Effect of lemon water vapor extract (LWAE) from lemon byproducts on the physiological activity and quality of lemon fermented products

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ABSTRACT
The byproducts of lemon juice have always constituted an environmental issue. In this study, the byproducts extracted to lemon water vapor extract (LWAE) by distilled, which was added to lemon fermented products (LFP) to evaluate its effect on its quality and bioactivity. Based on the gas chromatography-mass spectrometry results, the main component of the LWAE was D-limonene (>41%). After added 5% LWAE the amount of D-limonene in non-sterilized lemon fermented product (NLFP) increased from 10.1% to 20.9%, while that in LFP increase from 10.5% to 19.9%. Besides, anti-browning test results showed that LWAE could delay browning. This study demonstrated that LWAE improved the antioxidant capacity, limonene content, anti-browning ability, and bioactive ingredients in a gastrointestinal simulation. These results may serve as the principal basis for byproduct reuse and improvement of product quality.

Introduction
Eureka lemon (Citrus limon (L.) Burm) is the second most commonly planted citrus fruit in Taiwan. Taiwan utilizes approximately 33,000 hectares of land for citrus fruit planting and harvests approximately 534,000 tons per year.[1] Past research had indicated that lemon contains excellent antioxidant properties,[2] anti-inflammatory activities, and high bioactive compound amounts, e.g. limonene terpene.[2,3] Therefore, lemons are suitable for the development of new products. Lemon fermented products are produced via lactic acid fermentation with Eureka lemon as a substrate. According to our past research, lemon fermented products had higher amounts of polyphenols, flavonoids, and vitamin C as well as stronger antioxidant capacity and reducing cellular oxidative stress. Previous studies had also indicated that lactic acid fermentation can improve the physiological activity, value, and flavor of products.[4,5]

Lemon is the most planted citrus fruit in the world with a global output of 730 million tons.[6,7] Lemon is typically used as fruit juice; however, it produces significant amounts of peel and pomace as byproducts and causes environmental problem. In addition, lemon peel contains large amounts of active compounds, including pectin, polyphenols, and flavonoids,[2,8] and is rich in volatile ingredients, such as terpenes, esters, and alcohols; thus, lemon aroma components are often used

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for processing purposes. For example, lemon water vapor extract essential oil with antibacterial effects was applied for the quality improvement physiological activity.\footnote{9} Therefore, lemon byproducts can be recycled as raw materials and double the profits of the business and technology industries.\footnote{10,11} Browning is a widely present chemical reaction in foods that has a significant impact on appearance, aroma, quality, and nutritional value. Browning reactions of food with positive impacts include coffee, bread, soy sauce, and black tea\footnote{12} while those with negative impacts include fruits, juices, frozen or dehydrated foods, and some fermented foods. This occurrence illustrates that controlling the browning reaction, appearance, and color of foods are important for indicating product quality. The fermentation and maturation process of producing lemon fermented products occurs easily, resulting in the deterioration of product appearance and quality. The browning phenomenon in lemon fermented products often leads to concern from consumers. According to statistics, approximately 50% of the loss in the processing market is due to browning\footnote{13}, therefore, improving the browning phenomenon of food products is important and valuable.

In this study, lemon byproducts were recycled to produce lemon water vapor extracts (LWAE) by distillation and extraction, and then added to lemon fermented products to improve the process and product quality. The bioactive, browning reaction, and volatile compound amounts were investigated by gas chromatography-mass spectrometry (GC-MS), and sensory evaluation was performed to understand the consumer value of the products.

**Materials and methods**

**Chemicals and reagents**

Methanol and potassium persulfate were purchased from Aencore Chemical Co. (Melbourne, Australia). Hydrochloric acid and ascorbic acid were obtained from R&D Systems (Minneapolis, MN, USA) while pepsin, gallic acid, 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS), hydroperoxidases, 2,6-dichlorophenol indophenol, trypsin, and Folin-Ciocalteu reagent were purchased from Sigma-Aldrich (St. Louis, MO, USA). Potassium ferricyanide was obtained from Thermo Fisher Scientific (Waltham, MA, USA). 2,2-diphenyl-1-picrylhydrazyl (DPPH), 1,2-phthalic acid, and hydrogen peroxide (H\textsubscript{2}O\textsubscript{2}) were purchased from Alfa Aesar (Haverhill, MA, USA).

**Sample preparation**

**Preparation of the lemon-fermented products**

Organic lemons were obtained from Jiuru, Pingtung, Taiwan. The lemons were harvested, picked, washed, and dried. *Lactobacillus OPC1* was provided by Openmind International Co., Ltd. (Kaohsiung, Taiwan). The whole lemon was then juiced, and the seed and pulp were removed. The lemon juice, which had a Brix value of 7–10 °Bx and a pH of 2.5–2.8, was placed in a fermentation tank with *Lactobacillus OPC1* (0.1%) inoculated at 25°C. The strain was activated for 30 min and agitated to prevent lumps.

After inoculation into the fermentation tank, the tank was opened and stirred for 15 min. After standing for 24 h, the tank was stirred for 30 min followed by stirring for 30 days every 48 h. After 30 days of fermentation, the tank was stirred for 60 days at a frequency of 30 min every 72 h. The sugar content was determined to be 3–6 °Bx, and the pH value was 2.3–2.7. The fermentation endpoint was identified when the upper and lower layers of the finished product were clearly separated with a light yellow upper layer and a dark yellow lower layer, which is on-sterilized lemon fermented products (NLFP). Sterilized lemon fermented products (LFP) were obtained after the sample was sterilized at 80°C for 1 min, and lemon juice was obtained after pressing and removing the seeds and pulp. Two samples were stored at −18°C until further use.\footnote{14}
**LWAE preparation**

First, 2 kg of frozen recycled lemon byproducts was defrosted and placed in the extraction machine. Water vapor extraction was performed for 1 h, and distillate concentrations of 0%, 1%, 2%, 3%, and 5% were added to the NLFP and LFP samples.

**Antioxidant analysis**

**DPPH antioxidant analysis**

The free radical scavenging activity was determined using the DPPH method. First, 20 mL of the sample was added to 180 μL DPPH reagent and reacted in the dark for 30 min. Then, the absorbance was measured at 517 nm. Vitamin C (1000 ppm) was used as a control. The free radical scavenging activity was expressed as the percent inhibition of DPPH and calculated using the following formula:

\[
\text{Inhibition (\%)} = \left[ \frac{(A_0 - A_A)}{A_0} \right] \times 100
\]

\(A_0\) is absorbance of the control group, \(A_A\) is absorbance of the sample group.

**Reducing power analysis**

First, 1 mL of 200 mM phosphate buffer solution (pH 6.6) was added to 1 mL of the sample, and 1% potassium ferricyanide was added, mixed well, and incubated for 20 min in a 50°C water bath. After incubation, the mixture was rapidly cooled, and 1 mL of 10% trichloroacetic acid (TCA) was added. Then, the sample was centrifuged at 3000 rpm for 10 min. Next, 100 μL of supernatant was drawn, 100 μL of distilled water and 100 μL of 0.1% ferric chloride (FeCl₃·6H₂O) solution (prepared with 3.5% HCl solution) were added, and the solution was mixed well and incubated for 10 min. The absorbance was measured at 700 nm. The higher the absorbance, the stronger the reducing power [C.-Y.15]

**Trolox equivalent antioxidant capacity (TEAC) test**

Potassium persulfate was added to 7 mM ABTS to prepare a final concentration of 2.45 mM solution, mixed well, and reacted in the dark for 12–16 h at room temperature to stabilize the blue ABTS⁺ cation free radical aqueous solution. The solution was diluted using phosphate-buffered saline (PBS) to an absorbance of 0.70 (± 0.02) at 734 nm for later use. Then, 1 mL of the diluted solution was added to 10 μL of different concentrations and left to stand for 1 min before the absorbance was measured at 734 nm. Peroxidase, ABTS, and H₂O₂ were reacted in the dark for 1 h before 0.1 μL of sample solution was added, and the absorbance was measured at 734 nm. The total antioxidant capacity was calculated as follows:

\[
\text{Total antioxidant capacity (\%)} = \left[ 1 \right. - \left. \left( \frac{A_{734 \text{ nm sample}}}{A_{734 \text{ nm blank}}} \right) \right] \times 100
\]

**Bioactive compound analysis**

**Ascorbic acid analysis**

The sample was centrifuged at 8,000 rpm for 15 min, and 0.1 mL of the supernatant was drawn, added to 0.9 mL of 1% metaphosphoric acid and 9 mL of 2,6-dichloroindophenol (50 μmol/L), mixed well, and measured at 515 nm.[16]

**Polyphenols**

First, 100 μL of the sample was added to 100 μL of 1 N Folin-Ciocalteu reagent, mixed well, and incubated for 5 min. Then, 200 μL of 20% sodium carbonate was added, and the mixture was left to stand for 20 min. Then, the sample was centrifuged at 10000 rpm for 30 min, and the supernatant was withdrawn for absorbance determination at 750 nm with a spectrophotometer (Hitachi U-2100, Japan).[17]
**In vitro gastrointestinal digestion**

**Gastric phase**
First, 20 mg of the freeze-dried NLFP sample was added to the phosphate buffer (pH 7.0) before 1 M HCl was used to adjust the pH to 2.0. Pepsin (enzyme-substrate ratio of 1:50 w/w) was then added and incubated at 37°C for 2 h before use.

**Intestinal phase**
First, 0.9 M NaHCO₃ was used to adjust the pH of intestinal solution to 5.3, and 1 M NaOH was used to further adjust it to 7.5. Then, pancreatin was added and heated at 37°C for 2 h, centrifuged, and stored for later use.[18]

**Volatile compound analysis**
This study used solid-phase microextraction (SPME) for extraction followed by GC-MS for deodorization at 250°C for 10 min. Then, 10 mL of the sample respectively was added to 30% NaCl to extract the aroma components at 56°C for 55 min. The sample was tested with a high-resolution gas chromatography flight mass spectrometer (OP2010; Shimadzu, Kyoto, Japan) entrusted to the Instrument Center of National Cheng Kung University. The conditions of this analysis were as follows: HP-INNOWax 60 m, ID: 0.32 mm, film: 0.25 μm; temperature of ion source: 250°C; column conditions: maintain 50°C for 0 min, increase the temperature to 270°C at a rate of 6°C/min, and maintain for 23 min with helium as the carrier gas and a flow rate of 0.8 mL/min. Then, we analyzed and compared the compounds using the MS database.

**Anti-browning test**
First, 30-day fermented LFP and NLFP samples were added to different concentrations (0%, 1%, 2%, 3%, and 5%) of LWAE. Then, 197 μL of each sample was added to 3 μL of 3% H₂O₂. The anti-browning test was performed after simulating fermentation for 60 days[19] using a spectrophotometer (MT-200; Metertech, Hsinchu, Taiwan) at 420 nm to determine the wavelength and a colorimeter (SA2000; NIPPON DENSHOKU, Tokyo, Japan) to determine the L*, a*, and b* values.

**Sensory evaluation**
The sensory evaluation was carried out with four different samples of commercial lemon juice by 30 consumers. The questionnaire was designed to identify flavor acceptability, acidity taste, sweetness taste, flavor distinctness, taste acceptability, and overall acceptability. The sensory evaluation was utilized a 9-point hedonic scale (dislike = 1, extremely liked = 9).

**Statistical analysis**
The results were analyzed within groups using a one-way analysis of variance and SPSS Statistics 12.0 software (IBM SPSS, Armonk, NY, USA). Significant difference between groups was analyzed with Duncan’s multiple range test and Tukey’s test (P<.05). In order to identify the significant difference in concentration, heatmap clustered analysis (HCA) was used to analyze the volatile compounds, representing the content value in the data matrix between each sample. The relative concentration value is represented with white (low density) to black (high density) color intensity.[20] Principal component analysis (PCA) was used to reduce the dimensions for evaluating differences in results and statistically analyze the volatile compounds through Bartlett’s sphericity test.[20,21]
Figure 1. Effect of different concentration of LWAE on antioxidant capacity of non-sterilized lemon fermentation product. (a) DPPH radical scavenging activity; (b) DPPH radical scavenging activity after gastrointestinal simulation test; (c) reducing power activity; (d) reducing power activity after gastrointestinal simulation test; (e) Trolox equivalent antioxidant capacity; (f) Trolox equivalent antioxidant capacity after gastrointestinal simulation test. VitC: 1000 ppm; Control – Lemon juice; NLFP – Non-sterilized lemon fermented products; Mean ± SD (standard deviation) of five measurements. Values are expressed as mean ± standard deviation, and there is a significant difference between the average of different letters in the same column (p < .05).
Figure 2. Effect of different concentration of LWAE on antioxidant capacity of lemon fermentation product. (a) DPPH radical scavenging activity; (b) DPPH radical scavenging activity after gastrointestinal simulation test; (c) reducing power activity; (d) reducing power activity after gastrointestinal simulation test; (e) Trolox equivalent antioxidant capacity; (f) Trolox equivalent antioxidant capacity after gastrointestinal simulation test. VitC: 1000 ppm; Control – Lemon juice; LFP – lemon fermented products; Mean ± SD (standard deviation) of five measurements. Values are expressed as mean ± standard deviation, and there is a significant difference between the average of different letters in the same column ($p < .05$).


Table 1. Bioactive compounds before and after in vitro gastrointestinal digestion.

| Indices          | LJ     | NLFP | NLFP+1% LWAE | NLFP+2% LWAE | NLFP+3% LWAE | NLFP+5% LWAE |
|------------------|--------|------|--------------|--------------|--------------|--------------|
| Polyph,mgGAE     | 4.14 ± 1.6<sup>a</sup> | 27.8 ± 1.5<sup>b</sup> | 27.7 ± 1.8<sup>b</sup> | 28.5 ± 2.1<sup>b</sup> | 28.1 ± 1.7<sup>b</sup> | 29.4 ± 1.0<sup>b</sup> |
| VitC(mg/mL)      | 23.0 ± 2.3<sup>a</sup> | 59.1 ± 1.9<sup>b</sup> | 59.1 ± 2.1<sup>b</sup> | 60.4 ± 1.8<sup>b</sup> | 60.7 ± 1.4<sup>b</sup> | 62.9 ± 1.3<sup>b</sup> |
| Polyph(mg/L)     | 53.3 ± 1.8<sup>a</sup> | 77.3 ± 1.4<sup>b</sup> | 78.6 ± 1.6<sup>b</sup> | 78.4 ± 1.6<sup>b</sup> | 78.8 ± 1.4<sup>b</sup> | 77.2 ± 1.8<sup>b</sup> |

In vitro assay

| Polyph,mgGAE     | 2.2 ± 2.0<sup>a</sup> | 14.5 ± 1.8<sup>b</sup> | 15.2 ± 1.1<sup>b</sup> | 16.8 ± 1.1<sup>b</sup> | 18.8 ± 1.8<sup>c</sup> | 22.7 ± 1.5<sup>d</sup> |
| VitC(mg/mL)      | 13.6 ± 1.8<sup>a</sup> | 38.4 ± 1.9<sup>b</sup> | 38.8 ± 1.4<sup>b</sup> | 40.7 ± 2.0<sup>c</sup> | 42.1 ± 1.7<sup>cd</sup> | 45.9 ± 1.4<sup>d</sup> |
| Polyph(mg/L)     | 28.6 ± 1.8<sup>a</sup> | 41.7 ± 1.5<sup>b</sup> | 42.6 ± 1.7<sup>b</sup> | 45.4 ± 1.4<sup>c</sup> | 49.7 ± 1.4<sup>cd</sup> | 52.0 ± 1.3<sup>d</sup> |

Table 2.

Results and discussion

Effect of different LWAE concentrations on the antioxidant capacity of LFP

This study aimed to resolve the issue of excess LFP byproducts by determining where the byproducts are recycled and reused. The byproducts underwent distilled extraction to prepare the LWAE and were then added to LFP, and investigated the biological effect of different LWAE concentrations on LFP. The results of the DPPH free radical scavenging of NLFP and LFP are shown in Figure 1a. The scavenging ability of NLFP without LWAE was 82% while that of LFP was 83%; however, the scavenging ability increased as the LWAE addition increased. When the LWAE added to NLFP increased to 5%, the scavenging ability increased to 91% while decreasing to 42% without LWAE addition in the gastrointestinal simulation test. The scavenging ability of LFP increased to 89% and remained at 53% in the gastrointestinal simulation test. The scavenging ability was directly proportional to the addition of LWAE. The reducing power in the gastrointestinal simulation test after adding LWAE was shown in Figures 1c, Figures 1d, Figures 2c, and Figures 2d. The reducing power increased when LWAE was added as well as after gastric and gastrointestinal stimulation. The TEAC test was able to determine the antioxidant capacity of polar and nonpolar compounds; thus, limonene had a more significant effect as shown in Figures 1e and Figures 2e. When NLFP was added to 2% LWAE, the antioxidant capacity increased from 49% to 53% and further increased to 56% when 5% LWAE was added. In addition, the antioxidant capacity of LFP reached 53% when 5% LWAE was added, which has a similar expression with NLFP. This phenomenon also resulted in a gastrointestinal simulation test where NLFP and LFP showed 31% and 27% antioxidant capacities, respectively. Previous studies had shown that limonene had a strong antioxidant capacity, was stable in the presence of acids and alkaline conditions, and was able to isomerize to α-terpineol, which had the same antioxidant capacity. [22–24]

Effect of LWAE addition to the bioactive component in LFP

As shown in Table 1, NLFP and LFP did not show any significant differences after adding LWAE before the gastrointestinal simulation test but increased after the gastrointestinal simulation test (same results as the previous antioxidant capacity test). With every LWAE increase, NLFP showed an increase in total polyphenols from 14.5 ± 1.85 mg gallic acid equivalents (GAE) to 22.7 ± 1.5 mg GAE, Vitamin C increased from 38.4 ± 1.9 mg/mL to 45.9 ± 1.4 mg/mL, and total flavonoids increased
from 41.7 ± 1.5 mg/L to 52.0 ± 1.3 mg/L. Similar results were observed in the LFP test results with a significant difference between the initial total polyphenols amount (13.2 ± 1.7 mg GAE) and that of the 5% LWAE addition (20.7 ± 1.6 mg GAE). Vitamin C retention also increased from 35.3 ± 2.0 mg/mL to 41.9 ± 1.6 mg/mL, and total flavonoids increased from 39.2 ± 1.8 mg/L to 50.4 ± 1.6 mg/L. Previous studies had shown that limonene was able to reduce the depletion of compounds under acidic and alkaline conditions by the high antioxidant capacity of limonene; thus, the initial amounts of

Figure 3. The heatmap plot and the PCA biplot analysis for volatile compound and aroma compounds in different concentration of LWAE. (a) Heatmap plot for volatile compound of NLFP added different concentration of LWAE; (b) the heatmap plot for volatile compound of LFP group addition different concentration of LWAE; (c) the PCA biplot for aroma compound of NLFP added different concentration of LWAE; (d) the PCA biplot for aroma compound of LFP added different concentration of LWAE. The relative percentages for volatile compounds (%) are depicted by color intensity from white (lowest concentration) to black (highest concentration). Biplot graphs show relationships among factors and variables.
bioactive compounds did not change with the addition of LWAE. However, after gastric and bile salt simulation, the retention amounts increased.

**Effect of LWAE addition to the volatile component in LFP**

Aroma components are one of the primary sensory characteristics of fruits, especially in fermented foods. The aroma components of lemons are composed of complex volatile compounds, including terpenes, alcohols, esters, and aldehydes, while lemon peel contains even greater volatile compounds than the fruit itself. In this study, the LWAE-added LFP was analyzed by GC-MS, and the results are shown in Figure 3. Since the LFP in this study was a product of hetero-lactic fermentation, alcohol

| LWA concentration (%) | 0% LWAE | 1% LWAE | 2% LWAE | 3% LWAE | 5% LWAE |
|------------------------|---------|---------|---------|---------|---------|
| **NLFP**               |         |         |         |         |         |
| L*                     | 24.7 ± 1.2a | 27.5 ± 1.3a | 29.5 ± 1.1b | 36.9 ± 1.3c | 44.3 ± 1.0d |
| a*                     | 44.3 ± 1.4a | 39.0 ± 1.8b | 26.5 ± 1.1c | 11.4 ± 0.9d | 10.8 ± 1.0d |
| b*                     | 45.3 ± 0.8a | 46.1 ± 1.3a | 54.7 ± 1.5b | 57.3 ± 1.8a | 65.3 ± 1.3c |
| **LFP**                |         |         |         |         |         |
| L*                     | 26.2 ± 0.9a | 29.7 ± 1.9b | 31.3 ± 2.8c | 36.4 ± 1.1d | 46.5 ± 1.9a |
| a*                     | 49.4 ± 0.8a | 39.5 ± 0.9b | 28.1 ± 0.7c | 12.8 ± 0.8d | 10.5 ± 0.7d |
| b*                     | 42.0 ± 0.9a | 44.5 ± 0.4a | 52.1 ± 0.7b | 56.1 ± 0.8c | 64.8 ± 1.4d |

Value with different letters are significantly different in the same row (p < 0.05).
metabolites were produced during the fermentation process, so ethanol was detected. Overall, α-terpineol (45.41%), dimethyl phthalate (11.7%), and D-limonene (10.16%) were relatively abundant among the total volatile compounds. Other compounds, such as β-terpineol and o-Cymene, were also commonly found in lemon components. LWAE aroma component analysis was simultaneously performed, and the results are shown in Figure 3. LWAE contained most of the volatile compounds in lemon peel, such as the main component D-limonene (41.16%) and secondary components like α-terpineol, lemonol, and Terpinen-4-ol.\textsuperscript{[25,26]} Figure 3a illustrates the changes in the aroma components of LWAE and NLFP in the heat distribution matrix. The limonene content in NLFP increased for every increase in LWAE while the other components showed no significant changes. As shown in Figure 3c, the NLFP volatile component analysis indicated D-limonene as the main component. The

\textbf{Figure 5.} Sensory evaluation analysis of non-sterilized lemon fermented products by adding different concentrations of LWAE. (a) NLFP group; (b) LFP group. NLFP = sterilized lemon fermented products. LFP = Non-sterilized lemon fermented products.
degree of dispersion between samples in the coordinate map represented the degree of difference. The closer the sample coordinate point to the compound, the higher the content. The distance between the coordinate point of the NLFP sample and that of limonene after the addition of LWAE was significantly reduced. As the LWAE addition increased, the degree of dispersion decreased, which demonstrated a significant difference in the distance between the LJ and NLFP coordinate points; thus, as the amount of LWAE increases, the distance becomes discrete.

Similar results were observed in the LFP group. Figure 3b shows the aroma components of LFP after adding different concentrations of LWAE. From the existing literature, it was noted that lactic acid fermentation can change the volatile compounds of the fermentation base value to achieve the effect of improving flavor.\(^{[27,28]}\) However, Figure 3b and Figure 3d illustrated that LWAE addition resulted in increased D-limonene content in LFP.

**Effect of LWAE addition to the browning phenomenon of LFP**

In order to stabilize food quality and reduce the browning effect, this study underwent 60 days of simulated fermentation to accelerate the oxidative browning of LWAE-added LFP. Figure 4 shows that the results of NLFP and LFP without LWAE addition obtained respective absorbances of 0.26 and 0.31, and the degree of browning gradually slowed as the amount of added LWAE increased. When the added amount reached 5%, the absorbance values of the two samples both dropped to 0.22 ± 0.07 (NLFP) and 0.21 ± 0.05 (LFP), and the L*, a*, and b* values were measured using a colorimeter to evaluate the change in browning. As shown in Table 2, the L* value of NLFP increased as the amount of LWAE increased, the a* value color changed from red to green, and the b* value color gradually changed from orange to bright yellow. Previous studies had highlighted that limonene can partially prevent oxidative browning.\(^{[23]}\) Its oxidative ability can prevent oxidative browning of vitamin C\(^{[29]}\) and indirectly inhibit enzymatic browning through self-oxidation.\(^{[30,31]}\)

**Sensory evaluation of LWAE-added LFP**

In this study, we also performed a sensory evaluation of NLFP and LFP after LWAE addition. As shown in Figure 5a, NLFP displayed a flavor change after adding LWAE, where a 5% LWAE addition resulted in increased sweetness, flavor, odor, and overall consumer acceptance. The overall acceptance represented the overall score of the products, which resulted in an increase from 5.4 (without LWAE added) to 5.9 (5% LWAE added). Based on Figure 5b, the flavor of LFP was better than that of NLFP; thus, LWAE appears to be able to increase LFP flavor, where a 5% LWAE addition increased the overall acceptance to 6.4.

The volatile compounds in lemon peel produce a unique aroma. Previous studies had reported that many peel extracts are used to improve the flavor of products and exert a positive effect.\(^{[32,33]}\) After adding LWAE to the NLFP and LFP samples, the flavor was enhanced. When the addition amount reached 5%, the flavor, smell, and overall acceptance significantly increased.

**Conclusion**

Fermented lemon products were produced via lactic acid fermentation of lemon juice, which contains excellent physiological and bioactive compounds. LWAE was produced by distillation and extraction of lemon peels. This study showed that LWAE contains a high amount of limonene, and adding LWAE to LFP improved its antioxidant capacity and retained its high level of bioactive compounds after a gastrointestinal simulation test. Changes in the volatile compounds of LFP after LWAE addition were observed through HMCA and PCA. The anti-browning test indicated that LWAE can delay the oxidation phenomenon while the sensory evaluation showed positive consumer acceptance after adding LWAE to LFP. In conclusion, LWAE preparation using lemon byproducts and addition to LFP had a positive impact on improving physiological and bioactive compounds that also possess development
value. The byproducts from food factories could be quantified in the future, obtaining water vapor extract from water vapor extraction, then adding to products to create varieties of products.

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