (≥95%), (E,E)-2,4-heptadienal (≥98%), (E)-2-nonenal (≥98%), safranal (≥90%), decanal ≥(95%), β-cyclocitral (≥95%), 2,4-decadienal (≥90%), (E,E)-2,4-decadienal (≥95%), (E)-dodecanal (≥95%), alpha-terpineol (≥96%), hexanal (≥95%), β-ionone (≥97%), nonanal (≥96%), limonene (≥97%), dihydroactinidiolide (≥95%) and diisobutyl phthalate (≥98%) were purchased from Sigma-Aldrich (St Louis, USA). Anhydrous sodium chloride was purchased from Sinopharm Chemical Reagent Co., Ltd. (Shanghai, China).

2.2. Sample preparation

Instant tea powder (3.00 g) was added into a flask with 30 mL distilled water to obtain a 10% instant tea solution, which was hermetically sealed using a cap and set aside. The frozen duck meat that was pre-thawed completely (about 5 min) under running water, was minced with a meat grinder to ensure sample homogeneity. For preparing the instant tea treated meat (ITM), the minced meat (2.00 g) was mixed with 2 mL instant tea solution (10%) in a 25 mL headspace vial before mixing the samples well with a vortex shaker. By comparison, the control group (NITM) was prepared by mixing the 2.00 g minced duck meat with 2 mL deionized water in a 25 mL headspace vial. The ITM and NITM samples were incubated at 60 °C for 30 min before the analysis to stimulate the volatile compounds in the samples and the incubation was sealed with a cap throughout.

2.3. Sensory evaluation

The sensory evaluation was approved by the Science and Technology Ethics Committee of Jimei University and informed consent was obtained from the panelists. The evaluation was performed according to previous literature (Jiang, Li, et al., 2022; Jiang, Wang, et al., 2022) and the international method ISO 8589 with minor modifications. The sensory panel consisted of 10 professionally trained assessors (5 males and 5 females, 23–26 years old) who were trained to be familiar and distinguish the fishy, fatty, floral, baked and grassy notes according to the standards in Table 1. To ensure consistency of the study, ITM and NITM samples (both meat paste) were prepared according to section 2.2 and the samples were sensory evaluated in a specialized sensory laboratory. Assessors were required to open the cap and smell the aroma of the sample for no >30 s. The assessors were randomly asked to determine the intensity of fishy, fatty, floral, baked and grassy notes by rating scores within 0 to 5, where 0 is un-sniffed and 5 is very strong intensity.

2.4. Determination of Volatile Compounds

The volatile compounds were analyzed using the headspace solid phase micro-extraction and chromatography-mass spectrometry analysis (HS-SPEM-GC–MS). In this study, SPME extraction and adsorption were done manually. The meat samples were mixed with 2 mL of 5% NaCl solution, 10 μL of 100 mg/L 2,4,6-trimethylpyridine solution, 1 μL of 100 mg/L ethyl decanoate solution into a 60 mL headspace vial, followed by equilibration at 60 °C for 30 min in a HH-4 digital thermostat water bath (Changzhou Guohua Electric Co., Ltd. Jiangsu Province, China). Then, the samples were extracted with a 65 μm DVB/CAR/PDMS SPME fiber (Supelco, Bellefonte, PA) at 60 °C for 20 min. After adsorption, the SPME fiber was submitted to the desorption of volatiles in the GC injector at 250 °C for 3 min. The volatile compounds were qualitatively and quantitatively analyzed with a QP 2010plus GC–MS instrument (Shimadzu, Kyoto, Japan) equipped with a 60 m × 0.32 mm × 0.25 μm Rtx-5MS column (Restek Corporation, Bellefonte, PA, USA). Helium (99.999%) was used as the carrier gas at a flow rate of 1.52 mL/min in a spotless mode. The inlet temperature was 250 °C. The oven temperature was initially 35 °C for 3 min, then was raised to 98 °C at a rate of 7 °C/min, 150 °C at a rate of 6 °C/min, 180 °C at a rate of 4 °C/min, 250 °C at a rate of 5 °C/min for 5 min. The temperature of the ion

Table 2
Quantitative determination and standard curves of volatile compounds in duck meat with and without the instant tea treatment.

No	Aroma compound	Retention time /min	RI [a]	RI [b]	CIF [c]	Identification basis [d]	Standard curves [e]	R^2	Linear ranges [f]	Concentration (μg/L) (¯X ± SD) [g]	
										ITM	NITM
	Alcohols										
1	1-pentanol	8.781	N	762	42 70	MS. Std	Y = 0.1150× + 0.0074	0.9925	50–300	120.28 ± 11.68	215.02 ± 4.30
2	(*Z*)-3-hexen-1-ol ***	11.344	859	858	41 67 82	MS. P. Std	Y = 0.1140× + 0.0025	0.9955	25–200	91.54 ± 16.57	ND
3	hexanol **	11.674	870	870	56 69 84	MS. P. Std	Y = 0.4540× + 0.0370	0.9996	50–200	45.15 ± 7.41	34.47 ± 1.52
4	heptanol **	14.542	971	970	41 70 83	MS. P. Std	Y = 0.5130× + 0.0723	0.9999	50–225	20.14 ± 3.20	75.41 ± 3.30
5	1-octen-3-ol	14.820	981	981	57 72 85	MS. P. Std	Y = 2.8380× + 0.0990	0.9910	25–100	59.44 ± 7.42	40.42 ± 4.95
6	2-ethylhexanol **	16.209	1031	1030	57 70 83	MS. P. Std	Y = 1.8040× + 0.2160	0.9965	10–70	13.06 ± 1.30	2.81 ± 0.27
7	benzyl alcohol ***	16.492	1041	1041	51 79108	MS. P. Std	Y = 0.0940× + 0.0003	0.9919	25–200	442.01 ± 87.69	ND
8	octanol **	17.319	1071	1071	56 84112	MS. P. Std	Y = 1.2040× + 0.3530	0.9944	50–225	ND	129.12 ± 1.41
9	linalool ***	18.184	1103	1101	41 71 93	MS. P. Std	Y = 0.7390× + 0.0051	0.9906	5–45	196.87 ± 34.25	1.68 ± 0.27
10	hotrienol ***	18.322	1108	1104	43 71 82	MS. P. Std	Y = 0.7390× + 0.0051	0.9906	5–45	755.54 ± 123.53	ND
11	phenethyl alcohol ***	18.702	1122	1111	65 91122	MS. P. Std	Y = 0.2490× – 0.0005	0.9900	25–200	1041.12 ± 156.11	ND
12	dihydrolinalool **	19.085	1137	1130	69109138	MS. P. Std	Y = 1.7910× + 0.0620	0.9900	10–70	3.31 ± 0.89	ND
13	1-nonanol **	20.008	1172	1172	56 70 83	MS. P. Std	Y = 0.2990× – 0.0046	0.9997	50–225	ND	26.33 ± 3.31
14	linalool oxide (pyranoid) ***	20.189	1179	1173	43 68 94	MS. P	SCIS	–	–	61.84 ± 7.29	ND
15	.alpha.-terpineol ***	20.790	1202	1202	59 93121	MS. P. Std	Y = 2.8080× + 0.0610	0.9902	50–300	8.82 ± 1.49	ND
16	geraniol ***	22.247	1258	1258	41 69 93	MS. P. Std	Y = 0.7150× + 0.0082	0.9929	10–70	88.14 ± 14.75	3.44 ± 0.19
	Total									**2947.26 ± 473.58**	**528.70 ± 19.52**
	Aldehydes										
1	hexanal **	9.665	800	800	44 72 82	MS. P. Std	Y = 0.3660× + 0.0015	0.9931	25–200	149.30 ± 2.14	1160.68 ± 82.69
2	furfural *	10.686	836	836	39 67 96	MS. P. Std	Y = 0.0720× + 0.0045	0.9923	50–200	101.59 ± 2.25	ND
3	(*E*)-2-hexenal	11.230	855	855	41 69 83	MS. P. Std	Y = 0.1120× + 0.0092	0.9930	50–250	ND	10.18 ± 0.24
4	heptanal ***	12.597	903	903	44 70 86	MS. P. Std	Y = 0.6980× + 0.0202	0.9912	25–200	8.33 ± 3.12	62.76 ± 2.94
5	benzaldehyde **	14.432	967	967	51 77105	MS. P. Std	Y = 0.8370× + 0.0252	0.9920	10–70	ND	14.07 ± 2.02
6	octanal ***	15.488	1004	1004	43 69 84	MS. P. Std	Y = 1.2830× + 0.1340	0.9974	50–200	ND	63.50 ± 6.17
7	(E,E)-2,4-heptadienal **	15.758	1014	1014	39 81110	MS. P. Std	Y = 0.3690× + 0.0340	0.9954	10–70	ND	3.90 ± 1.73
8	benzeneacetaldehyde **	16.785	1052	1052	65 91120	MS. P. Std	Y = 0.3900× + 0.0367	0.9914	50–225	25.09 ± 7.75	ND
9	(E)-2-octenal **	17.046	1061	1061	41 70 83	MS. P. Std	Y = 2.8400× + 0.4060	0.9938	50–200	ND	4.98 ± 0.00
10	nonanal ***	18.275	1106	1106	57 70 98	MS. P. Std	Y = 3.0530× + 0.7300	0.9941	50–225	ND	76.78 ± 2.02
11	(E)-2-nonenal ***	19.782	1163	1164	41 70 83	MS. P. Std	Y = 0.8840× + 0.0267	0.9900	25–100	ND	19.92 ± 4.44
12	decanal ***	20.970	1208	1208	41 70 83	MS. P. Std	Y = 0.7230× + 0.0717	0.9965	50–225	ND	10.32 ± 0.48
13	safranal **	21.086	1213	1212	91107150	MS. P. Std	Y = 1.3820× + 0.0456	0.9911	10–70	12.04 ± 2.57	ND
14	(E,E)-2,4-nonadienal ***	21.240	1219	1219	41 81138	MS. P. Std	Y = 2.8160× + 0.0486	0.9940	10–70	ND	7.73 ± 0.00
15	neral *	21.976	1247	1248	41 69 94	MS. P. Std	Y = 0.6070× + 0.0500	0.9919	50–200	ND	2.87 ± 0.18
16	(E)-2-decenal **	22.445	1265	1265	41 70 83	MS. P. Std	Y = 8.1820× + 0.2090	0.9917	50–250	ND	4.37 ± 0.66
17	citral ***	22.728	1276	1276	41 69 84	MS. P. Std	Y = 4.5590× + 0.0759	0.9987	50–250	ND	16.80 ± 0.48
18	2,4-decadienal ***	23.322	1299	1298	41 81152	MS. P. Std	Y = 1.2500× + 0.0655	0.9931	50–225	ND	19.94 ± 1.15

(*continued on next page*)

Table 2 (*continued*)

No	Aroma compound	Retention time /min	RI [a]	RI [b]	CIF [c]	Identification basis [d]	Standard curves [e]	R^2	Linear ranges [f]	Concentration (μg/L) (¯X ± SD) [g]	
										ITM	NITM
19	undecanal *	23.600	1310	1310	41 67 82	MS. P. Std	Y = 1.0600× + 0.0059	0.9962	10–70	ND	2.02 ± 0.07
20	(E,E)-2,4-decadienal ***	23.937	1323	1323	41 81152	MS. P. Std	Y = 3.8360× + 0.0432	0.9942	10–70	ND	11.37 ± 0.23
21	(E)-2-undecenal ***	25.140	1368	1368	41 70 83	MS. P	SCIS	–	–	ND	49.72 ± 4.96
22	(E)-dodecenal ***	27.891	1471	1466	43 70 83	MS. P. Std	Y = 2.8990× + 0.0438	0.9944	10–70	ND	0.17 ± 0.01
23	hexadecanal ***	36.749	1822	1822	57 68 82	MS. P. Std	Y = 2.1340× + 0.0202	0.9944	50–225	13.49 ± 1.76	2.52 ± 0.09
	Total									**309.84 ± 19.59**	**1544.60 ± 110.56**
	Ketones										
1	2-heptanone *	12.302	892	892	43 58 99	MS. P. Std	Y = 0.4280× + 0.0726	0.9927	10–70	35.5 ± 11.15	5.25 ± 0.82
2	2,3-octanedione ***	14.935	985	984	43 71 99	MS. P	SCIS	–	–	98.49 ± 4.62	ND
3	6-methyl-5-heptene-2-one **	15.053	989	989	43 69108	MS. P. Std	Y = 1.3550× + 0.0658	0.9906	25–200	71.84 ± 14.26	2.39 ± 0.08
4	acetophenone ***	17.430	1075	1075	77105 120	MS. P. Std	Y = 1.3880× + 0.0272	0.9903	50–250	21.13 ± 3.89	ND
5	(E,*E*)-3,5-octadien-2-one **	18.035	1097	1098	81 95124	MS. P. Std	Y = 3.1850× + 0.3210	0.9901	50–200	4.38 ± 0.90	ND
6	isophorone **	18.945	1131	1117	82123138	MS. P. Std	Y = 2.7380× + 0.3030	0.9905	50–200	2.53 ± 0.82	ND
7	4-oxoisophorone ***	19.505	1153	1138	68 96152	MS. P. Std	Y = 0.9190× + 0.0899	0.9965	50–200	26.84 ± 5.09	ND
8	(*Z*)-jasmone **	26.344	1414	1415	41 79110	MS. P. Std	Y = 0.8290× + 0.0043	0.9923	50–250	14.93 ± 4.04	ND
	Total									**275.64 ± 44.77**	**7.64 ± 0.90**
	Esters										
1	benzoic acid, ethyl ester **	20.202	1179	1179	77105 122	MS. P. Std	Y = 2.7870× + 0.0181	0.9917	5–45	ND	0.61 ± 0.05
2	ethyl-octanoate **	20.650	1196	1196	57 70 88	MS. P. Std	Y = 2.8760× + 0.0608	0.9967	5–45	ND	2.28 ± 0.30
3	methyl salicylate ***	20.946	1208	1208	92120152	MS. P. Std	Y = 6.8320× + 0.4300	0.9919	50–300	5.24 ± 1.01	ND
4	benzenepropanoic acid, methyl ester ***	23.712	1314	1295	51 77104	MS. P	SCIS	–	–	34.76 ± 5.67	ND
5	(Z)-jasmin lactone ***	28.954	1511	1517	55 71 99	MS. P	SCIS	–	–	88.13 ± 10.03	ND
6	dihydroactinidiolide ***	30.284	1561	1548	43111137	MS. P. Std	Y = 0.0540× + 0.000007	0.9946	50–250	1206.91 ± 98.82	ND
7	diisobutyl phthalate **	38.160	1883	1881	57149167	MS. P. Std	Y = 9.2890× – 0.0580	0.9998	50–250	0.74 ± 0.15	ND
8	homosalate ***	38.826	1913	1903	69109138	MS. P. Std	Y = 20.981× – 0.0085	0.9929	50–200	0.26 ± 0.02	ND
9	ethyl-palmitate ***	40.570	1994	1994	43 70 88	MS. P. Std	Y = 7.5880× – 0.0684	0.9986	50–200	ND	0.33 ± 0.02
	Total									**1336.04 ± 115.70**	**3.22 ± 0.37**
	Acids										
1	hexanoic acid ***	14.707	977	977	41 60 87	MS. P	SCIS	–	–	ND	16.20 ± 0.94
2	octanoic acid ***	19.890	1167	1142	43 60101	MS. P	SCIS	–	–	60.64 ± 9.56	3.62 ± 0.29
3	nonanoic acid ***	22.397	1264	1264	57 60115	MS. P	SCIS	–	–	31.83 ± 4.28	ND
4	hexadecanoic acid ***	39.879	1962	1962	42 73129	MS. P. Std	Y = 0.4630× + 0.0001	0.9993	25–100	13.03 ± 2.58	ND
	Total									**105.50 ± 16.42**	**19.82 ± 1.23**
	Olefins										
1	styrene *	12.376	895	894	51 78104	MS. P. Std	Y = 4.8130× + 0.3210	0.9907	50–250	0.25 ± 0.11	ND
2	limonene **	16.335	1035	1035	68 93107	MS. P. Std	Y = 4.1230× + 0.3580	0.9900	50–225	7.32 ± 0.99	1.73 ± 1.28
	Total									**7.57 ± 1.10**	**1.73 ± 1.28**
	Oxides										
1	(*Z*)-linalool oxide ***	17.538	1079	1079	43 59 94	MS. P. Std	Y = 0.6850× + 0.0026	0.9919	25–200	177.10 ± 32.20	3.51 ± 1.12

(*continued on next page*)

Table 2 (*continued*)

No	Aroma compound	Retention time /min	RI [a]	RI [b]	CIF [c]	Identification basis [d]	Standard curves [e]	R^2	Linear ranges [f]	Concentration (μg/L) (¯X ± SD) [g]	
										ITM	NITM
2	(*E*)-linalool oxide ***	17.969	1095	1095	43 59 94	MS. P. Std	Y = 0.5230× − 0.00006	0.9908	25–200	145.02 ± 26.99	ND
	Total									**322.12 ± 59.19**	**3.51 ± 1.12**
	Other classes										
1	1-ethylpyrrole **	10.117	816	815	39 80 95	MS. P. Std	Y = 1.4030× − 0.0830	0.9941	50–225	24.15 ± 6.84	ND
2	2,6-dimethyl-pyrazine ***	12.958	915	915	42 67108	MS. P	SCIS	–	–	31.41 ± 5.91	ND
3	2-ethyl-3,6-dimethylpyrazine ***	17.682	1084	1084	42 80135	MS. P	SCIS	–	–	55.07 ± 8.31	ND
4	benzyl nitrile ***	19.403	1149	1135	63 90117	MS. P. Std	Y = 2.0820× − 0.0078	0.9937	25–200	88.58 ± 17.40	ND
5	anethole *	23.255	1297	1301	77117148	MS. P. Std	Y = 2.1830× + 0.0360	0.9944	5–45	ND	2.72 ± 0.08
6	Indole **	23.608	1310	1310	63 90117	MS. P. Std	Y = 1.0770× + 0.0046	0.9967	50–250	135.14 ± 27.43	ND
7	coumarin ***	27.699	1464	1465	90118146	MS. P	SCIS	–	–	26.64 ± 2.21	ND
	Total									**360.99 ± 68.10**	**2.72 ± 0.08**

ITM, Duck meat treated with instant tea; NAIM, Duck meat not treated with instant tea;*** means highly very significant differences ($P<0.001$), ** indicates a very significant difference ($P<0.01$), * indicates a significant difference ($P<0.05$), no marking indicates non-significant difference ($P>0.05$).

[a] : The RI was calculated Rtx-5MS.

[b] : The RI of the reference website (http://webbook.nist.gov/chemistry).

[c] : Characteristic ion fragment.

[d] : MS represents the library search results. P indicates the qualitative nature of the retention index. Std means quantification by standard curve.

[e] : Standard curves of aroma compounds. SCIS indicates that the content of the compound was calculated according to the internal standard method.

[f] : Linear ranges of aroma compounds.

[g] : X was the average. SD was the standard deviation. N indicates that the compound retention index could not be calculated. - indicates that the standard curve equation for the compound had not been measured; ND indicates that the compound was not detected.

source was set at 230 °C. The MS was operated in electron impact (EI) mode with an ionization voltage of 70 eV. The interface was set at 150 °C. The mass scan range of *m/z* was set from 35 to 500 amu. The delay time of the solvent was 6 min. Each sample was analyzed three times.

The mass spectrometry databases (NIST11, NIST11s, FFNSC1.3) were used to search and screen similar substances with mass spectrometry matching >80%. The C_8-C_{20} alkanes standard was analyzed for the calculation of the retention index (RI) values based on Kratz's and Vaeool's methods. The volatiles were confirmed by matching the base peak, characteristic ion peak and RI with those of standards. Most of the volatiles that were purchased with standards, were quantitatively analyzed using calibration curves of the according standards. For the volatiles without available standards, the relative quantification was carried out using the internal standard method with 2,4,6-trimethylpyridine and ethyl decanoate selected as the nearest internal standard.

2.5. Odor activity value (OAV) analysis

The OAV value was calculated by dividing the concentration of the volatile compound calculated from the standard curve by its threshold. Only the volatile compounds whose contents were calculated based on the standard curve method could further calculate their OAV values.

2.6. Validation of the interactions between aldehydes and the instant tea

Standard chemicals of aldehydes were put into the instant tea solution (ITS), followed by analyzing the content changes. Firstly, the standard aldehyde solutions, hexanal, heptanal, octanal, (E)-2-octenal, nonanal, (E)-2-nonenal, decanal, (E,E)-2,4-nonadienal, (E)-2-decenal, 2,4-decadienal, undecanal and (E,E)-2,4-decadienal, were prepared at their respective content as detected in NITM (Table 2). The control (NITS) was the standard solution without addition of instant tea solution. The analysis was conducted in triplicate using HS-SPME-GC–MS as described above.

2.7. Statistical analysis

All samples were analyzed and evaluated in triplicate. The calculation of the average and standard deviation and the drawing of radar plots were performed using Office 2016 (Microsoft, Redmond, WA). The chemical structure formula was drawn with the ChemDraw software (PerkinElmer, Waltham, MA). Analysis of ANOVA was performed using the SPSS 20.0 software (IBM, Armonk, NY).

3. Results and discussion

3.1. Effect of instant tea on the aroma profile of duck meat

The overall aroma profiles of duck meat with and without instant tea treatment were shown in Fig. 1. The NITM sample was dominated by fishy (3.33), fatty (3.50) and grassy (1.33) notes, showing similar aroma profiles of the uncooked duck reported previously (Sohail et al., 2022; Soncin et al., 2007). In addition, the ITM sample was dominated by baked (4.33), grassy (4.17), floral (3.67), fatty (1.67) and fishy (0.83) notes. By comparison, it was shown that the treatment of instant tea resulted in decreased fishy ($P<0.01$) and fatty ($P<0.05$) notes, as well as increased baked ($P<0.001$), floral ($P<0.001$) and grassy ($P<0.01$) notes. Researches have shown that instant tea mainly presented floral, grassy, baked and sweet notes (Jiang, Li, et al., 2022; Jiang, Wang, et al., 2022), indicating the increased baked and floral notes of duck meat might come from the floral and baked notes of instant tea. Additionally, the tea polyphenols have been shown to reduce the fishy note (Chen et al., 2016; Jongberg, Torngren, Gunvig, Skibsted, & Lund, 2013; Zhu, Poojary, Andersen, & Lund, 2020), indicating the decreased fishy and fatty notes might be related to polyphenols in the instant tea interact with the

Table 3
OAV analysis of volatile components in duck meat with and without the instant tea treatment.

No	Aroma compound	Retention time /min	Odor description [a]	Odor threshold [b] (μg/L)	OAV [c]	
					ITM	NITM
1	1-pentanol**	8.781	grassy, almond	5 (Wang et al., 2021)	24.06 ± 2.34	43.00 ± 0.86
2	hexanal**	9.665	fishy, fatty	4.5 (Wang et al., 2021)	33.18 ± 0.47	257.93 ± 18.38
3	1-ethylpyrrole*	10.117	roasted, sweet	625 (Ni et al., 2021)	0.04 ± 0.01	ND
4	furfural***	10.686	almond, woody	9.56 (Sohail et al., 2022)	10.63 ± 0.24	ND
5	(E)-2-hexenal***	11.230	grassy	17 (Guo et al., 2021)	ND	0.60 ± 0.01
6	(Z)-3-hexen-1-ol*	11.344	grassy	70 (Zhang et al., 2020)	1.31 ± 0.24	ND
7	hexanol	11.674	floral, grassy	92 (Ni et al., 2021)	0.49 ± 0.08	0.37 ± 0.02
8	2-heptanone	12.302	fruity, woody	140 (Zhang et al., 2020)	0.25 ± 0.08	0.04 ± 0.01
9	heptanal**	12.597	fishy, fatty, grassy	3 (Li et al., 2016)	2.78 ± 1.04	20.92 ± 0.98
10	benzaldehyde*	14.432	almond, burnt sugar	320 (Wang et al., 2021)	ND	0.04 ± 0.01
11	heptanol**	14.542	chemical, green	2.4 (Wang et al., 2021)	8.39 ± 1.33	31.42 ± 1.38
12	1-octen-3-ol	14.820	mushroom	1.00 (Feng et al., 2018)	59.44 ± 7.42	40.42 ± 4.95
13	6-methyl-5-hepten-2-one*	15.053	grassy, mushroom	68 (Sohail et al., 2022)	1.06 ± 0.21	0.04 ± 0.00
14	octanal**	15.488	fruity, fatty	0.7 (Feng et al., 2018)	ND	90.72 ± 8.81
15	(E,E)-2,4-heptadienal*	15.758	nut, fatty	5 (Guo et al., 2019)	ND	0.35 ± 0.35
16	2-ethylhexanol*	16.209	sweet, fruity, fatty	25.48 (Sohail et al., 2022)	0.51 ± 0.05	0.11 ± 0.01
17	limonene*	16.335	lemon, orange	10 (Zhang et al., 2020)	0.73 ± 0.10	0.17 ± 0.13
18	benzyl alcohol*	16.492	floral, fruity	100 (Jiang, Li, et al., 2022; Jiang, Wang, et al., 2022)	4.42 ± 0.88	ND
19	phenylacetaldehyde*	16.785	floral, sweet	4 (Jiang, Li, et al., 2022; Jiang, Wang, et al., 2022)	6.27 ± 1.94	ND
20	(E)-2-octenal *	17.046	fatty, grassy	3 (Guo et al., 2021)	ND	1.66 ± 0.00
21	octanol***	17.319	fatty, grassy	54 (Zhang et al., 2020)	ND	2.39 ± 0.03
22	acetophenone**	17.430	floral, milky	65 (Jiang, Li, et al., 2022; Jiang, Wang, et al., 2022)	0.33 ± 0.06	ND
23	(Z)-linalool oxide*	17.538	floral, sweet	6 (Jiang, Li, et al., 2022; Jiang, Wang, et al., 2022)	29.52 ± 5.37	0.59 ± 0.19
24	(E)-linalool oxide*	17.969	floral, woody	6 (Jiang, Li, et al., 2022; Jiang, Wang, et al., 2022)	24.17 ± 4.50	ND
25	(E,E)-3,5-octadien-2-one*	18.035	woody, sweet	0.5 (Xu et al., 2022)	8.77 ± 1.81	ND
26	linalool**	18.184	floral, sweet	10 (Jiang, Li, et al., 2022; Jiang, Wang, et al., 2022)	19.69 ± 3.43	0.17 ± 0.03
27	nonanal ***	18.275	fatty, citrus, green	1.1 (Guo et al., 2021)	ND	69.80 ± 1.83
28	hotrienol **	18.322	floral, sweet	110 (Jiang, Li, et al., 2022; Jiang, Wang, et al., 2022)	6.87 ± 1.12	ND
29	phenethyl alcohol**	18.702	floral, sweet	60 (Jiang, Li, et al., 2022)	17.35 ± 2.60	ND
30	isophorone*	18.945	sweet, woody	11 (Guo et al., 2021)	0.23 ± 0.07	ND
31	dihydrolinalool*	19.085	floral, camphor	3.8 (Yang, Zhao, & Du, 2022)	6.61 ± 1.77	ND
32	4-oxoisophorone*	19.505	musty, honey	25 (Yang et al., 2022)	1.07 ± 0.20	ND
33	(E)-2-nonenal	19.782	fishy, grassy	0.19 (Guo et al., 2021)	ND	104.85 ± 23.38
34	1-nonanol*	20.008	fatty, greasy	46 (Sohail et al., 2022)	ND	0.57 ± 0.070
35	ethyl-octanoate*	20.650	fruity	5 (Zhao et al., 2021)	ND	0.46 ± 0.06
36	α-terpineol	20.790	floral	330 (Guo et al., 2021)	0.03 ± 0.00	ND
37	methyl salicylate	20.946	caramel, peppermint	40 (Jiang, Li, et al., 2022; Jiang, Wang, et al., 2022)	0.13 ± 0.03	ND
38	decanal**	20.970	fatty, grassy	0.1 (Jiang, Li, et al., 2022; Jiang, Wang, et al., 2022)	ND	103.21 ± 4.79
39	safranal*	21.086	woody	0.7 (Jiang, Li, et al., 2022; Jiang, Wang, et al., 2022)	17.21 ± 3.67	ND
40	(E,E)-2,4-nonadienal	21.240	fatty, grassy	0.09 (Feng et al., 2018)	ND	85.9 ± 0.04
41	neral	21.976	floral	300 (Yin et al., 2022)	ND	0.01 ± 0.00
42	geraniol**	22.247	floral, citrus	7.5 (Jiang, Li, et al., 2022; Jiang, Wang, et al., 2022)	11.75 ± 1.97	0.46 ± 0.02
43	(E)-2-decenal**	22.445	fatty, grassy	0.4 (Feng et al., 2018)	ND	10.93 ± 1.66
44	citral	22.728	woody, mold	53 (Jiang, Li, et al., 2022; Jiang, Wang, et al., 2022)	ND	0.32 ± 0.01
45	2,4-decadienal	23.322	fishy, fatty	0.2 (Feng et al., 2018)	ND	99.68 ± 5.73
46	undecanal	23.600	floral, grassy	0.12 (Sohail et al., 2022)	ND	16.85 ± 0.60
47	indole*	23.608	mothball, burnt	40 (Guo et al., 2021)	3.38 ± 0.69	ND
48	(E,E)-2,4-decadienal	23.937	fishy, fatty	0.07 (Guo et al., 2021)	ND	162.41 ± 3.22
49	(Z)-jasmone*	26.344	jasmine, sweet	7 (Guo et al., 2021)	2.13 ± 0.58	ND
50	(E)-dodecenal**	27.891	fatty, sweet	1.4 (Sohail et al., 2022)	ND	0.12 ± 0.01
51	dihydroactinidiolide**	30.284	musky, coumarine	3.8 (Yang et al., 2022)	317.61 ± 26.00	ND

ITM, Duck meat treated with instant tea; NITM, Duck meat not treated with instant tea; ND means not detected; *** means highly very significant differences ($P<0.001$), ** indicates a very significant difference ($P<0.01$), * indicates a significant difference ($P<0.05$).
[a] : The odor description from literature and web. (http://www.flavornet.org/, http://www.odour.org.uk/).
[b] : Odor threshold of the compound in water.
[c] : Odor activity values were calculated by dividing the concentrations by the respective odor threshold.

contributors of fatty and fishy notes.

3.2. Effect of instant tea on the volatile components of duck meat

Table 2 were the qualitative and quantitative analyses with the GC–MS method. A total of 39 volatile compounds were identified in the NITM sample, including 20 aldehydes (total 1544.60 μg/L), 9 alcohols (total 528.70 μg/L), 2 ketones (total 7.64 μg/L), 2 acids (total 19.82 μg/L), 3 esters (total 3.22 μg/L), 1 olefin (total 1.73 μg/L), 1 oxide (total 3.51 μg/L) and 1 other (total 2.72 μg/L). In addition, a total of 47 volatile components were detected in the ITM duck meat, including 14 alcohols (total 2947.26 μg/L), 6 aldehydes (total 309.84 μg/L), 8 ketones (total 275.64 μg/L), 6 esters (total 1336.04 μg/L), 3 acids (total 105.50 μg/L), 2 olefins (total 7.57 μg/L), 2 oxides (total 322.12 μg/L) and 6 others (total 360.99 μg/L). By comparing the above analysis of volatile compounds between NITM and ITM, there was an increase of 32 new volatile components (including alcohols, ketones, esters and other substances) and a decrease of 24 volatile components (including aldehydes, alcohols, esters, acids and other substances) in the instant tea treated samples. The decreased 17 aldehydes were (E)-2-hexenal, benzaldehyde, octanal, (E,E)-2,4-heptadienal, (E)-2-octenal, nonanal, (E)-2-nonenal, decanal, (E,E)-2,4-nonadienal, neral, (E)-2-decenal, citral, 2,4-decadienal, undecanal, (E,E)-2,4-decadienal, (E)-2-undecenal and (E)-2-dodecenal. It was worth noticing that some alcohols, ketones and esters volatiles were only found after the instant tea treatment, including (Z)-linalool oxide, (E)-linalool oxide, linalool, geraniol, (Z)-

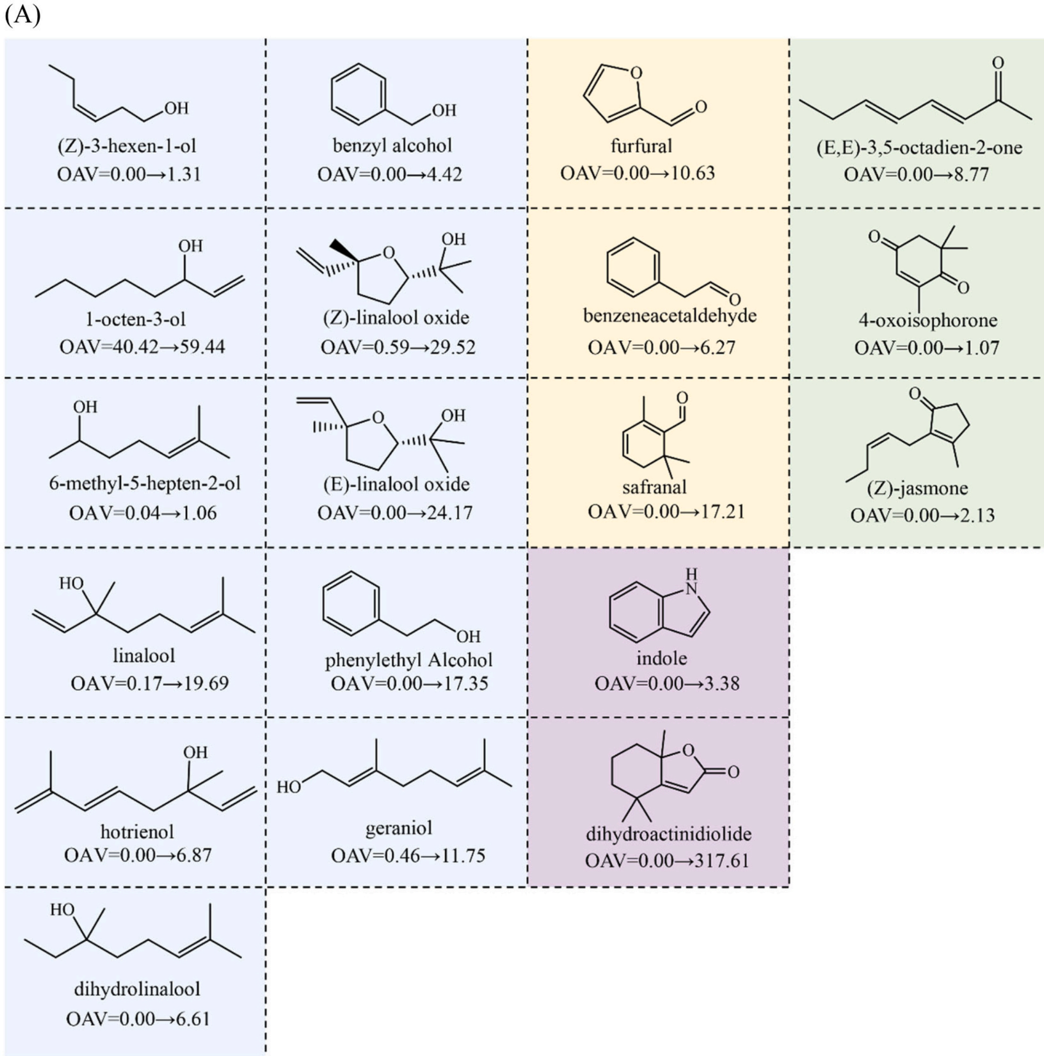

Fig. 2. Chemical formula of volatile compounds with OAV variation after instant tea treatment (OAV>1). (A) volatiles with increasing OAV; (B) volatiles with decreasing OAV. (C) Putative coupling mechanism diagram of saturated and unsaturated aldehydes in duck meat with instant tea treatment.

jasmone, indole, methyl salicylate, (Z)-jasmin lactone and dihydroactinidiolide. These compounds were widely reported and regarded as important contributors to instant tea aroma (Jiang, Li, et al., 2022; Jiang, Wang, et al., 2022), indicating that these increased volatiles come from instant tea. Researches have shown that tea polyphenols could reduce the content of aldehydes (Chen et al., 2016; Fu, Lin, Xu, & Wang, 2015; Guan, Ren, Li, & Mao, 2019), indicating the decreased aldehydes might be related to the interaction of polyphenols and volatiles.

3.3. *Effect of instant tea on OAVs of volatile components of duck meat*

The OAVs analysis of ITM and NITM was presented in Table 3. According to those compounds with OAV ≥ 1 have been considered with the sniffed contribution to the overall aroma (Zhang et al., 2020), 16 and 23 volatiles with OAVs over 1 were concerned as the aroma active volatiles for the NITM and ITM (Table 3), respectively. For the NITM, hexanal, (E,*E*)-2,4-decadienal, (E)-2-nonenal, decanal, 2,4-decedienal, octanal, (E,E)-2,4-nonadienal and nonanal that have been reported to have fishy and fatty notes in many food products (Li et al., 2022; Ren, Ma, Lv, Tong, & Guo, 2021; Xu et al., 2022; Zhou, Chong, Ding, Gu, & Liu, 2016), had the respective OAVs (257.93, 162.41, 104.85, 103.21, 99.68, 90.72, 85.90 and 69.80) far >1, indicating they were the major contributors to the fishy and fatty notes of duck meat. In the ITM sample, dihydroactinidiolide, 1-octen-3-ol, hexanal, (*Z*)-linalool oxide, (E)-linalool oxide, pentanol, linalool, phenethyl alcohol and safranal that have been reported to have floral, honey, mushroom, grassy, sweet and woody notes (Jiang, Li, et al., 2022; Jiang, Wang, et al., 2022; Zhang et al., 2020), had the respectively OAVs (317.61, 59.44, 33.18, 29.52, 24.17, 24.06, 19.69, 17.35 and 17.21) >1, indicating they were the major contributors to floral, grassy and baked notes of the duck meat after the instant tea treatment.

By comparison, it was shown that 11 alcohols (including (*Z*)-3-hexen-1-ol, 1-octen-3-ol, 6-methyl-5-hepten-2-ol, benzyl alcohol, (Z)-linalool oxide, (E)-linalool oxide, linalool, hotrienol, phenylethyl alcohol, dihydrolinalool, geraniol), 3 aldehydes (including furfural, benzeneacetaldehyde, safranal), 3 ketones (including (E,E)-3,5-octadien-2-one, 4-oxoisophorone, (Z)-jasmone), indole and dihydroactinidiolide, had significantly raised OVA values after the instant tea treatment (Fig. 2a). A study reported that the main alcohols in oolong tea samples were linalool, (Z)-linalool oxide, (E)-linalool oxide, geraniol, hotrienol, phenylethyl alcohol, (E)-nerolidol, which had typical floral and fruity notes (Wang, Feng, et al., 2023). It has been shown that benzeneacetaldehyde, 6-methyl-5-hepten-2-one, 3,5-octadien-2-one, β-ionone and (Z)-jasmone are the major aldehydes and

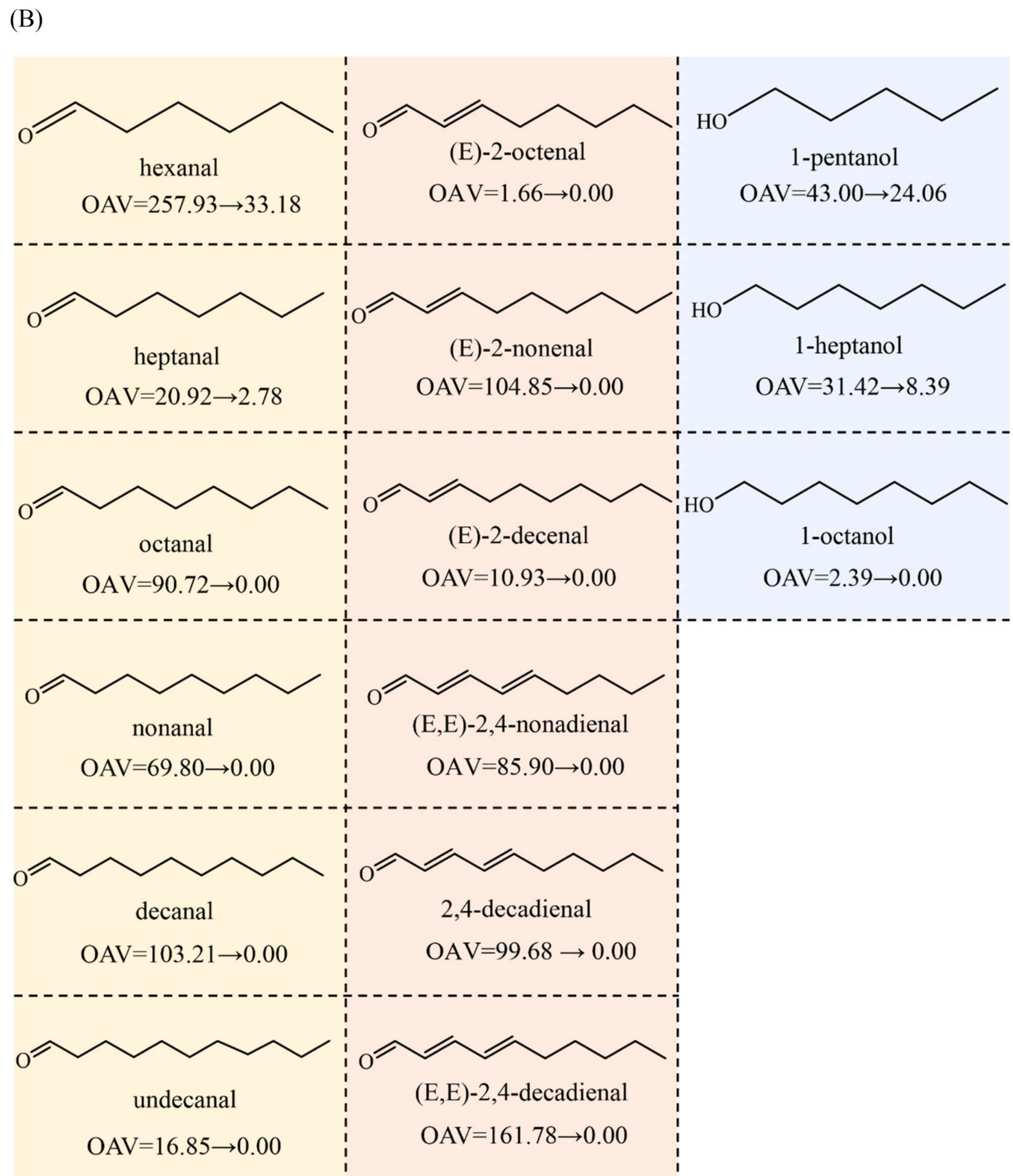

Fig. 2. (*continued*).

ketones in tea samples (Wang, Feng, et al., 2023; Wang, Liu, et al., 2023). Volatile compounds, including linalool, phenylethyl alcohol, geraniol and benzeneacetaldehyde have been identified as characteristic odorants in oolong tea from three cultivars (Guo, Schwab, Ho, Song, & Wan, 2021). Based on the fact that instant teas are rich in alcohols, ketones, aldehydes and dihydroactinidiolide as reported before (Ma et al., 2023), it is reasonable to conclude that the instant tea brings the aroma of alcohols, aldehydes, ketones and dihydroactinidiolide into duck meat, resulting in the increased content of 11 alcohols, 3 aldehydes, 3 ketones and dihydroactinidiolide and enhanced floral, grassy and baked notes. Thus, it is clear that the increased floral, baked and grassy notes were attributed to the instant tea bringing in volatiles with floral, grassy and baked notes.

The comparison also showed that 6 unsaturated aldehydes, 6 saturated aldehydes and 3 alcohols had dramatically decreased OAVs after the instant tea treatment, which were (E)-2-octenal, (E)-2-nonenal, (E, E)-2,4-nonadienal, (E)-2-decenal, 2,4-decadienal, (E,E)-2,4-decadienal hexanal, heptanal, octanal, nonanal, decanal, undecanal, 1-pentanol, 1-heptanol and 1-octanol (Fig. 2b). The lipid degradation generates low threshold aldehydes and alcohols, such as hexanal, (E,E)-2,4-decadienal, (E)-2-nonenal, etc., which contribute to the fishy and fatty notes (Bassam, Noleto-Dias, & Farag, 2022; Ferreira et al., 2016; Huang et al., 2019; Sohail et al., 2022). Instant green tea can inhibit lipid oxidation and reduce the content of aldehydes (Alghazeer et al., 2008). Phenolic compounds and phenolic derivatives can link with flavor-relevant saturated aldehydes (Hidalgo, Aguilar, & Zamora, 2017). Tea polyphenols could interact with saturated aldehydes (Hidalgo, Aguilar, & Zamora, 2017; Hidalgo, Delgado, & Zamora, 2017; Zamora & Hidalgo, 2018). Thus, it can be hypothesized and concluded that tea polyphenols interact with the unsaturated aldehydes, saturated aldehydes and alcohols, resulting in the decreased OAVs of the 6 unsaturated aldehydes, 6 saturated aldehydes and 3 alcohols after the instant tea treatment for duck meat.

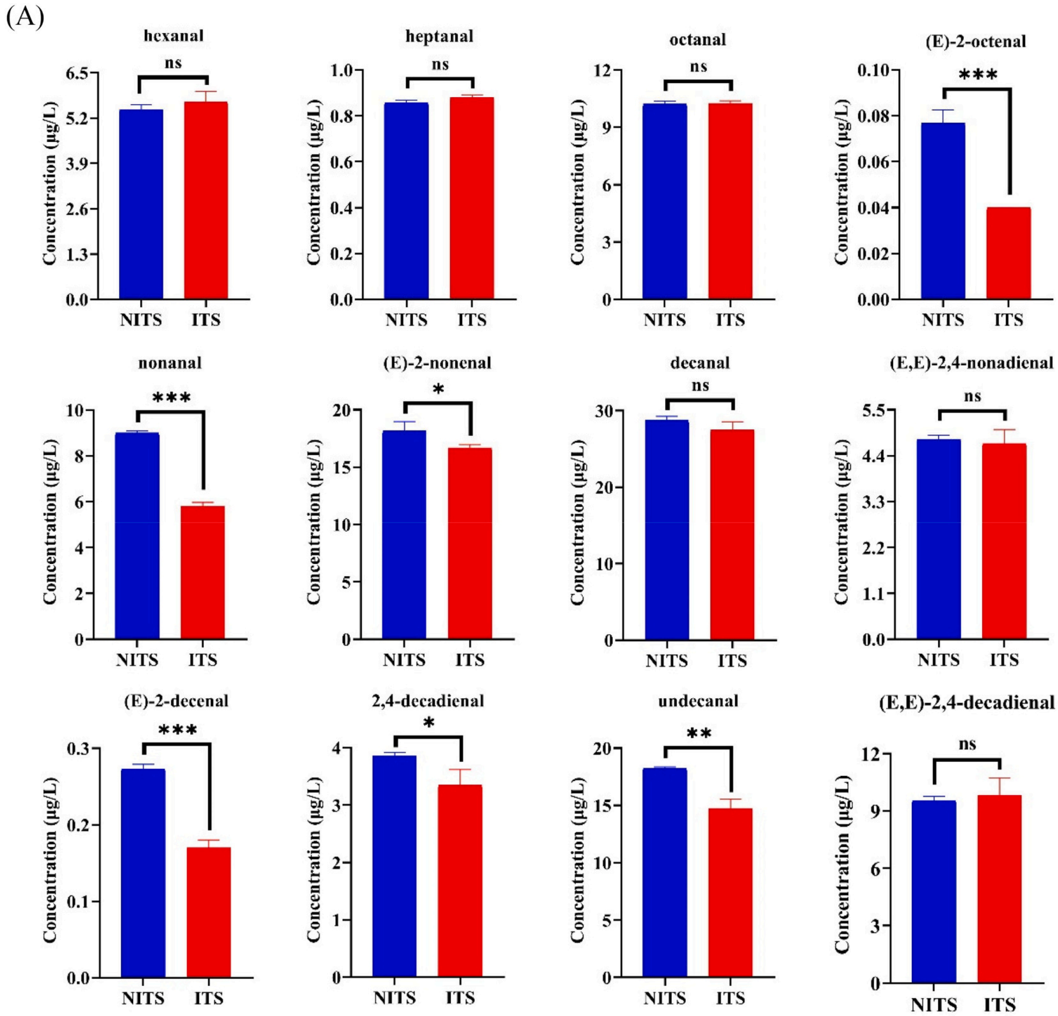

Fig. 3. (A) Histograms of changes in the content of aldehyde mixing standards before and after instant tea treatment; (B) Classification diagram of aldehydes that can and cannot be linked after instant tea treatment; (C) Putative coupling mechanism diagram of saturated and unsaturated aldehydes in duck meat with instant tea treatment.

Note: ITS, aldehyde mixture standards treated with instant tea; NITS, aldehyde mixture standards not treated with instant tea; ns means not significant difference.

3.4. Validation of the interaction between aldehydes and instant tea

To verify how the instant tea could reduce the aldehydes, the 12 standard chemicals were respectively added into the instant tea solution (ITS), followed by analyzing the concentration changes of the aldehydes. The results (Fig. 3a) indicated that 6 aldehydes, i.e., (E)-2-octenal ($P<0.001$), nonanal ($P<0.001$), (E)-2-nonenal ($P<0.05$), (E)-2-decenal ($P<0.001$), 2,4-decadienal ($P<0.05$) and undecanal ($P<0.01$) were significantly decreased in the concentration after the ITS treatment, whereas the other 6 aldehydes, i.e., hexanal, heptanal, octanal, decanal, (E,E)-2,4-nonadienal and (E,E)-2,4-decadienal were not significantly changed after the ITS treatment. Based on this result, it can be reasonably inferred that the 6 aldehydes with significantly reduced content could interact with the compounds in instant teas, while the other 6 aldehydes might be linked to the complex of instant tea and duck meat (Fig. 3b). This result is similar to previous studies that the addition of phenolics to food might alter the flavor of food, not only because of their sensory properties, but also because they could trap off-odor compounds produced in processed foods (Hidalgo, Aguilar, & Zamora, 2017; Hidalgo, Delgado, & Zamora, 2017).

Among the 6 saturated aldehydes, instant tea was more likely to reduce the content of long-chain saturated aldehydes (Fig. 3b). In detail, the instant tea had basically no effect on saturated aldehydes with 6, 7, 8 and 10 carbons (decanal), whereas it could significantly reduce the content of nonanal and undecanal, which contained 9 and 11 carbons, respectively. For the 6 unsaturated aldehydes, instant tea was more likely to reduce the content of aldehydes containing a single unsaturated bond, such as (E)-2-octenal, (E)-2-nonenal and (E)-2-decenal. On the other hand, the instant tea had no or little effect on aldehydes containing multiple unsaturated bonds, such as (E,E)-2,4-nonadienal and (E,E)-2,4-decadienal (Fig. 3b). Tea polyphenols, including epicatechin (EC), epigallocatechin (EGC), epicatechin gallate (ECG) and epigallocatechin gallate (EGCG), were nucleophilic at C-6 and C-8 positions of the A-ring structure. When the C-8 in the A-ring of catechin is deprotonated under the base attack condition, it becomes a carbon negative ion with nucleophilicity that is easy to link to the β carbon of unsaturated aldehydes, the carbonyl carbon of unsaturated aldehydes and a saturated aldehyde with the C—C bond (Fig. 3c), resulting in the generation of new coupling compounds (Hidalgo, Aguilar, & Zamora, 2017; Hidalgo, Delgado, & Zamora, 2017; Jansson et al., 2017; Sugimoto et al., 2021; Zamora & Hidalgo, 2018; Zhu et al., 2020). Wang et al. studied that the binding affinity of the starch-tannic acid complex with aldehydes was in the order of nonanal>heptanal>hexanal>pentanal, which mainly depended on the fact that long-chained aldehydes had stronger

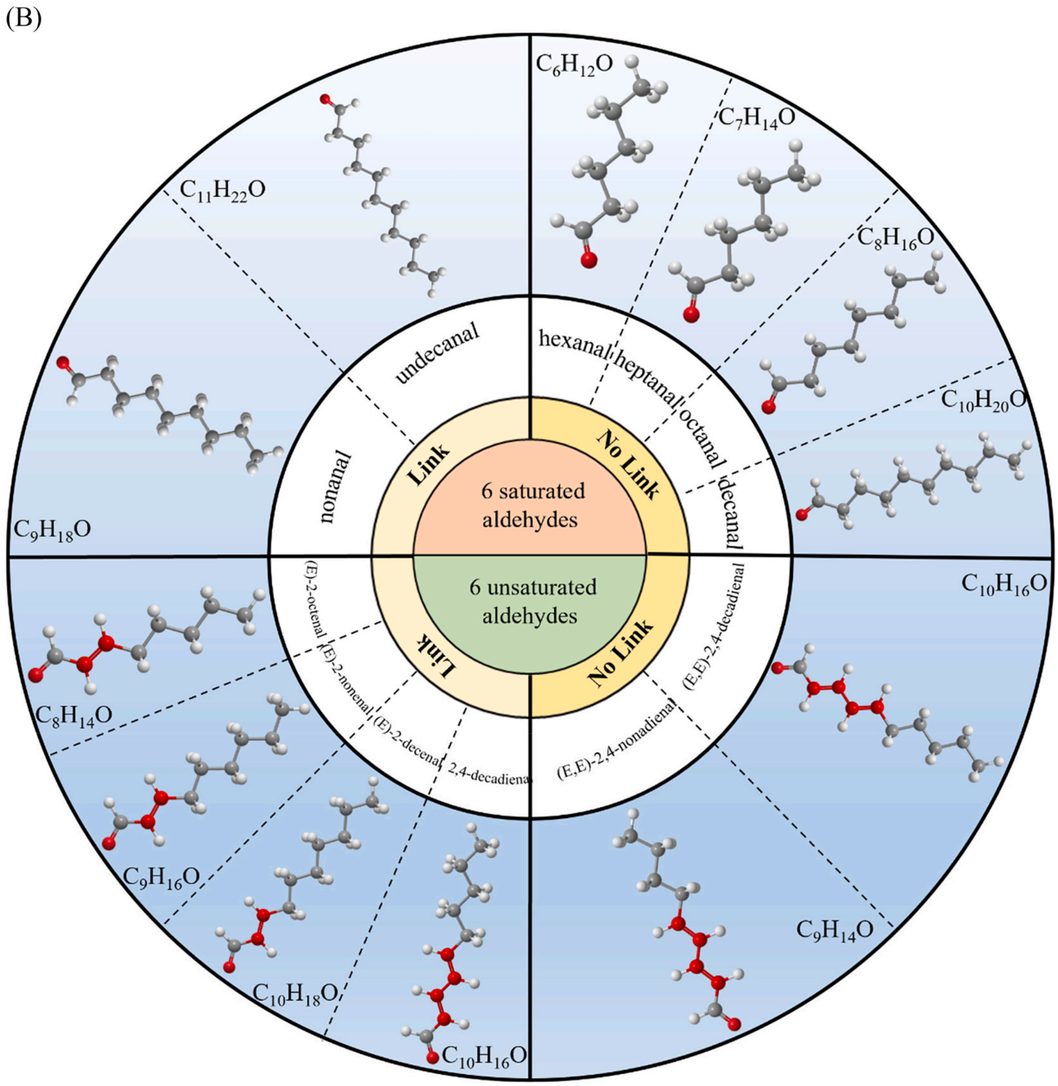

Fig. 3. (*continued*).

hydrophobic interactions with them (Wang, Feng, et al., 2023; Wang, Liu, et al., 2023). From the above results, it was indicated that the interaction between saturated aldehydes and tea polyphenols was mainly attributed to hydrophobic interactions. Zamora et al. found that phenolic compounds could react with saturated aldehydes such as alkanals, 2-alkenals and 2,4-alkadienals, depending on electronic effects, steric hindrances and collateral reactions (Zamora & Hidalgo, 2018). The unsaturated aldehydes with a higher number of electrophilic groups were easier to attach with nucleophilic tea polyphenols, but the steric hindrance was greater than the electronic effect for the polyunsaturated aldehydes. Thus, single unsaturated aldehydes were easier to link with tea polyphenols. Further study is needed to investigate which kind of tea polyphenols are able to couple with the volatile components. In short, the reduced content of aldehydes may be related to hydrophobic interactions, electronic effects and steric hindrances between the aldehydes and instant tea solution.

4. Conclusion

After the treatment of instant tea, the duck meat showed decreases in fishy and fatty notes and increases in floral, baked and grassy notes. Three aldehydes, 10 alcohols, 4 ketones, indole and dihydroactinidiolide that had significantly increased OAVs, and 6 unsaturated aldehydes, 6 saturated aldehydes and 3 alcohols that had significantly declined OAV values, which were the major contributors to the aroma change resulted from the instant tea treatment. The increased floral, baked and grassy notes were attributed to the instant tea brought in volatiles with floral, grassy and baked notes. After verifying the experiments, the decreased fishy and fatty notes were ascribed to tea polyphenols linked to unsaturated aldehydes and saturated aldehydes. The decrease of long-chain saturated aldehydes depended mainly on hydrophobic interactions, and the decrease of monounsaturated aldehydes might be concerning electronic effects. This finding helps to improve the overall sensory properties of duck meat, and facilitates the understanding of how the instant tea treatment affects the aroma of meat products. Nevertheless, the study has the limitation of not characterizing which tea polyphenols are responsible for the coupling of volatile components. More work would be needed to investigate what kind of tea polyphenol structure was involved.

CRediT authorship contribution statement

Xieyuan Liu: Writing – original draft, Visualization. **Ning Cai:** Resources. **Zhenzhen Cai:** Conceptualization. **Lijun Li:** Funding acquisition. **Hui Ni:** Supervision, Project administration, Formal analysis. **Feng Chen:** Methodology.

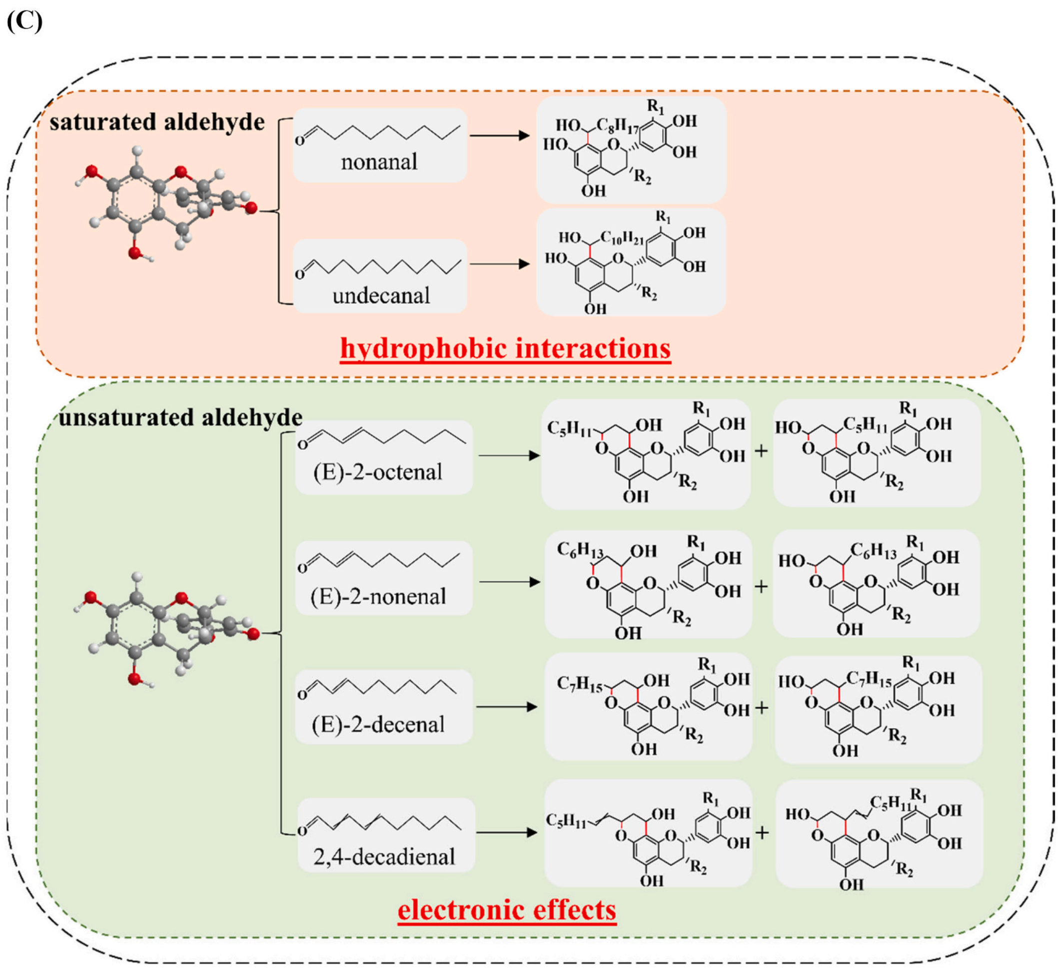

Fig. 3. (*continued*).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgments

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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.2024.101401.

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