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Original article

The effect of yam (*Dioscorea japonica*) addition on aroma and properties of gluten-free rice chiffon cake

Shang-Ta Wang,[1,2] Hong-Jhang Chen,[3] Mingchih Fang,[2] Ching-Wen Huang[2] & Wen-Chieh Sung[2,4]*

1 Institute of Food Safety and Risk Management, National Taiwan Ocean University, 2 Pei-Ning Road, Keelung, Taiwan
2 Department of Food Science, National Taiwan Ocean University, 2 Pei-Ning Road,, Keelung 202301, Taiwan
3 Institute of Food Science and Technology, National Taiwan University, No. 1 Section 4, Roosevelt Road, Taipei 10617, Taiwan
4 Center of Excellence for the Oceans, National Taiwan Ocean University, 2 Pei-Ning Road, Keelung 202301, Taiwan

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Summary The aim of this study was to create gluten-free chiffon cakes by replacing wheat flour with rice flour (100%, 90% and 70% w/w) and adding yam (0%–30%). The effect of yam's water-soluble fibre on cake batter properties was studied, including batter density, specific volume, colour, texture, moisture content, water activity and volatile compounds. Results revealed that yam addition decreased crumb lightness value, crust brown index and batter density. Batter viscosity and cake specific volume increased with yam levels, with the optimal amount being 10%. Specific volume decreased at a yam addition of 30%. Twenty-four compounds were identified in gluten-free chiffon cake with 10% yam addition (10Y). 1-Octen-3-ol was the primary contributor, accounting for 89.9% odour activity value (OAV) of the aroma with a fruity, buttery, and mushroom odour, attributed to its low threshold. In addition, aldehyde compounds including hexanal, 3-methylbutanal, 2-methylbutanal, pentanal, 2-methylpropanal, nonanal, octanal and heptanal, accounting for 9% of OAV, had high perception thresholds.

Keywords Chiffon cake, GC–MS, gluten-free, rice flour, yam.

Introduction

Wheat flour (WC) serves as a ubiquitous cereal ingredient in baked goods due to its ability to form a cohesive dough when mixed with water, resulting in a fine-grained and elastic crumb post-baking (Schopf *et al.*, 2021). However, its utilisation poses the risk of triggering celiac disease, also known as gluten-sensitive enteropathy, an immune response affecting individuals intolerant to specific amino acid sequences, notably the prolamins present in wheat, barley and rye gluten (Comettant-Rabanal *et al.*, 2023; Kumari & Morya, 2021; de Souza Nespeca *et al.*, 2023;). Prolamin ingestion can lead to gastrointestinal inflammation and damage, causing reduced nutrient, vitamin, and mineral absorption, including vitamins A, D, E, K, iron, folate and calcium (Jnawali *et al.*, 2016). Approximately 1% of the population in the USA and Europe is afflicted with this condition (Grace-Farfaglia, 2015), necessitating adherence to a gluten-free diet comprising rice, corn, sorghum, millet and legumes (Dhen *et al.*, 2016; Marston *et al.*, 2016; Rybicka *et al.*, 2019; Punia Bangar *et al.*, 2022). While rice flour (RC) is the primary cereal flour used as a substitute for WC, other gluten-free flours such as corn, oats and sorghum are also utilised (Perez & Juliano, 1988; Johnson, 1990; Mohamed & Hamid, 1998). However, these alternatives often do not provide the same physicochemical properties and aroma as wheat products. To address this issue, polysaccharides such as chia seed flour, tamarind seed gum and xanthan gum have been used to provide similar viscoelastic properties in gluten-free rice bakery products (Huttner & Arendt, 2010; Sung & Chai, 2017; Sung *et al.*, 2020; Wu *et al.*, 2020).

Native to Japan, yam (*Dioscorea japonica*) belongs to the *Dioscoreaceae* family. Yam tubers typically boast an 18% starch and 1%–5% protein content, rendering them a healthy, low-fat (up to 2%) option. Renowned for their high water-soluble polysaccharide content, yam tubers, particularly *Dioscorea japonica*, exhibit the highest viscosity among varieties. Recently, yam has been utilised as a gluten substitute in various food applications (Saklani & Kaushik, 2020). Moreover, yam is a rich source of antioxidants, containing significant levels of phenolic compounds (13–166 mg/

*Correspondent: Fax: +886-224634203;
e-mail: sungwill@mail.ntou.edu.tw

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100 g) that exhibit various antioxidant activities, including ferrous ion chelating, total antioxidant activity, DPPH free radical scavenging, and reducing power. Yam also contains succinic acid as the predominant organic acid (1316 mg/100 g), and consumption of yam has been associated with a lower risk of cancer and cardiovascular diseases (Bhandari & Kawabata, 2004). These findings suggest that yam may be a promising alternative additive for improving the texture properties and nutritional value of gluten-free rice-based baked products.

While rice cakes show promise in the gluten-free food industry, they are often criticised for their lower volume and less desirable texture compared to wheat cakes. In addition, the limited knowledge of aroma compounds in gluten-free chiffon cakes hampers their industrial production and development. There has been little research on the impact of yam on the quality properties of gluten-free chiffon cakes. Therefore, the aim of this study is to evaluate how various ratios of yam and RC affect the physical properties and volatile compounds of gluten-free rice chiffon cakes.

Materials and methods

Raw materials

RC obtained from the Ping-Tung Foods (Pingtung County, Taiwan) was wet-milled Japonic rice. Frozen yam (*Dioscorea japonica*) was obtained from local farmer (New Taipei City, Taiwan). Eggs, fresh milk, sugar, soybean oil, baking powder, lemonade and WC (Ta Fong Flour Mill Co., Ltd., Taichung, Taiwan) were obtained from the local market. Acetone was purchased from Panreac AppliChem (Gatersleben, Soaxony-Anhalt, Germany). Ethyl ether was purchased from Nihon (Shiyaku industries Ltd., Taipei, Taiwan). The chemicals, ethanol, 3-heptanol and hydrocarbon/C5-C30 straight chain alkane analytical standards were purchased from Sigma Aldrich (St. Louis, MO, USA), and all reagents used were of analytical grade.

Production of chiffon cake, and measurement of batter characteristics

The chiffon cake was prepared following the instructions of Pi *et al.* (2017), and Table S1 shows the basic formulation for a gluten-free rice chiffon cake with dry base yam substitutions ranging from 10% to 30% (10Y and 30Y). The wheat chiffon cake (WC) had the following formulation: 70 g WC, 70 g milk, 133 g egg white, 70 g egg yolk, 26.5 g soybean oil, 77 g sucrose, 2.1 g baking powder and 1 g lemon juice. To create the batter, yam and milk were blended into a paste, followed by mixing the egg yolk, soybean oil, and WC. The batter was then rested. The lemon juice and egg whites were whipped, then sucrose was added until they formed soft peaks. The whipped egg white was combined with the rested batter and mixed quickly. The batter was then poured into a cake pan and baked at 170 °C for 30 min. After baking, the cake was cooled for an hour before being removed from the pan. To make the gluten-free rice chiffon cakes, the above formulation was used with substitutions of 80.5, 26.8 and 0 g of yam and 10.9, 50.2, and 70 g of milk replacing 49–70 g of RC.

The batter density (g cm^{-3}) of the cake was determined by dividing the weight of 24 mL of cake batter by the volume of the beaker (24 mL of water) (Allais *et al.*, 2006). The viscosity of a cake batter was measured after cake batter preparation using a rheometer (Physica MCR 92, Anton Paar Gmblt, Ostildern, Germany) at a temperature range of 25 °C–95 °C, with an increasing temperature of 2 °C min^{-1}. All the rheological measurements were analysed using the Rheoplus software (version 3.21, Anton-Paar). To investigate the flow behaviour and apparent viscosity of the cake batter, the measurements were taken at a shear rate of 960 s^{-1} within 35 min (Pongsawatmanit & Srijunthongsiri, 2008).

Chiffon cake baking performance and physical properties

To assess the baking performance, the specific volume of the chiffon cake was measured in accordance with the method outlined by Sangnark & Noomhorm (2003). The water content of the chiffon cake was determined by weighting before and after complete desiccation by the Association of Official Analytical Chemists (AOAC, 1998), specifically AOAC method 935.29, which involves drying the sample in an oven at 105 °C for 3 h. The water activity of the cake was measured using a Novasina Thermoconstanter (RTD 33 TH-1 avumeter, Novasina Co. Ltd., Pfaffikon, Switzerland) following the method outlined by Mathlouthi (2001). Water activity data was collected at various time points, including 0, 1, 3, 5 and 7 days after the cake was stored in a refrigerator (3–9 °C).

Colour and texture analysis and sensory evaluation of chiffon cakes

The colour of the chiffon cake's crumb and crust was assessed using a spectrocolourimeter (TC-1800 MK-II, Tokyo, Japan) following the method of Cruz-Romero *et al.* (2007) and expressed in terms of CIEL*a*b* parameter. The whiteness index (WI) and Euclidean distance (ΔE) were calculated using equations proposed by Lewandowicz & Le Thanh-Blicharz (2018). Before measuring the crumb samples, a standard white tile was calibrated.

Cake texture profile analysis (TPA) was conducted using a Rapid TA+® Texture Analyser (Horn Instruments Co., Ltd., Taoyuan City, Taiwan) following the procedure defined by Paraskevopoulou *et al.* (2020). The centre of the chiffon cake crumb (25 mm × 25 mm × 20 mm) was cut to analyse texture using a cylindrical probe (25 mm diameter: P25) at a deformation of 25% and a test speed of 1.0 mm s^{-1}, respectively, with the time interval of 30 s delay between the first and second compression. The average texture was calculated from TPA graph hardness (N), cohesiveness, and gumminess (Paraskevopoulou *et al.*, 2020) based on triplicate measurements.

For sensory evaluation, 14 males and 25 females undergraduate and graduate students and employees from the Department of Food Science, National Taiwan Ocean University (Keelung, Taiwan) between the ages of 20 and 89, were panel participants. Cake samples were coded with three digits, and panellists were instructed to evaluate the appearance, odour, texture, flavour and overall score using a nine-point hedonic scale ranging from "1 = extremely dislike" to "9 = extremely like".

Isolation and analysis of volatiles of chiffon cake

Chiffon cakes were frozen at −20 °C and cut into 1 cm^3 before analysis. The frozen samples were then milled using a knife mill Grindomix (GM200, Retsch, Berlin, Germany). To prepare the sample for analysis, 3 g of milled cake sample and 4 μL of an internal standard aqueous solution (containing 3-heptanol in double distilled water) were added to a headspace vial, which was then sealed with a Teflon-lined septum and screw cap. The sealed vial was then placed in a water bath (60 °C) for 10 min to reach equilibrium. A 50/30 μm DVB/CAR/PDMS fibre was used to extract the volatiles of the cake sample. The fibre was inserted into the GC injector at 270 °C for 30 min to prevent contamination before being inserted into the sample headspace to extract the volatiles for 30 min. The fibre was then desorbed in triplicate at 250 °C for 5 min in splitless mode, following the procedure described by Papageorgiou *et al.* (2020).

GC–MS with EI analysis

Volatile compounds were separated and analysed using a gas chromatograph equipped with a mass spectrometer (GCMS-QP2020NX, Taipei, Taiwan). A DB-5MS column (30 m × 0.25 mm i.d., film thickness 0.25 μm; Agilent Technologies, Taipei, Taiwan) was used for the separation of volatile compounds with helium as the carrier gas at a flow rate of 2 mL min^{-1}. The oven temperature was kept at 30 °C for 6 min and then increased to 80 °C at a rate of 4 °C min^{-1}, followed by a further increase to 270 °C at a rate of 30 °C min^{-1}, and maintained at 270 °C for 4.86 min, with a total analysis time of 46 min. The mass spectrometer set in the electron ionisation mode (EI) at 70 eV, scanning the range 35–550 m/z at a rate of 2 scans s^{-1}. The ion source temperature was operated at 230 °C to ensure the accuracy of the analysis.

GC–MS with QCI analysis

The GC separation conditions for GC-EI-MS analysis were the same as previously described. Chemical ionisation reagent gas, isobutane, was used in the selected ejection quick chemical ionisation (QCI) mode to assess stability and sensitivity. The detector voltage was set to 0.7 kV, and reagent ions were ionised for a variable duration as operated by automatic reaction control. QCI full scan data were acquired using mass range 60–550 m/z, scan time 1 s, solvent delay 10 min, manifold temperature 50°C, MS ion-trap temperature 160°C, and ARC ionisation time 0.1 ms.

Volatile compounds were identified based on their retention indices (RI), which were calculated using n-paraffin (hydrocarbon C5-C30; Aldrich Co., USA) under the same chromatographic conditions. The identification was also based on available standards, literature reports, or tentative identification of the volatile compounds was based on their mass spectra compared with those in the NIST library (Version 2.0 g, 2011, Gaithersburg, MD, USA). Semi-quantitative results were calculated from the characteristic ion peak areas with regard to the peak area of the internal standard, assuming a response factor (RF) equal to one for identified volatile compounds. Concentrations were reported as mg isobutene equivalents per kg of sample. The odour activity value (OAV) of the selected volatile was calculated by dividing the concentration by the odour threshold (OT).

Statistical analysis

The results presented were based on the analysis of at least three samples of chiffon cake for each parameter. All cake preparation and analyses were conducted in triplicates. Statistical analysis was carried out using SPSS version 12.01c (2000) (SPSS Inc., Chicago, IL, USA). One-way analysis of variance (ANOVA) and Duncan's multiple range test were performed to evaluate differences between means at a 5% significance level ($P < 0.05$). The General Linear Model (GLM) was assessed for a one-way analysis of variance in SPSS. Pearson correlation analysis was used to examine linear correlations at significance levels of $P < 0.01$ and $P < 0.05$. Principal component analysis (PCA) was conducted on gluten-free rice chiffon cake samples with varying amounts of yam addition and 100% WC chiffon cake samples using MetaboAnalyst 5.0 (http://www.metaboanalyst.ca/) to examine the similarities between the samples.

Results and discussion

Effect of yam addition on batter and cake characteristics of gluten-free chiffon cake

The batter density of gluten-free rice chiffon cake with 0% yam (RC), 10% yam (10Y) and 30% yam (30Y) additions was 0.50, 0.41 and 0.37 g cm^{-3}, respectively. The batter density of 10Y and 30Y was significantly lower ($P < 0.05$) than that of cakes made with 100% RC (RC: 0.50 g mL^{-1}) and 100% WC (WC: 0.46 g mL^{-1}). The specific volume was highest for the WC cake was 3.43 mL g^{-1}, which is significantly surpassing the RC cake at 3.09 mL g^{-1}, 10Y cake at 3.19 mL g^{-1} and 30Y cake at 3.11 mL g^{-1} ($P < 0.05$). The reduction in batter density observed upon yam addition, attributed to the increased batter viscosity of 1725 mPa·s resulting from the incorporation of 30% yam, facilitated enhanced air incorporation during mixing. Consequently, this led to a lower density compared to cakes made solely with WC and RC. The comparison of batter viscosity values indicated that 10Y exhibited a viscosity of 1230 mPa s, while WC recorded 1295 mPa s, showcasing their remarkable similarity. This similarity suggests that incorporating 10% yam into gluten-free RC chiffon cake yields batter characteristics akin to those of cakes made entirely with WC. Moreover, both 10Y and WC batters displayed higher viscosity compared to 100% RC chiffon cake, which recorded a viscosity of 1088 mPa s. However, the specific volume of gluten-free rice chiffon cakes was measured at 3.09 mL g^{-1}, while those supplemented with 10% and 30% yam exhibited similar specific volumes of 3.19 and 3.11 mL g^{-1}, respectively. These values were significantly lower ($P < 0.05$) than that of the WC group at 3.43 mL g^{-1}. In a study conducted by Gularte *et al.* (2012), the inclusion of water-soluble guar gum was shown to enhance batter viscosity wheares reduced the specific volume of gluten-free layer cakes. In our current investigation, it appears that the water-soluble polysaccharides present in yam also contribute significantly to the improved viscosity and the reduced specific volume observed in the prepared batters.

After baking, the moisture content of the 10Y gluten-free rice chiffon cake was significantly higher than that of the 30Y and WC groups (Fig. 1). This higher moisture content is considered a desirable sensory characteristic for chiffon cake. The addition of yam in the 10Y cake could maintain water and delay moisture evaporation during baking. A comparable phenomenon was observed by Amandikwa *et al.* (2015)

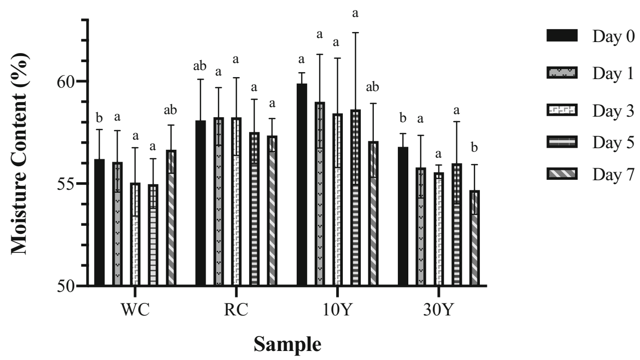

Figure 1 Effect of varying contents of cake on the moisture content during different storage periods. [a,b]Indicating significant difference between different samples ($n = 3$; $P < 0.05$). WC: cake supplemented with 100% of wheat flour; RC: cake supplemented with 100% of rice flour; 10Y: rice cake supplemented with 10% of yam; 30Y: rice cake supplemented with 30% of yam.

when incorporating yam flour into wheat bread production. This effect is likely attributable to the moisture-capturing capacity of the highly water-soluble polysaccharides present in yam. However, this pattern was not observed in cakes with higher yam content. The moisture content of cakes containing 30% yam was comparable to that of cakes made solely with WC. This result may stem from the initial moisture disparity between yam flour and WC. Hsu *et al.* (2004) conducted a proximate analysis of these raw materials, revealing a moisture content of 2.89% for freshly prepared yam flour and 11.00% for commercial WC. Consequently, excessive yam flour addition may not contribute to moisture enhancement in the cake. The moisture content of the 10Y and 30Y groups decreased from 1 to 7 days of storage at room temperature, in comparison to cakes made with WC and RC (Fig. 1). It is noteworthy that the water content of the 10Y chiffon cake with yam addition on day 0 was higher than that of the cake made with WC and 30Y. The moisture content of the gluten-free rice chiffon cake with 10% yam addition after baking was approximately 60%. Additionally, it is noteworthy to highlight that the moisture levels observed in the gluten-free chiffon rice cake were notably higher compared to those reported in various types of cakes in prior studies. For instance, Gunasekara *et al.* (2021) reported a moisture content of 33% in muffins (sponge cake) crafted from purple yam, whereas another investigation on wheat-African yam bean cake documented a moisture content of 14% (Alozie *et al.*, 2009).

Colour, texture and sensory evaluation of chiffon cakes

Table 1 displays the crust and crumb colour parameters, including L*, a*, b*, brown index (WI) and ΔE.

Table 1 Colour profiles of crust and crumb of chiffon cakes

	L*	a*	b*	ΔE[#]	BI[##]
Crust					
WC	73.2 ± 4.5[a]	8.0 ± 3.5[a]	62.2 ± 9.5[a]	—	167.0 ± 15.6[a]
RC	68.9 ± 4.9[a]	8.8 ± 4.4[a]	56.1 ± 5.4[b]	12.3 ± 8.4[a]	152.2 ± 27.2[ab]
10Y	72.5 ± 15.4[a]	3.6 ± 8.2[b]	53.9 ± 6.9[b]	18.2 ± 13.6[a]	132.4 ± 38.6[bc]
30Y	73.7 ± 8.8[a]	2.7 ± 3.1[b]	53.0 ± 6.8[b]	14.1 ± 8.8[a]	117.0 ± 14.8[c]
Crumb					
WC	93.7 ± 0.5[a]	−11.8 ± 0.8[d]	46.4 ± 2.6[b]	—	54.2 ± 4.4[b]
RC	92.3 ± 1.8[a]	−9.5 ± 2.6[c]	51.6 ± 4.7[a]	7.8 ± 5.1[b]	67.7 ± 11.6[a]
10Y	89.2 ± 7.0[b]	−10.7 ± 1.3[b]	49.2 ± 7.4[ab]	9.8 ± 7.8[b]	63.3 ± 11.9[a]
30Y	78.9 ± 6.8[c]	−6.7 ± 1.4[a]	41.8 ± 4.8[b]	17.1 ± 6.9[a]	63.0 ± 8.8[a]

Expressed as mean ± standard deviation ($n = 3$). Values followed by the different letter within each row are significantly different ($P < 0.05$). WC (control): cake supplemented with 100% of wheat flour; RC: cake supplemented with 100% of rice flour; 10Y: rice cake supplemented with 10% of yam; 30Y: rice cake supplemented with 30% of yam.

[#]ΔE: $[(L^*_{sample}—L^*_{control})^2 + (a^*_{sample}—a^*_{control})^2 + (b^*_{sample}—b^*_{control})^2]^{1/2}$.

[##]BI: $[100(\chi-0.31)]/0.17$ $\chi = (a^*+1.75 L^*)/(5.645L^*+a^*-3.012 b^*)$.

The incorporation of yam led to a significant reduction in the L* value (lightness) of the gluten-free chiffon cake crumb. However, the addition of yam did not result in a relatively darker, redder or yellower colour of the cake crumb and crust compared to the WC or RC group. The incorporation of 10% and 30% yam did not significantly increase the brown index (BI) of the crust and crumb. Nevertheless, increasing the amount of yam resulted in an increase in the Euclidean distance (ΔE), with the most significant change observed in the chiffon cake with 30% yam (30Y) (Table 1 and Fig. S1). The ΔE between WC and RC groups was more than 7.8, which was a detectable difference observable to the eye. The crumbs of gluten-free rice chiffon cakes became darker and more distinguishable compared to the cake made with 100% WC or RC. However, the similar L values and lower browning index (BI) values on the crust of yam addition observed for gluten-free chiffon rice cakes are possibly related to less Maillard reaction were occurred on the surface of cakes. The colour of the cake is a significant characteristic that attracts consumers and motivates them to purchase the cake.

The texture of gluten-free chiffon cakes was analysed with respect to the influence of RC and yam, as presented in Fig. 2. Results show that the WC group had lower values for both hardness and gumminess (Fig. 2). With increasing yam incorporation, the hardness and gumminess of the gluten-free rice chiffon cake gradually increased, particularly for the 30% yam addition (30Y), compared to the cake made with RC. However, the cake with 10% yam addition exhibited similar hardness and gumminess values to the cake made entirely from RC (Fig. 2). Although yam can bind water and form a barrier to mitigate water evaporation during baking, the moisture content of gluten-free chiffon cake still decreased rapidly during storage, as shown in Fig. 1, when compared to cakes made with WC or RC. The rise in hardness and gumminess observed in gluten-free chiffon cakes as the proportion of yam replacing RC increased may be linked to the elevated content of water-soluble polysaccharides derived from yam. Cohesiveness was found to be similar for all test cakes, indicating that the addition of yam did not have any dramatic effect on cohesiveness. Furthermore, there is an increase in both the hardness and gumminess of cakes over time during storage. A similar trend was observed in a study on RC chiffon cake conducted by Ferng *et al.* (2016).

For the sensory evaluation, the results indicate that the appearance, odour, texture, flavour and overall scores for all tested groups exceeded 7, with no significant differences observed among them. In a study by Mau *et al.* (2017), black RC was used to replace WC in chiffon cake production, revealing a declining trend in sensory indicators including flavour, texture and overall acceptance when the substitution ratio exceeded 60%. However, in this study, both the group entirely replacing WC with RC and the group further supplemented with yam exhibited sensory scores equivalent to the WC control group. This suggests that this gluten-free formulation has the potential to serve as an alternative to conventional cakes.

Volatile aroma profile of chiffon cakes

In Table S2, the volatile profile of WC-based chiffon cakes is presented, consisting primarily of 34 volatile organic compounds from 10 various chemical classes, including 5 alkanes, 4 alcohols, 3 alkenes, 8 aldehydes, 3 ketones, 2 esters, 6 benzenes, 1 furan derivative, 1 pyrazine and 1 enol. Aldehyde and ketone volatile

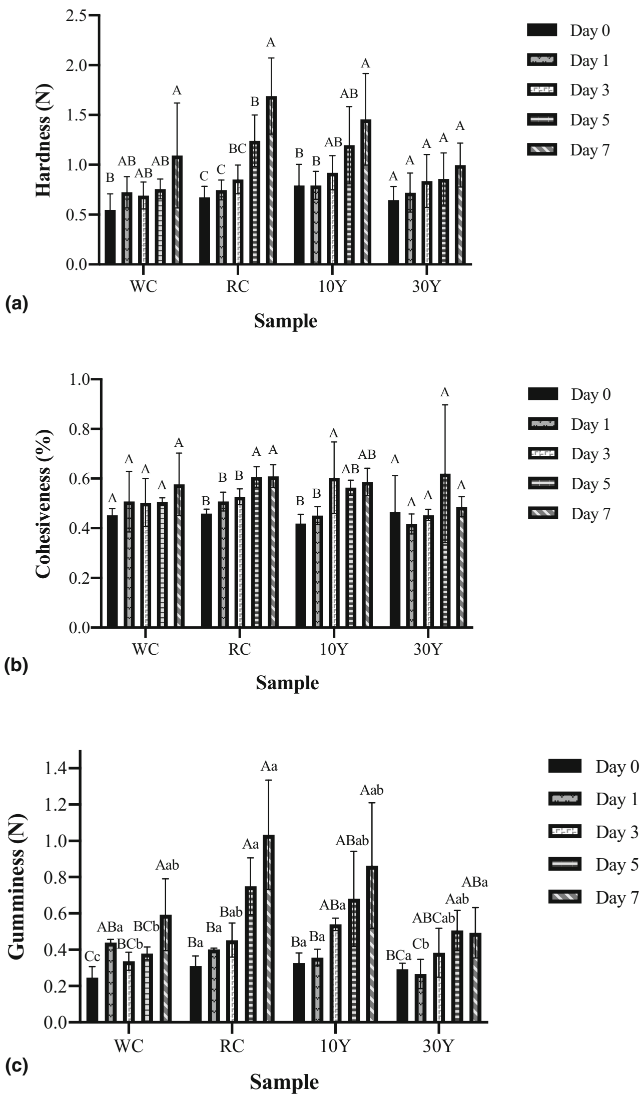

Figure 2 Texture characteristics of chiffon cakes during storage over different time periods. (a) Hardness, (b) cohesiveness and (c) gumminess. [a–c]Indicate significant difference between different samples ($n = 3$; $P < 0.05$). [A–C]Indicate significant difference between different days ($n = 3$; $P < 0.05$). WC: cake supplemented with 100% of wheat flour; RC: cake supplemented with 100% of rice flour; 10Y: rice cake supplemented with 10% of yam; 30Y: rice cake supplemented with 30% of yam.

compounds in WC-based chiffon cakes are primarily produced by alcohol oxidation during baking (Garvey *et al.*, 2021). 1-Hexanol is a common aroma compound found in WC (De Flaviis *et al.*, 2021), WC-based chiffon cakes (Table S2), Madeira cakes (Matsakidou *et al.*, 2010) and sponge cakes (Garvey *et al.*, 2021), and it is not present in RC-based chiffon cakes (Tables S3–S5). It is responsible for the green floral odour and can be used as a marker to distinguish between WC and RC-based chiffon cakes (De Flaviis *et al.*, 2021). During baking, the Maillard reaction occurs, leading to the formation of compounds such as furfuryl alcohols and pyrazines, which are derivatives of furan. These compounds are commonly found in foods exposed to temperatures exceeding 100 °C. (Matsakidou *et al.*, 2010; Garvey *et al.*, 2021).

According to the GC–MS analysis, twenty-nine aroma-active volatile organic compounds were detected in RC-based chiffon cake, which included 4 alkanes, 2 alcohols, 3 alkenes, 8 aldehydes, 3 ketones, 2 esters, 4 benzenes, 1 furan derivative, 1 pyrazine and 1 alkene (Table S3). The profile of volatile compounds was affected by the heating temperature and time during the baking process (Kim *et al.*, 2012). The volatile compounds identified in rice cake were not as numerous as in wheat cake. The study revealed the presence of 2-methylpropanal (isobutyraldehyde), which is responsible for the 'fruity' and 'almond' notes. Additionally, the Strecker degradation products, including 3-methylbutanal (isovaleraldehyde) and acetaldehyde, generated from the Maillard reaction, and hexanal, a lipid oxidation product, were also detected in rice cake (Kim *et al.*, 2012).

The volatile compounds of gluten-free rice chiffon cake with 10% yam addition (10Y) were analysed by GC–MS, revealing a total of 28 compounds from 10 various chemical classes, including alkanes, alcohols, alkenes, ketones, aldehydes, esters, benzenes, furan derivatives, pyrazine and enol (Table S4). However, gluten-free chiffon cake with 30% yam addition (30Y) showed only 16 compounds from 8 various chemical classes, including alkanes, alcohols, alkenes, aldehydes, ketones, esters, benzene and enol (Table S5). No unique volatile compounds were found in 10Y and 30Y cakes compared to WC and RC cakes. Among the compounds identified, 1-octen-3-ol was described as having fruity, buttery and mushroom aromas in roasted yam (Lasekan & Teoh, 2019). Ethanol, 2-ethyl-1-hexanol, 3-methylbutanal, 2-furanmethanol and limonene were reported as having alcohol, vegetable, bread, and citrus aromas, respectively, in cheese and WC (Chen *et al.*, 2020; Papageorgiou *et al.*, 2020). According to the above results, the volatile compound classes identified in 10Y, WC and RC were similar (Tables S3–S5).

OAV was determined using the volatile OT and semiquantitative concentration of each volatile compound. Higher OAV indicates a more significant contribution to the flavour profile of the food aroma. Upon evaluating the appearance, texture properties, and volatile compound profiles of each group, we determined that the formulation of gluten-free chiffon cake with 10% yam addition was more favourable compared to the 30Y group. Consequently, we proceeded to analyse the respective OAV of each aroma compound present in the 10Y group. The study detected 24 volatile compounds from 10 various chemical classes, including 2 alcohols, 1 alkane, 3 alkenes, 8 aldehydes, 3 ketones, 2 esters, 2 benzenes, 1 furan derivative, 1 pyrazine and 1 enol. The OAV of 1-octen-3-ol was the highest at 11.726 and accounted for 89.9% of the OAV values. The details of the volatile compounds identified in the study are provided in Table 2, except for 2 alkanes and 2 benzenes.

Aldehydes accounted for 9% of the OAV in the gluten-free chiffon cake with a 10% yam addition. The study detected eight aldehyde volatile compounds, namely hexanal, 3-methylbutanal, 2-methylbutanal (butyraldehyde), pentanal, 2-methylpropanal, nonanal, octanal and heptanal, which contributed to the cake's aroma. Hexanal was generated by lipid oxidation and had a green apple and grassy aroma. The volatile compounds 3-methylbutanal and 2-methylbutanal were the degraded products of Strecker degradation from the Maillard reaction and had malty, chocolate, cocoa, almond and apple aromas. Pentanal gave a woody, bitter, and oily aroma, while 2-methylpropanal had a pungent, varnish, fruity and almond aroma. Nonanal had a fatty, waxy and pungent aroma, and octanal contributed a citrus aroma. Both nonanal and octanal volatile compounds might be generated by the oxidation of oleic acid. Heptanal had an oily, fatty, and woody note aroma. These findings were supported by previous studies (Whitfield & Mottram, 1992; Morales *et al*., 2005; Chen *et al*., 2020).

Gluten-free chiffon cake with 10% yam contained three ketone volatile compounds, namely, 2-heptanone, acetone and 2,3-butanedione. Acetone is known for its pungent aroma and is commonly found in dairy products (Miettinen, 1994). On the other hand, 2-heptanone is associated with sweet and fruity notes. Although 2,3-butanedione was detected at the same semiquantitative concentrations (3.2%) as 1-octen-3-ol, its OT is higher (50 ppm) compared to that of 1-octen-3-ol (1 ppb). Thus, its OAV is significantly

Table 2 Aroma compounds in 10% yam-supplemented chiffon cake made by rice flour

	Compound	Concentra-tion* (ng mL^{-1})	OAV	%	OT (ng mL^{-1})	Odour	OT reference	Odour reference
1	1-octen-3-ol	11.73	11.726	3.2	1	Fruity, buttery, mushroom	p	o,p
2	hexanal	48.87	0.611	13.4	80	Green apple, grassy	a	a
3	3-methylbutanal	41.43	0.276	11.3	150	Malty, chocolate, cocoa	b	b
4	2-methylbutanal	24.76	0.141	6.8	175	Malty, almond, cacao, apple	b	b
5	pentanal	9.56	0.040	2.6	240	Woody, bitter, oily	a	a
6	1,4-dimethylbenzene	1.93	0.039	0.5	50	Sweet	c	d
7	2-methylpropanal	5.63	0.038	1.5	150	Pungent, varnish, fruity, almond	b	b
8	nonanal	5.51	0.037	1.5	150	Fatty, waxy, pungent	a	a
9	butyl-acetate	10.44	0.035	2.9	300	Green, fruity, pungent	a	a
10	octanal	1.64	0.029	0.5	56	Citrus	e	e
11	2-heptanone	6.19	0.021	1.7	300	Sweet, fruity	a	a
12	1,3-dimethylbenzene	3.55	0.012	1.0	300	Sweet	f	d
13	limonene	99.52	0.010	27.2	10 000	Citrus	h	h
14	α-terpineol	2.16	0.008	0.6	280	Fruity, floral	i	i
15	octane	7.20	0.008	2.0	940	Sweety, alcane	a	a
16	heptanal	2.36	0.005	0.7	500	Oily, fatty, woody	a	a
17	2,5-dimethylpyrazine	7.25	0.004	2.0	1700	Chocolate, roasted nuts, earthy chocolate, roasted nuts, fried	i	i
18	hexyl-acetate	3.86	0.004	1.1	1040	Green, fruity, sweet	j	j
19	2-furanmethanol	5.49	0.003	1.5	2000	Burnt sugar, bread, coffee	i	i
20	acetone	13.83	0.001	3.8	20 000	Pungent	k	l
21	2,3-butanedione	11.60	0.000	3.2	50 000	Butter, pastry, yeast	m	l
22	ethanol	5.67	0.000	1.6	30 000	Alcohol	a	a
23	β-myrcene	4.78	0.000	1.3	70 000	Woody, green	h	n
24	γ-terpinene	3.42	0.000	0.9	1 000 000	Woody, citrus	g	n

*Concentration: calculated by internal standard (40 ppm of 3-heptanol).

OAV, odour activity value; OT, odour threshold.

a: Morales *et al*. (2005); b: Chen *et al*. (2020); c: *CHRIS Hazardous Chemical Data*; d: Database of Hazardous Materials. https://cameochemicals.noaa.gov/ (accessed 2022-05-24); e: Reiners *et al*., (1998); f: Criteria for Recommended Standard; g: Gemert, (2003); h: Xiao *et al*., (2017); i: Papageorgiou *et al*. (2020); j: Aparicio & Luna (2002); k: Amoore & Hautala, (1983); l: Flavour Ingredient Libarty. https://www.femaflavor.org/flavor-library (accessed 2022-05-24); m: Burdock, (2016); n: Cho *et al*., 2018; o: Verma & Srivastav, (2020); p: Pico *et al*. (2017).

lower (0.002) than that of 1-octen-3-ol, which has the highest contribution.

Alcohols are volatile compounds commonly found in cake and bread. Among these, 1-octen-3-ol is the primary aroma contributor for cake, while α-terpineol provides fruity and floral notes to the cake's aroma (Papageorgiou *et al.*, 2020). Despite accounting for only 3.2% of the total volatile compound semiquantitative concentrations, 1-octen-3-ol has the highest OAV. On the other hand, limonene, which makes up 27.2% of the total volatile compounds, has the highest semiquantitative concentration but ranks 13th in OAV (Table 2). Therefore, a high semiquantitative amount of a volatile compound does not necessarily indicate a high contribution to odour. Additionally, 1-octen-3-ol has an OT of 1 ppb, enabling it to contribute to the cake's aroma even at low concentrations (Table 2 and Table S4). Lastly, ethanol is associated with an alcohol aroma (Morales *et al.*, 2005).

Esters are formed by the esterification of acids and alcohols and give to the fruity and sweet aroma of foods (Papageorgiou *et al.*, 2020). Butyl-acetate adds a fruity aroma to chiffon cake (Morales *et al.*, 2005), while hexyl-acetate adds a sweet aroma to the cake (Aparicio & Luna, 2002). Pyrazines and furan derivatives are mainly formed through the Maillard reaction, and they are widely detected in heated foods (Fadel *et al.*, 2006). These volatile compounds are associated with roasted, nutty, cocoa, and caramel aroma (Papageorgiou *et al.*, 2020). Gluten-free rice chiffon cake added 10% yam was found to contain 2,5-dimethylpyrazine and 2-furanmethanol (Table 2). Gluten-free chiffon cakes made with 100% RC, and 10% yam addition, and 100% WC were found to contain 2,5-dimethylpyrazine,

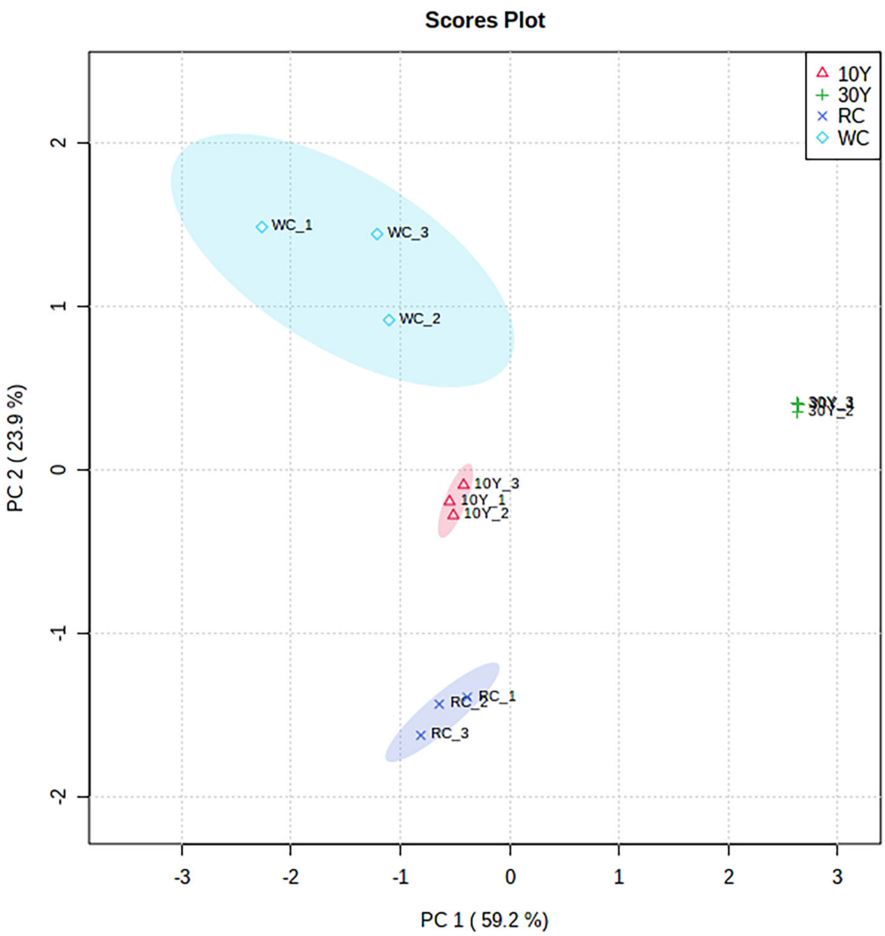

Figure 3 PCA analysis for volatile compounds of four different gluten-free chiffon cake samples. PC1 accounting for 59.2% of the variation and PC2 representing 23.9% of the variation. WC: cake supplemented with 100% of wheat flour; RC: cake supplemented with 100% of rice flour; 10Y: rice cake supplemented with 10% of yam; 30Y: rice cake supplemented with 30% of yam.

and it was not found in chiffon rice cake with 30% yam addition, although the threshold of pyrazine was low, the OAVs of 2,5-dimethylpyrazine in all gluten-free rice chiffon cakes were not high enough to be mentioned (Tables S3–S5). In gluten-free bread, 1,4-dimethylbenzene (*p*-xylene) and 1,3-dimethylbenzene (*m*-zylene) contribute to a sweet aroma (Pico *et al.*, 2017). Octane is detected in oil and adds a sweet aroma to food (Morales *et al.*, 2005). Finally, γ-terpinene is commonly found in plants and flowers, adding woody and citrus notes to the aroma (Cho *et al.*, 2018).

A correlation analysis was used to examine the relationship between the physicochemical properties of gluten-free chiffon cake with varying amounts of yam supplement. The study aimed to elucidate the impact of yam addition on the quality attributes of the cake. The results revealed that the density of the cake batter (−0.918; $P < 0.01$), moisture content (−0.581), water activity (−0.045), hardness (−0.36), gumminess (−0.621), crumb colour parameters L* (−0.994; $P < 0.01$) and b* (−0.995; $P < 0.01$), as well as crust a* (−0.84; $P < 0.01$) and b* (−0.912; $P < 0.01$) values were negatively correlated with the percentage of yam supplement ($P < 0.05$). Conversely, batter viscosity (0.993; $P < 0.01$), cohesiveness (0.439), crust L* value (0.887; $P < 0.01$) and crumb a* value (0.813; $P < 0.01$) were positively correlated with the percentage of yam addition ($P < 0.05$) (Table S6). These findings provide valuable insights into the effect of yam supplements on the physicochemical properties of gluten-free chiffon cake.

Principal component analysis

PCA was conducted to understand the volatile compounds of four different gluten-free chiffon cake samples through semiquantitative analysis. A score plot of the volatile compounds based on the first principal component (PC1) and second principal component

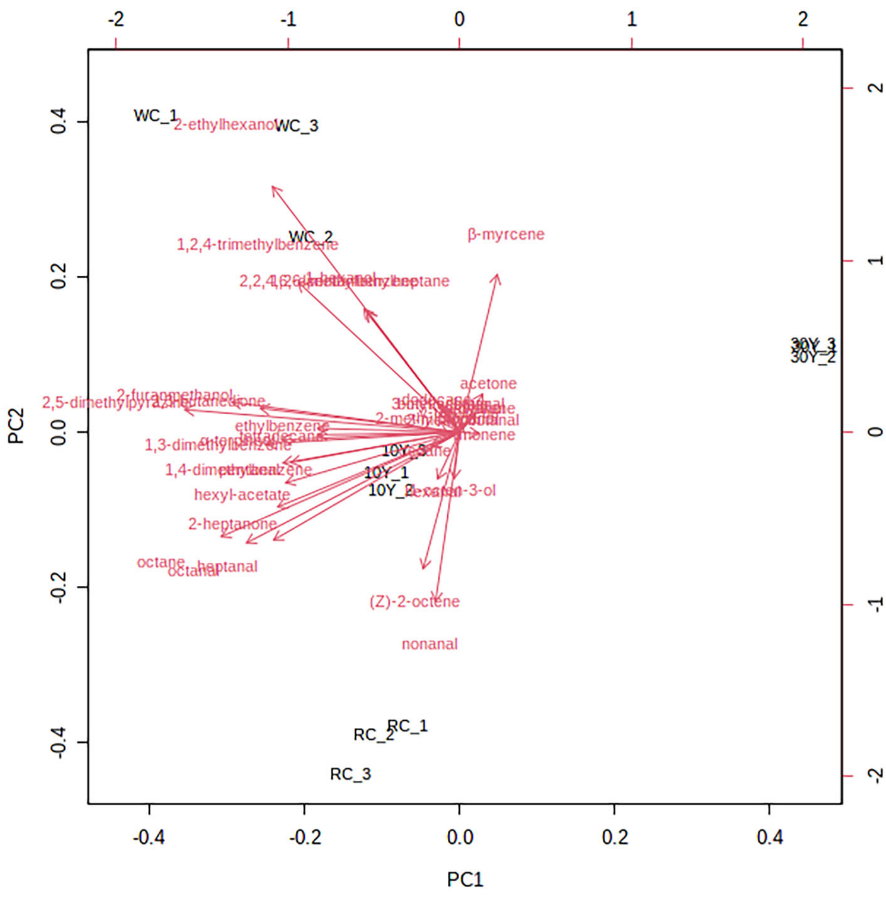

Figure 4 PCA biplot for the volatile compounds of four different gluten-free chiffon cake samples. WC: cake supplemented with 100% of wheat flour; RC: cake supplemented with 100% of rice flour; 10Y: rice cake supplemented with 10% of yam; 30Y: rice cake supplemented with 30% of yam.

(PC2) is generated in Fig. 3, which showed that the triplicate samples of each chiffon cake were clustered together and separated into four distinct groups, indicating the reproducibility of the results. The semiquantitative concentrations of volatile compounds in the four different chiffon cakes were also grouped into four categories. The loading factor and scores plot of volatile compounds in PC1 and PC2 were obtained through PCA analysis, with PC1 accounting for 59.2% of the variation and PC2 representing 23.9% of the variation. The volatile compounds of the various chiffon cake groups were identified as the major factors in both PC1 and PC2, as demonstrated by the PCA biplot in Fig. 4.

In comparison to the other three cake samples (10Y, WC and RC), the 30Y gluten-free chiffon cake was positioned in the positive area of PC1, while the volatile compounds loaded in the negative area of PC1, implying that the contribution of 30Y volatile compounds is minimal. The volatile compounds, including 2-ethylhexanol, 1,2,4-trimethylbenzene, 2,2,4,6,6-pentamethylheptane, 1-hexanol and β-myrcene of chiffon cake made with WC could be used to distinguish it from other groups. Nonanal and (Z)-2-octene of gluten-free rice (RC) chiffon cake volatile compounds could also differentiate it from other chiffon cakes. All other volatile compounds were found in WC, RC and 10Y chiffon cakes. The lower number of volatile compounds found in 30Y may be due to the higher viscosity of the chiffon cake batter resulting from the addition of more yam, which could have prevented the volatile compounds from evaporating during HS-SPME extraction.

The PCA aimed to find the key aroma active volatile compounds that are present in WC chiffon cake but absent in gluten-free chiffon cake. The analysis revealed five such volatile compounds: 2-ethylhexanol, 1,2,4-trimethylbenzene, 2,2,4,6,6-pentamethylheptane, 1-hexanol and β-myrcene (Fig 4). β-Myrcene contributes fruity and clove aromas to chiffon cake, while 2-ethylhexanol gives a rose flower aroma to food (Wakayama *et al.*, 2019). β-Myrcene also gives a woody and fatty aroma to food, and is commonly found in bleak tea (Mao *et al.*, 2018). Additionally, 1-hexanol contributes fatty, fruity and fermented aromas to food, while 2,2,4,6,6-pentamethylheptane gives tea aroma to food (Li & Wang, 2020).

Conclusions

The batter density of the RC group measured 0.50 g cm^{-3}, significantly higher than those of the 10Y, 30Y and WC groups, which recorded densities of 0.41, 0.37, and 0.46 g cm^{-3}, respectively. The WC cake had the highest specific volume at 3.43 mL g^{-1}, exceeding those of the RC, 10Y and 30Y cakes, which measured 3.09, 3.19 and 3.11 mL g^{-1}, respectively ($P < 0.05$). The addition of 10% yam to gluten-free chiffon cake improved its hardness, gumminess and appearance, approaching the quality of chiffon cake made with 100% WC. Substituting gluten-free rice chiffon cake with 10% yam resulted in higher specific volume and moisture content compared to other variations and WC chiffon cake. GC–MS analysis identified 24 aroma compounds in gluten-free chiffon cake with 10% yam. 1-octen-3-ol contributed the highest OAV at 11.726, providing fruity, buttery, and mushroom aromas. Aldehyde compounds accounted for 9% of OAV, with hexanal, 3-methylbutanal, 2-methylbutanal, pentanal, 2-methylpropanal, nonanal, octanal and heptanal being detected. Pyrazines and derivatives associated with roasted, nutty, cocoa and caramel aromas were also detected, including 2,5-dimethylpyrazine. The physicochemical and aroma properties of gluten-free chiffon rice cake were negatively correlated with the percentage of yam addition for batter density, moisture content, water activity, hardness, gumminess and certain colour parameters. Conversely, batter viscosity, cohesiveness and specific colour parameters were positively correlated with yam addition. These findings offer insights into the impact of yam addition on gluten-free chiffon rice cake properties.

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Author contributions

Shang-Ta Wang: Data curation; formal analysis; investigation; visualization; writing – original draft; conceptualization; methodology. **Hong-Jhang Chen:** Conceptualization; resources; methodology. **Mingchih Fang:** Conceptualization; methodology. **Ching-Wen Huang:** Data curation; investigation. **Wen-Chieh Sung:** Supervision; writing – review and editing; project administration; conceptualization; resources; funding acquisition.

Conflict of interest

All authors declare no conflict of interest.

Peer review

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Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. Formulations of chiffon cakes in this study.

Table S2. Volatile compounds in wheat flour-based chiffon cake.

Table S3. Volatile compounds in rice flour-based gluten-free chiffon cake.

Table S4. Volatile compounds in 10% yam-supplemented gluten-free chiffon cake.

Table S5. Volatile compounds in 30% yam supplemented gluten-free chiffon cake.

Table S6. The correlation coefficient between the contents of yam and the physicochemical properties of gluten-free chiffon cake.

Figure S1. Visual characteristics of yam-supplemented chiffon cakes made with wheat flour and rice flour.