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Coformulation with Mulberry and Hawthorn Masks the Bitterness of Exocarpium Citri Grandis While Retaining Its In Vitro Antioxidant Activity

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Abstract

Exocarpium Citri Grandis (ECG; Huajuhong), the dried immature exocarp of *Citrus grandis* 'Tomentosa', was admitted to China's food–medicine homology catalogue in 2024, yet the intense bitterness of its characteristic flavonoid naringin limits its use in foods. A bitterness-reduced, flavour-enriched compound beverage was developed by blending an aqueous ECG extract with mulberry (*Morus alba* L.) and hawthorn (*Crataegus pinnatifida* Bunge) juices and sucrose. Candidate fruits were selected by sensory evaluation, and the formulation was optimised by single-factor experiments and an $L_9(3^4)$ orthogonal design using the sensory score as the response; the factor-influence order was sucrose > mulberry juice > ECG extract > hawthorn juice. The optimal formulation scored 88/100 and gave a clear, stable beverage. Electronic-tongue analysis discriminated the beverage from its raw materials and showed significantly lower bitterness ($p < 0.05$), astringency and their aftertastes and higher richness than the ECG extract. After pasteurisation, the beverage retained strong antioxidant activity. The approach offers a simple route to functional ECG beverages.

1. Introduction

Exocarpium Citri Grandis (ECG), known in China as Huajuhong, is the dried immature or nearly mature exocarp of *Citrus grandis* 'Tomentosa' or *C. grandis* (L.) Osbeck (Rutaceae). It is a celebrated "genuine regional" medicinal material of Huazhou, Guangdong Province, and a national geographical-indication product (Li et al., 2026). ECG has long been used as an antitussive, expectorant and anti-inflammatory agent(Jiang et al., 2014), and modern pharmacological studies have additionally reported antioxidant, hypoglycaemic and hypolipidaemic activities (Chen & Wang, 2025; Kong et al., 2020). Its principal bioactive constituents are flavonoids, predominantly naringin and rhoifolin, along with coumarins, essential oils, and polysaccharides(J. L. Liu et al., 2026). Driven by rising health awareness and supportive government policy, the market for food–medicine homology products in China has expanded rapidly in recent years. In August 2024, Huajuhong was admitted, together with three other botanicals, to China's catalogue of substances that are "traditionally both food and Chinese medicinal material"(Zhang, Cao, Bao, Yang, & Liu, 2025). This inclusion removes the long-standing restriction of ECG to medicinal use, enabling its development into functional foods and beverages. However, naringin is the dominant bitter flavanone glycoside in citrus, has a human detection threshold of only 20 mg/L, such that even low levels impart a persistent bitter off-taste that limits consumer acceptance(Guadagni, Maier, & Turnbaugh, 1973). Mitigating this bitterness while preserving the bioactive flavonoids is therefore pivotal to broadening the food applications of ECG.

Various debittering approaches have been reported for citrus products, including enzymatic hydrolysis of naringin with naringinase, adsorption onto polymeric or cyclodextrin resins, and the addition of bitter-masking flavonoids such as neohesperidin dihydrochalcone(Kola, Kaya, Duran, & Altan, 2010; Puri, Marwaha, Kothari, & Kennedy, 1996). Although effective, these methods may remove or degrade the very flavonoids responsible for the health benefits of ECG, or require additives and specialised processing. A simpler, entirely food-grade alternative is co-formulation: blending a bitter juice with non-bitter, flavour-

rich matrices and sugars can suppress bitterness perception through taste interactions while enriching the overall flavour and introducing complementary bioactive compounds. This strategy is particularly attractive for a food–medicine homology product. Guided by this rationale, a growing number of food–medicine homology compound beverages have been developed, including formulations for the relief of visual fatigue(Kan et al., 2020), digestion-supporting beverages formulated with hawthorn(Cao et al., 2026), and multi-herb functional drinks based on *Polygonatum* species(Song et al., 2024) or finger citron (*Citrus medica* var. *sarcodactylis*)(Wu et al., 2023).

Mulberry (*Morus alba* L.) fruit and hawthorn (*Crataegus pinnatifida* Bunge) fruit were selected as co-formulation matrices, as both are food–medicine homology materials with appealing sensory and functional profiles. Mulberry, traditionally honoured as "tree-top ginseng", is rich in anthocyanins, principally cyanidin-3-*O*-glucoside and cyanidin-3-*O*-rutinoside, together with other polyphenols, which impart a deep purple-red colour, a pleasant sweet–tart taste, and strong antioxidant activity (Cheng et al., 2023; Du, Zheng, & Xu, 2008; Wen et al., 2019). Hawthorn is distinguished by its high content of organic acids, flavonoids, and procyanidins; it contributes pronounced acidity and a fruity note, possesses well-recognised digestive and antioxidant benefits, and its acidic matrix may additionally help stabilise anthocyanins and other polyphenols (P. Z. Liu, H. Kallio, et al., 2010; P. Z. Liu, Yang, & Kallio, 2010). The complementary sweetness, acidity, colour, and aroma of these two fruits were therefore expected to jointly mask the bitterness of ECG while conferring a synergistic antioxidant effect.

Objective, instrumental taste characterisation is increasingly employed to complement human sensory panels in beverage development. The electronic tongue, comprising an array of potentiometric sensors fitted with artificial lipid membranes, quantifies the basic taste attributes (sourness, bitterness, astringency, umami, and saltiness) together with aftertaste and richness. It is particularly valuable for bitterness assessment and for verifying taste-masking efficacy, as its bitterness sensors provide comparable or superior sensitivity and markedly higher reproducibility relative to human assessors (Escuder-Gilabert & Peris, 2010; Kobayashi et al., 2010; Woertz, Tissen, Kleinebudde, & Breitkreutz, 2011). The technique therefore offers an objective means of confirming whether co-formulation genuinely attenuates ECG bitterness.

In the present work, a bitterness-reduced, flavour-enriched ECG compound beverage was developed by blending an aqueous ECG extract with mulberry and hawthorn juices and sucrose. Candidate fruits were first screened by sensory evaluation, and the formulation was subsequently optimised through single-factor and orthogonal experiments. The finished beverage was characterised in terms of physicochemical quality, taste profile, and in vitro antioxidant activity. This work demonstrates a mulberry- and hawthorn-based strategy that simultaneously reduces bitterness and enriches the flavour of Huajuhong, offering a practical basis for developing functional ECG beverages following its 2024 inclusion in the food–medicine homology catalogue.

2. Materials and Methods

2.1 Materials and Reagents

ECG, dried mulberry fruit, and hawthorn slices were purchased from Guangzhou Caizhilin Pharmaceutical Co., Ltd. (Guangdong, China). DPPH (purity ≥ 98%) and ABTS (purity ≥ 98%) were purchased from Shanghai Aladdin Biochemical Technology Co., Ltd. (Shanghai, China); anhydrous ethanol (99.7%) and potassium persulfate (99.99%), both of analytical grade, were purchased from Sinopharm Chemical Reagent Co., Ltd. (Shanghai, China). Ultrapure water, produced by a GWB-1B system (Beijing Persee General Instrument Co., Ltd., Beijing, China), was used throughout the study.

2.2 Preparation of the ECG Extract

ECG peel was ground to a powder with a portable herb pulveriser. The powder was mixed with ultrapure water at a solid-to-liquid ratio of 1:20 (w/v), heated at 60°C for 10 min and filtered; the filtrate was collected as the ECG extract.

2.3 Preparation of Mulberry and Hawthorn Juices

Mulberry juice was prepared by homogenising the fruit with ultrapure water at a material-to-liquid ratio of 1:10 (w/v), followed by filtration. Hawthorn flesh was processed with ultrapure water at 1:15 (w/v) using a high-speed wall-breaking blender (L18-Energy103S; Joyoung Co., Ltd., Jinan, China), and the resulting juice was filtered before use.

2.4 Beverage Preparation

The ECG extract, mulberry juice, hawthorn juice, and sucrose were blended according to the proportions defined by the experimental design, with ultrapure water added to make up the balance. The blend was centrifuged at 4000 r/min for 10 min (JIDI-20D centrifuge; Guangzhou Jidi Instrument Co., Ltd., Guangzhou, China), and the clarified beverage was pasteurised at 85°C for 15 min in a constant-temperature water bath (SDY-4(H); Saiou Huachuang, China). After cooling to room temperature, the beverage was aseptically filled into sterile bottles.

2.5 Single-Factor Experiments

Using the trained-panel sensory score as the evaluation index, single-factor experiments were conducted to examine the addition level of each of the four components around the reference formulation (ECG extract 11%, mulberry juice 30%, hawthorn juice 25%, sucrose 8%), with the other three components held constant. Four levels were tested for each factor: ECG extract at 5, 8, 11, and 14%; mulberry juice at 30, 35, 40, and 45%; hawthorn juice at 15, 20, 25, and 30%; and sucrose at 5, 8, 11, and 14%. Based on the single-factor results, three appropriate levels of each factor were selected and carried forward into the orthogonal experiment.

2.6 Orthogonal Experiment

An $L_9(3^4)$ orthogonal experiment was carried out with four factors, namely ECG extract (A), mulberry juice (B), hawthorn juice (C), and sucrose (D), each at three levels (Table 1), using the trained-panel

sensory score as the response variable. Range (R) analysis was performed to rank the relative importance of the four factors and to determine the optimal level combination, which was subsequently verified by confirmation tests.

Table 1
Factors and levels of the $L_9(3^4)$ orthogonal design.

Level	A: ECG extract (%)	B: Mulberry juice (%)	C: Hawthorn juice (%)	D: Sucrose (%)
1	5	35	15	6
2	8	40	20	8
3	11	45	25	10

2.7 Sensory Evaluation

Preliminary screening was conducted by a panel of 12 assessors majoring in food science. For formulation optimisation, samples were scored by the trained panel on a 100-point scale according to the criteria listed in Table 2. A subset of ten assessors with good gustatory and olfactory discrimination (five men and five women, aged 20–24 years) additionally performed a descriptive evaluation of the finished product. Samples were coded and presented in random order in covered, odourless cups. Where the optimal formulation identified by range analysis differed from the highest-scoring individual run, both candidates were prepared and re-evaluated by 20 additional assessors majoring in food science to confirm the final choice. The sensory evaluation protocol was reviewed and approved by the Institutional Review Board (Academic Committee) of Shunde Polytechnic University (Approval No. SDPT-IRB-2026-041), and written informed consent was obtained from all participants prior to the evaluation.

Table 2
Sensory scoring criteria used in the single-factor and orthogonal experiments.

Attribute	Scoring description	Score range
Aroma	Well-coordinated flavour with the characteristic aroma of the raw materials	10–20
	Weak aroma; faint raw-material notes	0–10
Bitterness	Slight, non-objectionable bitterness	10–20
	Prominent bitterness	0–10
Sweetness	Moderate, well-balanced sweetness	10–20
	Too sweet or too bland	0–10
Sourness	Moderate, pleasant acidity	10–20
	Excessive or insufficient acidity	0–10
Overall acceptability	Well liked	10–20
	Acceptable	0–10

2.8 Electronic-Tongue Analysis

Taste attributes were measured using a potentiometric electronic tongue equipped with artificial lipid-membrane taste sensors (Shanghai Ruifen Intelligent Technology Co., Ltd., Shanghai, China). Prior to measurement, the pH and conductivity of the sample solutions were checked to ensure compliance with the instrument requirements. The reference solution was prepared from potassium chloride and tartaric acid; the cleaning solution for the negative electrode consisted of water/ethanol/hydrochloric acid, and that for the positive electrode consisted of potassium chloride/water/ethanol/potassium hydroxide. The sensors were stabilised in the reference solution for 30 s, after which each taste measurement was performed for 30 s; the sensors were then rinsed in the reference solution for 3 s, and the aftertaste was measured for a further 30 s. Sourness, bitterness, astringency, bitter aftertaste, astringent aftertaste, umami, richness, saltiness, and sweetness were recorded for the ECG extract, mulberry juice, hawthorn juice, and the optimised beverage, with five replicates per sample. The complete sensor-response matrix was subjected to autoscaling (mean-centring followed by scaling to unit variance) and analysed by linear discriminant analysis (LDA) and principal component analysis (PCA) to visualise the discrimination among samples.

2.9 Antioxidant Activity

DPPH radical-scavenging activity was determined according to the method of Brand-Williams et al(Brand-Williams, Cuvelier, & Berset, 1995) with minor modifications. Briefly, 2 mL of sample was mixed with 2 mL of 0.2 mmol/L DPPH solution in anhydrous ethanol. After incubation for 20 min in the dark at

room temperature, the absorbance was measured at 517 nm using a UV–Vis spectrophotometer. The DPPH radical-scavenging activity was calculated as:

$$\mathrm{DPPH\ scavenging}\ (\%) = 1 - \frac{|A_1 - A_2|}{A_0} \times 100 \quad (1)$$

Among them, A_0 is the absorbance of the water–DPPH mixture, A_1 that of the sample–DPPH mixture, and A_2 that of the sample–ethanol mixture.

ABTS radical-scavenging activity was determined following Re et al(Re et al., 1999). ABTS stock solution (7.4 mmol/L) was mixed with an equal volume of 2.6 mmol/L potassium persulfate and kept in the dark for 16 h; the resulting ABTS radical-cation solution was diluted with ethanol to an absorbance of 0.7 ± 0.02 at 734 nm. Sample and working solution were mixed at 1:4 (v/v), reacted in the dark for 6 min, and the absorbance was read at 734 nm (A_1); ultrapure water replaced the sample for the control (A_2). The ABTS scavenging activity was calculated as:

$$\mathrm{ABTS\ scavenging}\ (\%) = \frac{|A_2 - A_1|}{A_2} \times 100 \quad (2)$$

For both assays the beverage, ECG extract and hawthorn juice were diluted 1:5 with ultrapure water and the mulberry juice 1:10, and each sample was measured in triplicate.

2.10 Statistical Analysis

Measurements were performed in triplicate, and the results are expressed as mean ± SD. Differences among samples were evaluated by one-way analysis of variance followed by Duncan's multiple range test, using GraphPad Prism 8. Differences were considered statistically significant at $p < 0.05$.

3. Results and Discussion

3.1 Effects of Individual Components on Sensory Quality

The effects of the four components on sensory quality are shown in Fig. 1. As the ECG extract level increased from 5% to 14%, both the perceived bitterness and the characteristic ECG aroma intensified. At 5%, the beverage exhibited weak bitterness but also a faint aroma, resulting in a low sensory score. At 14%, the aroma was pronounced but the excessive bitterness reduced acceptability. A level of 8% offered the best compromise, combining mild bitterness with adequate aroma, and thus received the highest acceptability (Fig. 1a). This effect is consistent with the high bitter potency of naringin, the dominant bitter flavanone glycoside in ECG, whose detection threshold in water is only about 20 mg/L, such that even small increases in extract concentration sharply raise perceived bitterness(Guadagni et al., 1973). Bitterness, in turn, is a major determinant of the rejection of phytonutrient-rich foods and beverages. Increasing the mulberry juice level enhanced the sweetness and, up to approximately 40%, improved the aroma score. However, at 45% the mulberry aroma dominated and masked the flavours of the other raw materials, lowering acceptability (Fig. 1b). Mulberry juice thus served as a natural sweetener, colourant,

and source of fruity volatiles, owing to its sugars and abundant anthocyanins(Wen et al., 2019). Although an excessively strong matrix flavour is known to suppress the perception of other flavour notes (Keast & Breslin, 2003). For hawthorn juice, the perceived bitterness and acidity intensified with increasing addition level: 15% imparted an overly weak taste, whereas 30% was excessively sour and astringent, both resulting in low acceptability (Fig. 1c). The harsh, sour-astringent character at high levels can be ascribed to the high concentrations of organic acids and procyanidins in hawthorn fruit (P. Liu et al., 2010). Sweetness increased steadily with the sucrose level: below 8% the beverage tasted bland, above 11% it became cloying and masked the raw-material aromas, and 8% yielded the most balanced flavour (Fig. 1d).

3.2 Orthogonal Optimisation

The $L_9(3^4)$ orthogonal results and the corresponding range analysis are presented in Table 3. The magnitude of the range (R) indicated that the four components influenced overall acceptability in the order sucrose (D) > mulberry juice (B) > ECG extract (A) > hawthorn juice (C), identifying sucrose and mulberry juice as the dominant factors governing sensory quality. The predominance of sucrose is consistent with recent consumer studies showing that sweetness level is a primary driver of beverage liking and that sucrose remains the most accepted sweetening agent in dairy and juice matrices(Mah et al., 2024). Range analysis nominated the combination $A_2B_1C_3D_2$, whereas the highest-scoring individual run ($A_3B_1C_3D_2$) achieved 88 points. Such discrepancies between the theoretically optimal combination and the best-performing run are not uncommon in orthogonal designs, because range analysis estimates main effects averaged across levels and does not fully capture factor interactions. A confirmation test comparing both candidates is therefore essential(Lou et al., 2026). Accordingly, both formulations were prepared and re-evaluated by twenty assessors. The combination $A_3B_1C_3D_2$ received the higher score and was therefore selected as the optimal formulation, comprising 11% ECG extract, 35% mulberry juice, 25% hawthorn juice, and 8% sucrose, with ultrapure water as the balance. Notably, this formulation also retains a relatively high ECG content, which favours the functional positioning of the product without compromising sensory quality, given the well-documented antitussive, expectorant, and anti-inflammatory activities of ECG flavonoids(Jiang et al., 2014).

Table 3
$L_9(3^4)$ orthogonal design and sensory results for the main raw-material proportions.

Run	A	B	C	D	Sensory score
1	1	1	1	1	78.0
2	1	2	2	2	81.0
3	1	3	3	3	80.0
4	2	1	2	3	84.0
5	2	2	3	1	81.0
6	2	3	1	2	81.0
7	3	1	3	2	88.0
8	3	2	1	3	76.0
9	3	3	2	1	75.0
K_1	239	250	235	234	
K_2	246	238	240	250	
K_3	239	236	249	240	
k_1	79.67	83.33	78.33	78.00	
k_2	82.00	79.33	80.00	83.33	
k_3	79.67	78.67	83.00	80.00	
R	2.33	4.00	1.67	5.33	
Optimal level	A_2	B_1	C_3	D_2	$A_3B_1C_3D_2$

A, ECG extract; B, mulberry juice; C, hawthorn juice; D, sucrose; K values are the sums of the sensory scores at each level; k values are the corresponding means; R is the range (max − min of k).

3.3 Electronic-Tongue Discrimination of the Optimised Beverage from Its Raw Materials

Linear discriminant analysis (LDA) and principal component analysis (PCA) of the electronic-tongue responses of the four samples are shown in Fig. 2. In the LDA plot (Fig. 2a), the first two discriminant functions accounted for 93.48% and 5.54% of the variance, respectively, and the four samples formed clearly separated, non-overlapping clusters, confirming that the system successfully discriminated the compound beverage from the individual raw-material extracts. Along the first discriminant function, the ECG extract lay at the far negative end, consistent with its distinctive bitter character, while the mulberry extract was widely separated at the positive end; the compound beverage occupied an intermediate

position between the ECG and hawthorn extracts, indicating that its taste profile was dominated by the ECG and hawthorn contributions yet clearly modulated by the other components. This intermediate positioning corroborates the quantitative attribute data (Table 4), in which the bitterness and bitter aftertaste of the beverage were significantly lower than those of the ECG extract, and exemplifies the established use of electronic-tongue pattern analysis for verifying taste-masking efficacy in bitter matrices(Uchida, 2024). PCA yielded a consistent result (Fig. 2b), with the first two principal components explaining 32.82% and 16.67% of the variance; the lower cumulative variance relative to LDA is expected, as PCA is an unsupervised method that does not exploit sample-class information (Vanaraj, Bincy, Mayakrishnan, Kim, & Kim, 2025). Together, the two projections demonstrate that co-formulation generated a taste profile clearly distinct from that of any single raw material, providing objective, instrument-based evidence for the bitterness-reducing and flavour-balancing effect of the formulation.

The quantitative attribute values (Table 4) explain this separation. Relative to the ECG extract, the beverage showed significantly ($p < 0.05$) lower responses for bitterness, astringency, bitter aftertaste, and astringent aftertaste, together with higher richness. Co-formulation therefore attenuated the most objectionable attributes of ECG while enhancing perceived richness, achieving the intended outcome of reduced bitterness with improved mouthfulness. The elevated sourness response is consistent with the organic acids contributed by hawthorn and mulberry, whereas the sweetness and umami responses remained essentially unchanged.

Although electronic-tongue outputs are relative potentiometric responses rather than absolute concentrations, they correlate well with human bitterness scores in bitter matrices(Ke et al., 2022). The bitterness suppression is attributable to taste–taste interactions: sweetness from sucrose and mulberry sugars attenuates perceived bitterness(Mora, Wijaya, Jiang, Gibney, & Dando, 2023), and fruit aromas may further enhance perceived sweetness through cross-modal interactions, enabling effective masking at a moderate sugar level (Bertelsen et al., 2021). The electronic-tongue data thus corroborate the trained-panel results, providing objective confirmation of the debittering effect.

Table 4
Electronic-tongue taste attributes of the ECG extract and the optimised compound beverage.

Taste attribute	ECG extract	Compound beverage
Sourness	−7.87 ± 0.03	−12.19 ± 0.04
Bitterness	8.89 ± 0.14	7.87 ± 0.07
Astringency	11.04 ± 0.10	8.55 ± 0.04
Bitter aftertaste	2.41 ± 0.07	0.58 ± 0.06
Astringent aftertaste	−0.17 ± 0.03	−0.06 ± 0.01
Umami	2.20 ± 0.06	1.73 ± 0.32
Richness	0.59 ± 0.01	0.83 ± 0.03
Saltiness	−19.13 ± 0.10	−13.78 ± 0.06
Sweetness	6.65 ± 0.18	6.83 ± 0.13

Values are mean ± SD (n = 3). Different superscript letters within a row indicate a significant difference between the two groups ($p < 0.05$).

3.4 DPPH and ABTS Radical-Scavenging Activities

The DPPH and ABTS radical-scavenging activities of the beverage and the individual raw-material extracts are shown in Table 5 and Fig. 3. In the DPPH assay, the scavenging activities of the ECG extract, the compound beverage, and hawthorn juice were statistically comparable ($p > 0.05$), and all three were significantly higher than that of mulberry juice ($p < 0.05$), indicating that the radical-scavenging capacity contributed by the ECG flavonoids was largely retained in the finished beverage. In the ABTS assay, the pattern differed markedly: hawthorn juice exhibited by far the highest activity, significantly exceeding all other samples ($p < 0.05$), whereas the ECG extract, the compound beverage, and mulberry juice did not differ significantly. This assay-dependent divergence is consistent with the distinct reaction chemistries of the two assays, DPPH responding preferentially to lipophilic antioxidants in an ethanolic medium, whereas the ABTS radical cation reacts predominantly via single-electron transfer with both hydrophilic and lipophilic compounds(Gulcin, 2025). The superior ABTS activity of hawthorn juice can accordingly be ascribed to its abundant hydrophilic phenolics, among which chlorogenic acid, epicatechin, and procyanidin B2 have been identified as the predominant antioxidant contributors in hawthorn pulp (Ma et al., 2024). The lower ABTS value of the beverage relative to hawthorn juice also reflects the dilution of hawthorn within the blend and possible interactions among the raw-material constituents. Overall, the beverage retained strong radical-scavenging activity derived from the combined polyphenols of ECG, mulberry, and hawthorn, demonstrating that co-formulation improved palatability while largely preserving the antioxidant function of these food–medicine homology materials.

Table 5
DPPH and ABTS radical-scavenging activity of the compound beverage and the individual raw-material extracts.

Sample	DPPH scavenging (%)	ABTS scavenging (%)
Compound beverage	79.33 ± 3.06	40.17 ± 1.89
ECG extract	81.33 ± 2.08	48.23 ± 0.25
Mulberry juice	63.00 ± 2.00	39.47 ± 5.06
Hawthorn juice	75.00 ± 4.58	74.33 ± 7.77

Values are mean ± SD (n = 3). Different superscript letters within a column indicate a significant difference among samples ($p < 0.05$).

4. Conclusions

A bitterness-reduced, flavour-enriched compound beverage was successfully developed from ECG, mulberry and hawthorn. Single-factor and $L_9(3^4)$ orthogonal optimisation identified an optimal formulation of ECG extract 11%, mulberry juice 35%, hawthorn juice 25% and sucrose 8%, with sucrose and mulberry juice the most influential factors. The optimised beverage was a clear, stable product with an overall sensory score of 88/100. Electronic-tongue analysis discriminated the beverage from its raw materials and objectively confirmed significantly reduced bitterness, astringency and their aftertastes together with significantly increased richness relative to the ECG extract, and the pasteurised beverage retained strong antioxidant activity. The work provides a practical, food-grade strategy for debittering ECG and a technical foundation for the development of functional food–medicine homology beverages. Future studies should quantify the functional constituents by HPLC and probe their synergistic interactions, characterise the volatile aroma profile, evaluate storage stability and shelf life, and verify the antioxidant and health effects in vivo.

Declarations

Declarations

Ethics approval and consent to participate

This study involved only the non-invasive sensory evaluation of beverages prepared entirely from commercially available, food-grade ingredients that are commonly consumed in China, and posed no more than minimal risk to the participants. The study protocol, including the sensory evaluation procedure and the informed-consent process, was reviewed and approved by the Institutional Review Board (Academic Committee) of Shunde Polytechnic University (Approval No. SDPT-IRB-2026-041). The study was conducted in accordance with the Declaration of Helsinki. All participants were adult

volunteers who were fully informed of the study's purpose and procedures before participation. Participation was entirely voluntary and without coercion, and participants were free to withdraw at any time without consequence. Written informed consent was obtained from all participants prior to the sensory evaluation, and all responses were collected and analysed anonymously.

Consent to participate

Written informed consent to participate was obtained from all participants prior to the sensory evaluation. All participants were adult volunteers; they were fully informed of the purpose and procedures of the study, participated entirely voluntarily and without coercion, and were free to withdraw at any time without consequence. No children or other vulnerable groups were involved in this study, and no personally identifiable, biomedical, clinical or biometric data were collected.

Consent for publication

Not applicable. This manuscript does not contain any individual person's data in any form, including individual details, images or videos. All sensory data were collected anonymously and are reported only in aggregated form.

All data generated or analysed during this study are included in this

published article.

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Author Contribution

Conceptualisation, Writing original draft: Jie Deng; Methodology, Zhiming Zhang; Investigation, Junli Xu; Formal analysis, Yilu Bao; Writing-review&editing, Qiuling Li; Supervision, Caimin Feng; Project administration, Wenfeng Luo. All authors have read and agreed to the published version of the manuscript.

Data Availability

All data generated or analysed during this study are included in this published article.

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Figures

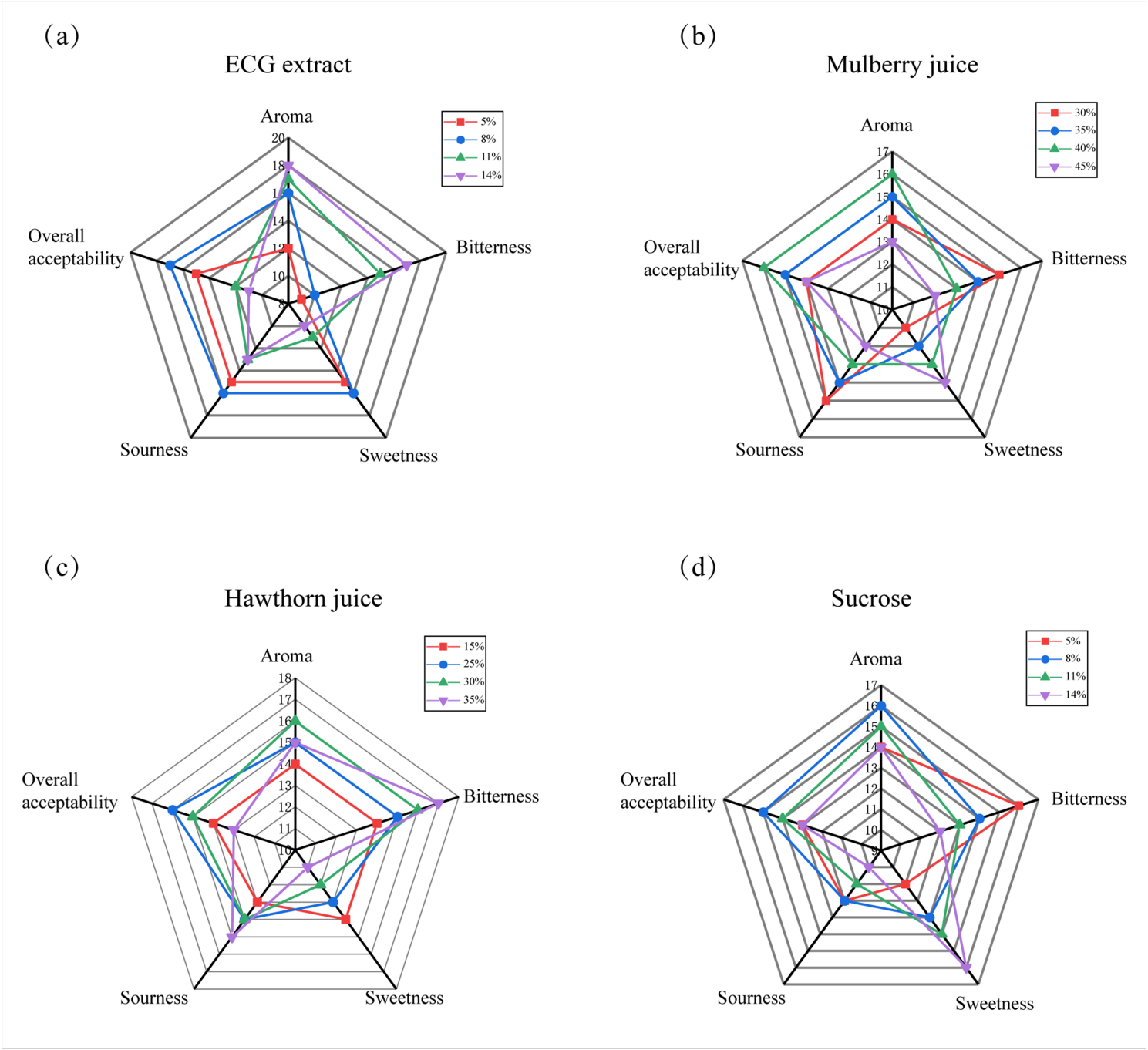


Figure 1

Effect of the addition level of (a) ECG extract, (b) mulberry juice, (c) hawthorn juice, (d) sucrose on the sensory evaluation of the beverage.

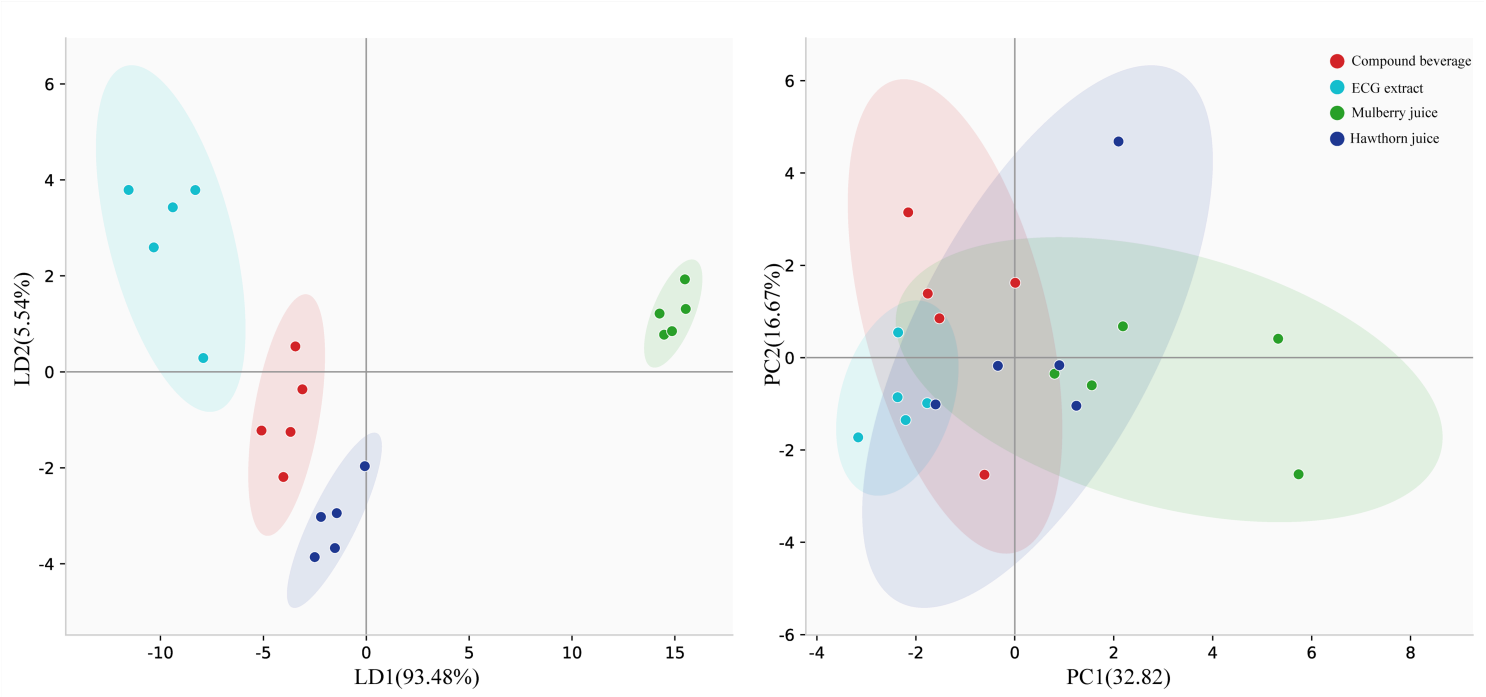


Figure 2

Multivariate analysis of the electronic-tongue responses of the compound beverage and the individual raw-material extracts (*n* = 5): (a) LDA analysis and (b) PCA analysis.

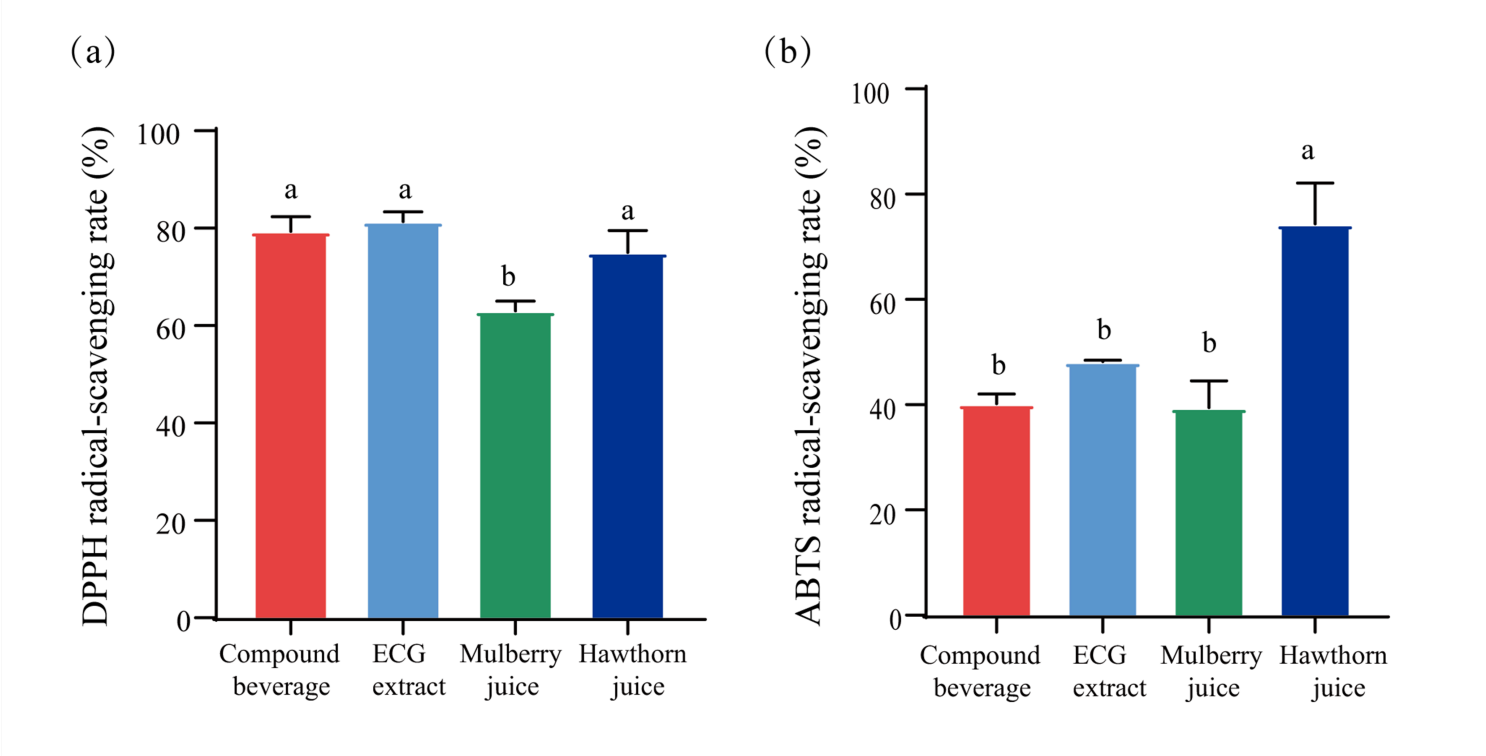


Figure 3

DPPH (a) and ABTS (b) radical-scavenging activity of the compound beverage and the individual raw-material extracts. Bars are mean ± SD (n = 3). Different letters denote significant differences ($p < 0.05$).