fermentation

MDPI

Article

Flavor and Functional Analysis of *Lactobacillus plantarum* Fermented Apricot Juice

Jinkui Sun, Cai Zhao, Xilei Pu, Tian Li, Xuewei Shi, Bin Wang * and Weidong Cheng *

Food College, Shihezi University, Xinjiang Uygur Autonomous Region, Shihezi 832000, China
* Correspondence: binwang0228@shzu.edu.cn (B.W.); cwd0221@163.com (W.C.)

Abstract: The small white apricot is a juicy, delicious fruit with a short shelf life. Slight fermentation can significantly promote the flavors and nutrient value of apricot juice. This study used high-performance liquid chromatography (HPLC) and headspace solid-phase microextraction combined with gas chromatography–mass spectrometry (HS-SPME-GC-MS) to examine the physicochemical properties, nutritive value and flavor substances of apricot juice fermented by *Lactobacillus plantarum* LP56. Fermentation significantly increased lactic acid bacteria (LAB) and their product lactic acid, adding probiotic benefits to fermented apricot juice. In addition, the total phenolic compounds and antioxidant capacity increased, while the levels of soluble solids and organic acids decreased. Gallic acid, 3-caffeoylquinic acid and rutin mainly contributed to the antioxidant activity of fermented apricot juice. Alcohols, aldehyde, acid, ester, etc., were the main volatile compounds. Among the flavors, 12 substances with high odor activity values (OAV > 1) were the key aroma-producing compounds with fruit, pine and citrus flavors. In conclusion, this study shows that *L. plantarum* LP56 fermentation can improve the nutritional value and aroma characteristics of apricot juice.

Keywords: fermented apricot juice; antioxidant activity; organic acids; phenolic compounds; volatile compounds

Citation: Sun, J.; Zhao, C.; Pu, X.; Li, T.; Shi, X.; Wang, B.; Cheng, W. Flavor and Functional Analysis of *Lactobacillus plantarum* Fermented Apricot Juice. *Fermentation* **2022**, *8*, 533. https://doi.org/10.3390/fermentation8100533

Academic Editor: Ye Liu

Received: 14 September 2022
Accepted: 10 October 2022
Published: 12 October 2022

1. Introduction

The apricot belongs to the Rosaceae family and originates from Northwest China [1]. It is a delicious widely eaten fruit all over the world, mainly in Mediterranean countries, South Africa, South America and North America [2]. In China, apricots are mainly distributed in the northwest and eastern regions, the crop planting area and yields are the largest in the Xinjiang region [1]. Apricot has become an important cash crop in Xinjiang with a cultivation history of over 1400 years [3]. The apricots cultivated in Xinjiang include small white apricots, Diaogan apricots, Liguang apricots, etc. The small white apricot has become an important economic fruit in Xinjiang because of its unique flavor and concentrated resource distribution [4].

The small white apricot is also preferred for its high nutritional value and rich functional properties [5], including benefits such as cancer prevention, beauty and skin care, etc. [6]. Due to seasonal limitations and storage difficulties, small white apricots are often processed into dried apricots, apricot pulp and other products [7]. However, these products fail to retain the full nutritional and flavor characteristics of the original fruit, limiting the development of apricot products to a certain extent. Lactic acid bacteria (LAB) can rapidly grow and reproduce in the intestine. Its products lactic acid and carbon dioxide can rapidly reduce the pH value in the intestinal tract, inhibit the propagation of pathogenic bacteria and bacteria harmful to human health, and thus regulate the balance of intestinal flora [8]. Notably, LAB fermentation can improve the functional and nutritional value of fermented food products by regulating the human intestinal microenvironment [9]. The nutritional and sensory quality of several fermented fruit and vegetable juices has been improved by

fermentation [10]. A compound beverage developed from jujube and dried apricot is well appreciated by consumers for its unique flavor and full taste [9].

In recent years, with the growing demand for functional foods, the research on probiotic products has increased significantly [11]. LAB fermentation is an economical biotechnology solution to improve the shelf life and nutritional, functional and sensory quality of fermented products [12]. In addition, providing sufficient nutrition, fruits and vegetables are good environments for the growth of LAB [10]. Currently, LAB are widely used in the fermented food industry. Moreover, LAB-fermented fruit and vegetable juices have certain health benefits such as reducing serum cholesterol, inhibiting the growth of intestinal spoilage bacteria, and regulating the balance of microbiota [13]. Although studies have reported the effects of LAB fermentation on the functional characteristics of many plant foods [14], the LAB fermentation effect on volatile flavor compounds, phenolic profiles and antioxidant capacity of apricot juice is largely unknown. In the fermentation process, LAB showed an upward trend. After fermentation, apricot juice obviously has a fermented taste and flavor.

Accordingly, this study examined the effect of *L. plantarum* LP56 fermentation on the flavor and nutritional value of apricot juice. The organic acids, phenolic compounds and aromatic compounds of apricot juice were analyzed by HPLC and HS-SPME-GC-MS in seven fermentation stages. Our results provide a theoretical reference for the industrial production of fermented apricot juice.

2. Materials and Methods

2.1. Apricot and Microbial Strains

The small white apricot came from the Luntai region, Xinjiang, China, and was harvested in June 2021. Five boxes of small white apricots (5 kg per box) were collected from the same orchard based on the five-point sampling method. The soluble solid content (SSC) of the small white apricot was 12.3–13.5 °Brix. The small white apricot was stored at 4 °C for subsequent testing. The *L. plantarum* LP56 strain was from Xiannong Biotechnology (Shanghai) Co. Ltd. Previous work reported that *L. plantarum* LP56 has been used in the fermentation of walnut milk, which can improve the nutritional value and flavor of walnut milk [15]. *L. plantarum* LP56 was inoculated on an MRS plate and incubated at 37 °C for 24 h until it reached log7 CFU/mL. Then, the culture was obtained by culturing aseptic apricot juice for 12 h.

2.2. Sample Preparation

Cleaned apricot fruits were enucleated and crushed with deionized water (50 °C) in a ratio of 3:7 in the presence of sodium erythorbate to protect the fruit color. The mixture was finely ground with a colloidal mill with a fineness of 2 mm. The soluble solids of apricot juice were adjusted to 13 °Brix by glucose. The prepared apricot juice was pasteurized in a water bath (85 °C) and inoculated with 2% (*v*/*v*) *L. plantarum* LP56 inoculum. The inoculated apricot juice was fermented in a 37 °C incubator for 12 h, and samples were collected for 0 h (S0), 2 h (S2), 4 h (S4), 6 h (S6), 8 h (S8), 10 h (S10) and 12 h (S12), respectively, for analysis.

2.3. Physicochemical Analysis

The number of viable bacteria was determined by the plate counting method. The pH was measured by a pH meter (PHS-3C, Shanghai INESA Scientific Instrument Co. Ltd., Shanghai, China) [16]. SSC was measured by a digital refractometer [17]. The titratable acidity (TA) of fermented apricot juice was determined by acid-base titration and is expressed as the percentage of lactic acid.

2.4. Determination of Organic Acids by HPLC

Organic acids in fermented apricot juice were extracted as described previously [18]. Briefly, 1 mL of fermented apricot juice was evenly mixed with 10 mL of distilled water.

The mixture was sonicated at room temperature (RT) for 30 min and then centrifuged at 6000 r/min for 10 min to separate the supernatant, which was filtered by a 0.22 μm aqueous phase filter membrane.

The filtered sample was used for organic acids determination by HPLC [19]. The HPLC conditions were as follows: chromatographic column, Dikma C_{18} column (250 mm × 4.6 mm, 5 μm, Diamonsil Plus, China); mobile phase, 1 mmol/L K_2HPO_4 (pH 2.0, A) and 3% methanol (B); elution, isocratic elution for 10 min; flow rate 0.5 mL/min; injection volume 10 μL. Respective standard curves were used for compound estimation.

2.5. Determination of Phenolic and Total Flavonoid Contents

Total phenolic content was determined using the Folin–Ciocalteu method [20]. Specifically, 0.1 mL of fermented apricot juice was evenly mixed with 5.9 mL of distilled water. Next, the mixture was added with 0.3 mL of Folin–Ciocalteu reagent with shaking. After 3 min, 2.0 mL of 6% sodium carbonate solution was added and mixed thoroughly. The mixture absorbance was measured at 765 nm after 60 min of the reaction in the dark. The results are expressed as gallic acid (mg/L).

The total flavonoid content (TFC) was determined as described elsewhere [21]. Briefly, 0.1 mL of fermented apricot juice was mixed with 0.9 mL of methanol. Then, 2.7 mL methanol (30% *v*/*v*) was added to the mixed sample with shaking. Next, 0.2 mL of 0.5 mol/L $NaNO_2$ and 0.4 mL of 0.3 mol/L $AlCl_3{\cdot}6H_2O$ solutions were added, and the mixture was shaken for 5 min. Finally, 1 mL of 1 mol/L NaOH solution was added to the mixed sample with mild shaking. The absorbance of the final mixture was measured at 510 nm. Distilled water instead of the developer $AlCl_3$ solution was used in control samples. The results are expressed in rutin equivalent values (mg/L).

2.6. Determination of Antioxidant Activity In Vitro

The DPPH radical scavenging activity of the fermented apricot juice was determined as in Granato et al. [21]. Briefly, the fermented apricot juice was diluted 10 times with distilled water. A 0.2 mL volume of diluted fermented apricot juice was added with 3.9 mL of DPPH methanol solution, and the reaction was allowed for 20 min in the dark. Methanol instead of fermented apricot juice was used in control samples. The final mixture absorbance was measured at 517 nm. The $ABTS^+$ radical scavenging activity of the fermented apricot juice was estimated according to Wang et al. [22]. The CUPRAC and FRAP reduction abilities of the fermented apricot juice were determined as described previously [23]. Antioxidant capacities are reported as Trolox equivalents.

2.7. Determination of Phenolic Compounds

Phenolic compounds were estimated using a Shimadzu HPLC system equipped with a photodiode array detector and Diamonsil Plus C18 column (5 μm, 4.6 mm × 250 mm, Beijing, China). The mobile phase included methanol (pump A) and 0.1% of phosphoric acid (pump B). The gradient elution was as follows: 15% A at 0 min, 20% A at 25 min, 75% A at 65 min and 15% A at 70 min [24]. The other parameters of HPLC were as follows: flow rate, 0.8 mL/min; column temperature, 30 °C; injection volume, 20 μL; detection wavelength, 280 nm. Corresponding standard curves were used for the quantification of phenolic compounds.

2.8. Determination of Aromatic Volatile Compounds

A 5 mL volume of fermented apricot juice, 1 g of sodium chloride and 10 μL of internal standard solution (3-octanol) were added to the 20 mL headspace vial. The mixture was incubated at 40 °C for 10 min. Then, the SPME fiber with divinylbenzene/carboxen/polydimethylsiloxane (DVB/CAR/PDMS, 50/30 μm) was immediately inserted into the vial for extraction of volatiles. After 50 min, the analytes were desorbed in the gas chromatography (GC) injector at 230 °C for 5 min [25].

Analysis of volatile substances was performed using gas chromatography (GC) and triple quadrupole mass spectrometer (Agilent 8890-7000D, Santa Clara, CA, USA) coupled with an HP-Innowax capillary column (30 m × 0.25 mm × 0.25 μm). Helium (99.999%) was used as a carrier gas at a flow rate of 1 mL/min. The GC program started at 40 °C for 5 min, then the temperature was increased to 115 °C at 3 °C/min, and then to 180 °C at 5 °C/min and maintained for 2 min. The temperature was finally increased to 230 °C at 10 °C/min and held for 5 min [26]. The ionization source temperature was 270 °C. The mass spectra were obtained at 70 eV for a scanning range of 35–350 m/z at an interval of 0.2 s. Identification of volatile components was performed by comparing the mass spectra of samples and retention indices (RI) in the NIST 14.0 library. The content of volatile compounds was calculated by the internal standard method.

2.9. Sensory Evaluation

The sensory evaluation of the fermented apricot juice was carried out by an evaluator group of 10 undergraduates and 10 master's students from the College of Food Science, Shihezi University, China. The samples were poured into transparent plastic cups and were randomly numbered. The experts were provided with water to gargle after each taste test. A 9-point characteristic scale was used for sensory evaluation (9, extremely popular; 8, very popular; 7, moderately popular; 6, slightly popular; 5, neither liked nor hated; 4, slightly unpopular; 3, moderately unpopular; 2, very unpopular; 1, extremely unpopular).

2.10. Statistical Analysis

All experimental data are expressed as mean ± standard deviation from three repetitions. The SPSS 20 software was used to assess significant differences between the two groups (IBM, Chicago, IL, USA). The principal component analysis (PCA) was performed by the SIMCA 14.1 software (Biometric Software Developer Umetrics, Umeå, Sweden). Origin 8.5 was used to generate histograms, heat maps and radar charts.

3. Results and Discussion

3.1. Microbial and Physicochemical Indicators of the Fermented Apricot Juice

The selected LAB strain increased immediately when inoculated into apricot juice (Figure 1). During fermentation, the number of viable cells in 0 h of fermentation was significantly lower than that in 12 h of fermentation ($p < 0.05$). The viable cell count increased rapidly after 4 h of fermentation, indicating the robust viability of *L. plantarum* LP56. After 10 h of fermentation, the rising trend of viable cell count began to slow down. This may be caused by the production of lactic acid and the decrease in pH during fermentation [15].

The changes in pH, SSC and TA were analyzed in the fermented apricot juice (Figure 1). TA in apricot juice fermentation showed an upward trend, and the TA in 12 h fermentation was significantly higher than that in 0 h fermentation ($p < 0.05$). TA of fermented apricot juice also increased because of the acid produced by the action of *L. plantarum* LP56 [27]. SSC is one of the key quality indicators, which has an impact on the taste of fruit juice. SSC in apricot juice fermentation showed a downward trend, and the SSC in 12 h fermentation was significantly lower than that in 0 h fermentation ($p < 0.05$). SSC decreased from 13.5 (before fermentation) to 12.7 °Brix, with a decrease of 0.8 °Brix. During the fermentation, *L. plantarum* LP56 could have consumed the carbon and nitrogen sources in apricot juice reducing its SSC [28]. The pH of fermented apricot juice varied from 3.6 to 4.2 during different stages of fermentation, indicating a minor change.

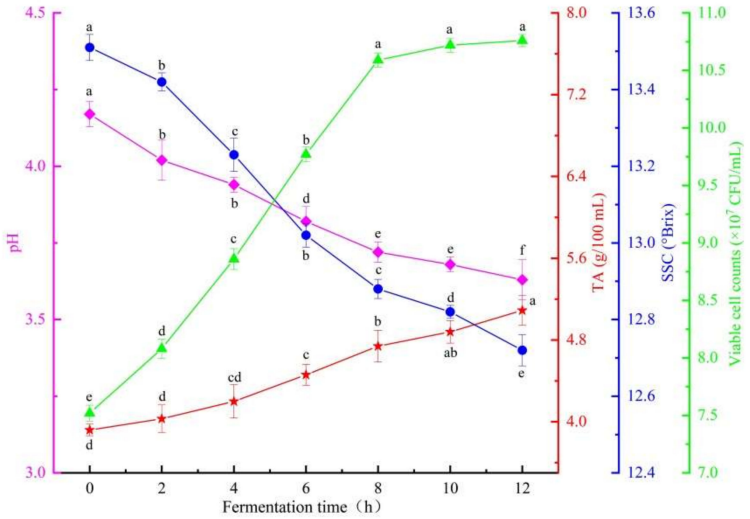

Figure 1. Physicochemical and microbiological chemical indicators of apricot juice of different fermentation stages. pH, titratable acid (TA), soluble solids content (SSC), viable cell counts. Different lowercase letters indicate significant differences between samples at different fermentation stages ($p < 0.05$).

3.2. Composition and Content of Organic Acids in Fermented Apricot Juice

The distribution of organic acids affects the sensory property of fruit juices [29]. The acidity of fermented apricot juice was determined by estimating the composition and concentration of organic acids [30]. The composition of the five organic acids (including malic, citric, lactic, quinic and oxalic acids) in fermented apricot juice was detected at different stages of fermentation (Figure S1A).

Malolactic fermentation is an important process improving the flavor of fruit and vegetable juices, in which malic acid is converted to lactic acid and CO_2 by malic lactase of LAB [31,32]. In this study, the content of organic acids in fermented apricot juice varied at different stages (Figure S1B). In the fermentation process, malic acid showed a downward trend and lactic acid showed an upward trend. The malic acid content was the highest at 2 h (1.93 mg/L), and the lactic acid content was the highest (2.36 mg/L) at the end of fermentation. The participation of malic acid in the production of lactic acid may lead to a decrease in malic acid [26]. Malic acid provides a pungent taste to apricot juice [33] and can synergize with other flavors to create a more natural flavor [34]. In the tricarboxylic acid cycle, lactic acid is the final product of LAB fermentation, which is synthesized by pyruvate reduction or malic acid conversion [17]. Lactic acid provides a full and soft flavor to apricot juice [35]. In addition to malic acid, residual sugar and citric acid, other components are also decomposed by LAB [36].

Citric acid has an effect on the acidity of fermented apricot juice [34]. Citric acid in fermented apricot juice showed a downward trend. The initial content was 1.63 mg/L, which was 1.52 mg/L after 12 h of fermentation, with a decrease of 0.11 mg/L. In LAB fermentation, citric acid can be degraded to produce acetic acid, diacetyl, etc. [37]. Quinic acid decreased from 0.67 to 0.51 mg/L. Oxalic acid content did not change significantly during the fermentation.

3.3. Composition and Content of Phenolic Compounds in Fermented Apricot Juice

Gallic acid, 3-caffeoylquinic acid, epicatechin, rutin, quercetin and kaempferol are the main phenolic compounds in fermented apricot juice (Figure S2A). Gallic acid and rutin showed an upward trend, while 3-caffeoylquinic acid and kaempferol showed a downward trend, while epicatechin and quercetin did not change significantly during apricot juice fermentation (Figure S2B). Rutin (8.19 mg/L) and quercetin (3.97 mg/L) were the main flavonols in the fermented apricot juice. Epicatechin remained at a low level during fermentation. Gallic (8.79 mg/L) and 3-caffeoylquinic acid (4.92 mg/L) acids

were the two main phenolic acids in fermented apricot juice. Similar changes were also observed in the LAB fermentation of bog bilberry juice [38]. During fermentation, several decarboxylases and esterases are released by *L. plantarum* to degrade phenolic acids [27].

Many factors can affect the phenolic content in apricot juice during fermentation. A study showed that the phenolic compounds in *L. plantarum* fermented bog bilberry juice decreased after fermentation [39]. On the contrary, mulberry juice fermented with *L. plantarum* and *L. paracasei* showed an increase in phenolic compounds [38]. Therefore, the change in phenolic content can be affected by the used strains and raw materials. The nutritional value of phenolic compounds is debatable. On the one hand, the composition and content of phenolic compounds may increase the flavor and nutritional value of fermented apricot juice, on the other hand, microbial metabolism of phenolic compounds may also have adverse effects [40]. In recent years, certain phenolic compounds have been shown to possess antioxidant activities [41] and therefore may improve the antioxidant function of fermented apricot juice.

3.4. Functional Components and Antioxidant Activity

Total phenolic (TPC) and flavonoid (TFC) contents are the bioactive substances in the fruit that possess antioxidant activity [42,43]. The TPC ranged from 69.61 to 82.48, and TFC ranged from 37.63 to 49.25 mg/L in seven fermentation periods of apricot juice (Table S1). TPC and TFC in apricot juice fermentation showed an upward trend. After 12 h fermentation, TPC and TFC increased by 5.82 mg/L and 4.18 mg/L, respectively. The TPC (82.48 mg/L) and TFC (49.25 mg/L) were the highest at 12 and 8 h of fermentation. The higher phenolic and flavonoid contents of fermented apricot juice can be the reason for its use in folk medicine [44].

In recent years, the antioxidant benefits of fermented foods on human health have gained much attention from research scholars. In vitro tests based on DPPH, ABTS, FRAP and CUPRAC scavenging methods are frequently used to evaluate the antioxidant capacity of food products [34]. The same was examined for fermented apricot juice (Figure S3). Post-fermentation, DPPH, ABTS and FRAP free radical scavenging activities increased by 282.73, 149.43 and 19.43, while CUPRAC free radical scavenging activity decreased by 419.66 µmol/L, respectively. Studies showed that the DPPH free radical scavenging activity of *L. rhamnosus* fermented carrot juice showed a decreasing trend, while the same increased for *L. bulgaricus* fermented carrot juice [45]. *L. plantarum* fermentation improved the antioxidant activity of kiwifruit pulp [46]. *L. plantarum* fermentation can affect the transformation or protection of bioactive compounds improving the antioxidant activity of fermented foods [47]. The antioxidant compounds can act as singlet oxygen quenchers, metal chelators, hydrogen donors of free radicals and free radical terminators [48]. Importantly, antioxidant capacity may be affected by factors such as strain type, bacterial cell concentration and bacterial metabolic capacity [49].

3.5. Correlation Analysis of Phenolic Compounds and Antioxidant Capacity

The results showed that each phenolic compound may have a different effect on the antioxidant capacity. Kaempferol, quercetin and rutin had a VIP > 1 (Figure 2A), indicating a high correlation with antioxidant capacity. The correlation analysis was performed by the SIMCA 14.1 software using phenolic compounds and antioxidant activity as variables (Figure 2B). Network analysis revealed that gallic acid, 3-caffeoylquinic acid, rutin and quercetin had a positive correlation with DPPH, ABTS, FRAP and CUPRAC free radicals. Kaempferol and TFC showed a negative correlation with DPPH and CUPRAC, while epicatechin and TPC were negatively correlated with CUPRAC free radicals. The correlation study may provide some insights into the changes in nutritional function of fermented apricot juice. For example, DPPH in blueberry juice is positively correlated with rutin and caffeic acid. [50]. The correlation between antioxidant activity and phenolic compounds can be affected by many factors and differ with estimation methods [51].

Therefore, the antioxidant functions of fermented wolfberry juice were determined through a series of rigorous tests, and then the correlation analysis was carried out [52].

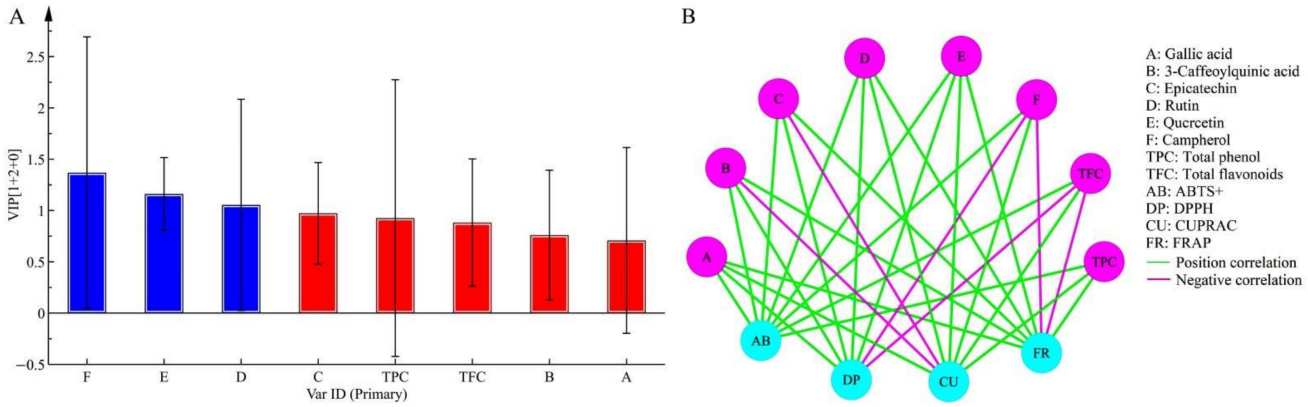

Figure 2. VIP value diagram (**A**) and correlation diagram (**B**) of antioxidant capacity and phenolic compounds in seven fermentation stages of apricot juice. Each node represents phenolic compounds or antioxidant capacities. The green solid line and purple solid line represent positive and negative correlation, respectively. In addition, line width indicates the strength of correlation.

3.6. Variable Changes in Volatile Substances during Fermentation of Apricot Juice

The sensory characteristics and consumer acceptance of fermented apricot juice depend on the composition and concentration of volatile flavors. The composition and types of volatile flavors in fermented apricot juice are shown by a Venn diagram in Figure 3A. The volatile flavors were dynamically monitored by HS-SPME-GC-MS during all the stages of fermentation. In total, 50 volatile compounds were determined (Figure S5 and Table S2) including terpenes (11), alcohols (8), ketones (8), aldehydes (7), esters (6), acids (4) and other compounds (6). Terpenes accounted for 52–61% of the total volatile matter, followed by alcohols (31–34%) and aldehydes (2–9%), esters, ketones, acids and other compounds accounted for 8–16% (Figure S4).

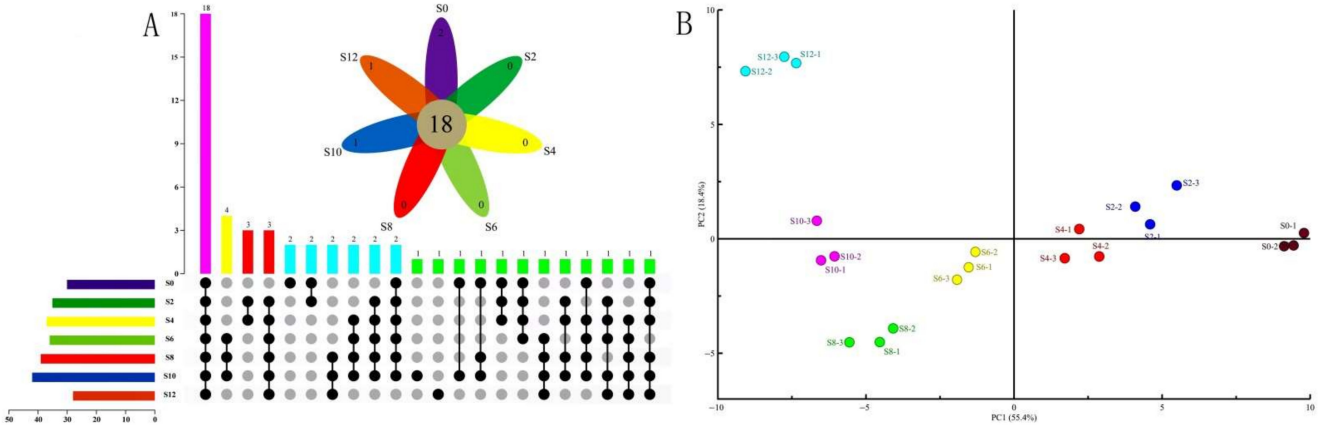

Figure 3. Venn diagram (**A**) and principal component analysis (PCA) (**B**) of volatile compounds from apricot juice during seven fermentation periods. S0, S2, S4, S6, S8, S10 and S12 represent fermentation for 0 h, 2 h, 4 h, 6 h, 8 h, 10 h and 12 h.

A scatter plot showing the results of principal component analysis (PCA) of volatile compounds in seven fermentation stages of fermented apricot juice is shown in Figure 3B. Each stage was clustered according to the concentration and type of substances. The PCA showed that apricot juice had different flavors and metabolic characteristics in different stages of fermentation [53]. The volatile compounds were low at the initial stages (at 0, 2 or

4 h) and then rapidly increased after 4 h of fermentation. At 6 h, the contents of volatile compounds such as α-terpineol, nerol, β-pinene and terpinene increased to the highest. At 8 h, the contents of volatile compounds such as (E, E)-2,4-heptadiene aldehyde, limonene, γ-decanolactone and 2,5-dimethylfuran were the highest. At 10 h, volatile compounds such as 3-hydroxy-2-butanone, 2-nonanone, β-ionone, 3-carene and methyl salicylate were the highest, and the types of volatile compounds were the most in the whole fermentation period. At 12 h, the volatile compounds showed a slight decrease, which may be due to the reduced growth of LAB. The total amount of volatile compounds in wheat sourdough increased by 7- to 100-folds after fermentation [54]. Esters and ketones significantly improve the flavor of fermented products [55]. The change in flavor compounds of apricot juice was consistent with the change in the number of viable bacteria (Figure 1), indicating the importance of fermentation.

3.7. Characteristics of Change in Volatile Components by GC-MS

Volatile compounds play an important role in the flavor of fruit juices [26]. We found fermentation significantly altered the amount and types of volatile compounds in fermented apricot juice (Figure S6). Terpenes and alcohols were the major flavor volatile compounds in fermented apricot juice. Linalool was the most abundant at 1716.45 ± 14.01 μg/L. β-pinene, β-myrcene and limonene were detected after 12 h of fermentation. These results are consistent with fermented pomegranate juice; higher terpene content (such as β-myrcene, limonene, etc.) produces pine and citrus odor [56]. The content of α-terpineol in the raw apricot juice (876.46 ± 35.78 μg/L) decreased to 567.54 ± 9.27 μg/L after fermentation. The microbial-produced alcohols are reduced by dehydrogenases to aldehydes or other alcohols [57]. In addition, eight ketones and seven aldehydes were detected after fermentation. Due to low stability, there were fewer aldehydes in fermented apricot juice, which might have been reduced to alcohol or oxidized to acids. Some aldehydes can negatively impact the odor of food products [58]. Glutaraldehyde and β-ionone appeared after 12 h of fermentation and produced a pleasant fruit and rose aroma.

3.8. Screening of Common Aromatic Substances in Fermented Apricot Juice

To understand the characteristic aroma of fermented apricot juice, 22 volatile compounds were selected at different fermentation stages as common aromatic substances (Figure S7). Linalool, α-terpineol and β-myrcene were present in high concentrations in all seven fermentation stages. The odor activity values (OAVs) of volatile compounds were calculated to evaluate their influence on the flavor of fermented apricot juice. The OAV of 12 key volatile compounds (Table 1), including β-pinene, β-myrcene, limonene, α-pinene, 2-amylfuran, decanal, α-ionone, linalool, 2-undecanone, β-ionone, γ-decanolactone and eugenol, was more than 1, indicating their contribution to the flavor of fermented apricot juice. Linalool, β-myrcene and β-ionone are important aromatic compounds and possess relatively high aroma thresholds.

3.9. Correlations between Chemical Characteristics and Aroma Components

The aromatic compounds may interact with each other affecting the final aroma of fermented food [53]. Correlation analyses can reveal the relationships between aromatic compounds and their chemical attributes [51]. The calculated Pearson correlation coefficients are shown in Figure 4 and Figure S8. TA (r = 0.74), lactic acid (r = 0.90), quinic acid (r = 0.95) and citric acid (r = 0.98) positively correlated with bacterial viable count, while lactic acid (r = −0.76), quinic acid (r = −0.85) and citric acid (r = −0.96) negatively correlated with α-ionone. Some aromatic compounds were related to organic acids. Some other positive correlations were α-pinene (r = 0.98), 2-undecanone (r = 0.88) and β-ionone (r = 0.91) with lactic acid, malic acid with limonene (r = 0.97) and β-pinene (r = 0.90), and citric acid with α-pinene (r = 0.74) and eugenol (r = 0.85).

Table 1. OAVs and flavor descriptions of selected main volatile compounds in seven fermentation stages of apricot juice.

Volatile Compounds	RI	Concentrations (μg/L)							Threshold in Water (μg/L)	Flavor Description
		S0	S2	S4	S6	S8	S10	S12		
β-Pinene	1112	17.04 ± 1.11 ^{f}	27.53 ± 0.90 ^{e}	32.81 ± 0.27 ^{e}	51.80 ± 3.38 ^{d}	140.21 ± 2.29 ^{a}	123.25 ± 8.05 ^{b}	110.45 ± 4.51 ^{c}	0.0022	Grassy, Rosin
β-Myrcene	1161	175.52 ± 12.90 ^{a}	120.27 ± 4.91 ^{b}	47.21 ± 0.77 ^{c}	20.53 ± 1.67 ^{d}	10.48 ± 0.34 ^{de}	6.89 ± 0.56 ^{e}	3.53 ± 0.07 ^{e}	0.0012	Malt-like
D-Limonene	1167	34.23 ± 0.84 ^{d}	36.99 ± 0.60 ^{d}	77.25 ± 1.89 ^{c}	82.43 ± 0.67 ^{c}	98.29 ± 4.01 ^{b}	100.80 ± 0.82 ^{b}	110.65 ± 5.42 ^{a}	0.034	Citrus-like
α-Pinene	1028	-	-	-	-	14.14 ± 0.34 ^{c}	23.06 ± 0.38 ^{b}	35.40 ± 2.02 ^{a}	0.0022	Turpentine odor
2-Amylfuran	1231	16.43 ± 0.54 ^{a}	13.77 ± 0.90 ^{b}	17.28 ± 0.85 ^{a}	-	-	-	-	0.0058	Bean, fruit
Decanal	1498	-	-	3.21 ± 0.02 ^{a}	2.51 ± 0.12 ^{b}	-	-	-	0.003	Citrus
α-Ionone	1627	2.65 ± 0.13 ^{b}	2.72 ± 0.13 ^{b}	3.02 ± 0.12 ^{a}	-	-	-	-	0.0026	Violet
Linalool	1547	1716.45 ± 14.01 ^{a}	1332.10 ± 54.38 ^{b}	1234.48 ± 8.89 ^{d}	1088.58 ± 8.57 ^{d}	1050.22 ± 8.91 ^{d}	1091.47 ± 10.08 ^{c}	1262.41 ± 10.30 ^{c}	0.025	Floral, sweet
2-Undecanone	1598	-	24.34 ± 0.60 ^{d}	20.29 ± 1.16 ^{e}	18.73 ± 0.61 ^{e}	31.66 ± 1.29 ^{c}	38.37 ± 0.63 ^{b}	52.43 ± 0.86 ^{a}	0.0055	Peach
β-Ionone	2308	10.74 ± 0.35 ^{a}	8.84 ± 0.29 ^{b}	5.84 ± 0.33 ^{e}	6.93 ± 0.45 ^{cd}	6.98 ± 0.29 ^{cd}	7.55 ± 0.43 ^{c}	6.23 ± 0.16 ^{de}	0.00009	Violets, rose
γ-Decanolactone	2138	14.57 ± 0.47 ^{a}	8.57 ± 0.70 ^{c}	5.10 ± 0.21 ^{e}	6.74 ± 0.44 ^{d}	7.38 ± 0.54 ^{d}	6.95 ± 0.29 ^{d}	12.41 ± 0.60 ^{b}	0.0011	Peach, strawberry
Eugenol	2169	-	2.37 ± 0.04 ^{e}	3.37 ± 0.16 ^{d}	4.90 ± 0.04 ^{c}	7.07 ± 0.40 ^{b}	10.30 ± 0.42 ^{a}	6.94 ± 0.51 ^{b}	0.006	Clove

Data are expressed as the mean ± standard deviation from replicate analyses (n = 3) of three replicate samples. The different lowercase letters in each row indicate significant differences between samples ($p < 0.05$). The symbol "-" means not found.

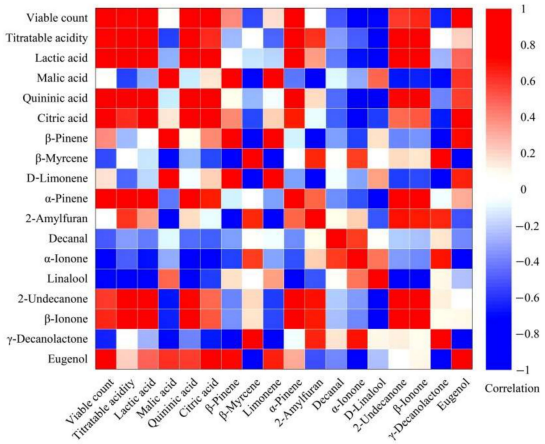

Figure 4. Heat map of Pearson correlation coefficient for variables. The correlations among fermentation time, viable count in juice, total acid and organic acid contents, and aroma-active compounds are shown. The larger the positive number, the stronger the positive correlation, and the opposite for negative correlation.

Some alcohols and esters are produced from acids. For example, the formation of ethyl lactate and ethyl acetate is related to the content of lactic and acetic acids [59]. Likewise, linalool is synthesized through a series of reactions during fermentation [60]. The correlation analysis showed that the aromatic odors were affected by the substrate and other odors in a complex manner [61]. The fermentation process can be improved, such as mixed fermentation, with a clear understanding of flavors [54], which demands more in-depth studies.

3.10. Sensory Evaluation

The sensory evaluation of fermented apricot juice was conducted based on indicators such as color, taste, aroma, posture, flavor and overall acceptability (Figure 5). The taste score of 10 h fermented apricot juice was the highest. By this fermentation stage, malic acid was consumed and lactic acid was generated, improving the taste of the fermented apricot juice. During the fermentation process, the color of apricot juice changed from the initial bright yellow to a yellowish brown. In addition, the sensory evaluator group found significant differences in their perception of the aroma and flavor of apricot juice at different fermentation stages ($p < 0.05$), highlighting the change in volatile compounds in respective samples. The overall evaluation showed that the LAB fermentation significantly improved the acceptability of fermented apricot juice over the unfermented one.

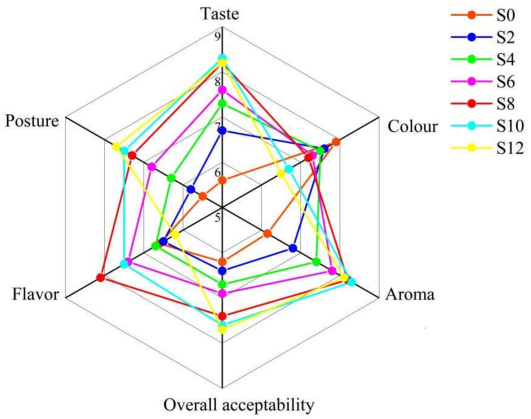

Figure 5. Sensory evaluation of apricot juice in seven fermentation stages. S0, S2, S4, S6, S8, S10 and S12 represent apricot juice samples in seven fermentation periods. The fermentation time is 0 h, 2 h, 4 h, 6 h, 8 h, 10 h and 12 h, respectively.

4. Conclusions

The results showed that the nutritional quality and flavor characteristics of apricot juice can be improved by *L. plantarum* LP56 fermentation. The post-fermentation increase in lactic acid improved the taste of fermented apricot juice. In addition, the contents of phenolic compounds and FRAP increased, improving nutritional quality. The dynamic changes in volatile substances during fermentation positively affected the aroma of fermented apricot juice increasing consumer acceptability.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/fermentation8100533/s1, Figure S1. A: Composition of organic acids in apricot juice at different fermentation stages. B: Content of organic acids in apricot juice at different fermentation stages. Different lowercase letters indicate significant differences between samples at different fermentation stages ($P < 0.05$; Figure S2. A: Composition of phenolic compounds in apricot juice at different fermentation stages. B: Content of phenolic compounds in apricot juice at different fermentation stages. Different lowercase letters indicate significant differences between samples at different fermentation stages ($P < 0.05$); Figure S3. In vitro antioxidant activity in fermented apricot juice. Different lowercase letters indicate significant differences between samples at different fermentation stages ($P < 0.05$); Figure S4. Composition and classification of volatile compounds in apricot juice at different fermentation stages; Figure S5. Load diagram of volatile compounds formation in seven fermentation periods of apricot juice; Figure S6. Aroma-active substances and their flavor attributes detected by GC-MS in juice before and after fermentation. S0 represents raw juices (0 h), S12 represents fermented juices (12 h); Figure S7. Overlay of the main chromatograms of the apricot juice in seven fermentation periods. S0 represents fermentation 0 h, S2 represents fermentation 2 h, S4 represents fermentation 4 h, S6 represents fermentation 6 h, S8 represents fermentation 8 h, S10 represents fermentation 10 h, S12 represents fermentation 12 h; Figure S8. Heat map of Pearson correlation coefficient for variables. The correlations among fermentation time, viable count in juice, total acid and the organic acid contents, and aroma-active compounds are shown. The larger the positive number, the stronger the positive correlation, and the opposite for negative correlation; Table S1 Physicochemical properties in fermented apricot juice; Table S2 Content of the aroma components in the apricot juice samples.

Author Contributions: Conceptualization, W.C., and B.W.; methodology, J.S.; software, J.S., and C.Z.; validation, X.P., and T.L.; formal analysis, J.S.; investigation, X.P.; resources, X.S.; data curation, C.Z.; writing—original draft preparation, J.S.; writing—review and editing, C.Z., and T.L.; visualization, X.P.; supervision, C.Z.; project administration, B.W., and W.C.; funding acquisition, B.W., and W.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Projects of Innovation and Development Pillar Program for Key Industries in Southern Xinjiang of Xinjiang Production and Construction Corps (2022DB007) and the Science and Technology Research Project of the Xinjiang Production and Construction Corps (2020AB014).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article or supplementary material.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Su, C.; Zheng, X.; Zhang, D.; Chen, Y.; Xiao, J.; He, Y.; He, J.; Wang, B.; Shi, X. Investigation of sugars, organic acids, phenolic compounds, antioxidant activity and the aroma fingerprint of small white apricots grown in Xinjiang. *J. Food Sci.* **2020**, *85*, 4300–4311. [CrossRef]
2. Greger, V.; Schieberle, P. Characterization of the key aroma compounds in apricots (*Prunus armeniaca*) by application of the molecular sensory science concept. *J. Agric. Food Chem.* **2007**, *55*, 5221–5228. [CrossRef]
3. Adachi, M.; Suzuki, Y.; Mizuta, T.; Osawa, T.; Adachi, T.; Osaka, K.; Suzuki, K.; Shijima, K.; Arai, Y.; Masuda, K. The "Prunus mume Sieb. et Zucc"(Ume) is a rich natural source of novel anti-cancer substance. *Int. J. Food Prop.* **2007**, *10*, 375–384. [CrossRef]
4. Wu, B.; Guo, Q.; Wang, G.; Peng, X.; Wang, J.; Che, F. Effects of different postharvest treatments on the physiology and quality of 'Xiaobai' apricots at room temperature. *J. Food Sci. Technol.* **2015**, *52*, 2247–2255. [CrossRef] [PubMed]

5. Vega-Gálvez, A.; Quispe-Fuentes, I.; Uribe, E.; Martinez-Monzo, J.; Pasten, A.; Lemus-Mondaca, R. Bioactive compounds and physicochemical characterization of dried apricot (*Prunus armeniaca* L.) as affected by different drying temperatures. *CyTA-J. Food* **2019**, *17*, 297–306. [CrossRef]
6. Liu, H.; Chen, F.; Yang, H.; Yao, Y.; Gong, X.; Xin, Y.; Ding, C. Effect of calcium treatment on nanostructure of chelate-soluble pectin and physicochemical and textural properties of apricot fruits. *Food Res. Int.* **2009**, *42*, 1131–1140. [CrossRef]
7. Ishaq, S.; Rathore, H.A.; Majeed, S.; Awan, S.; Shah, S.Z.A. The Studies on the Physico-Chemical and Organoleptic Characteristics of Apricot (*Prunus armeniaca* L.) Produced in Rawalakot, Azad Jammu and Kashmir During Storage. *Pak. J. Nutr.* **2009**, *8*, 856–860. [CrossRef]
8. Di Cagno, R.; Filannino, P.; Vincentini, O.; Cantatire, V.; Cavoski, I.; Gobbetti, M. Fermented *Portulaca oleracea* L. juice: A novel functional beverage with potential ameliorating effects on the intestinal inflammation and epithelial injury. *Nutrients* **2019**, *11*, 248. [CrossRef] [PubMed]
9. Wu, C.; Li, T.; Qi, J.; Jiang, T.; Xu, H.; Lei, H. Effects of lactic acid fermentation-based biotransformation on phenolic profiles, antioxidant capacity and flavor volatiles of apple juice. *LWT* **2020**, *122*, 109064. [CrossRef]
10. Filannino, P.; Di Cagno, R.; Gobbetti, M. Metabolic and functional paths of lactic acid bacteria in plant foods: Get out of the labyrinth. *Curr. Opin. Biotechnol.* **2018**, *49*, 64–72. [CrossRef]
11. Dimitrovski, D.; Velickova, E.; Langerholc, T.; Winkelhausen, E. Apple juice as a medium for fermentation by the probiotic *Lactobacillus plantarum* PCS 26 strain. *Ann. Microbiol.* **2015**, *65*, 2161–2170. [CrossRef]
12. Di Cagno, R.; Coda, R.; De Angelis, M.; Gobbetti, M. Exploitation of vegetables and fruits through lactic acid fermentation. *Food Microbiol.* **2013**, *33*, 1–10. [CrossRef] [PubMed]
13. Gupta, S.; Cox, S.; Abu-Ghannam, N. Process optimization for the development of a functional beverage based on lactic acid fermentation of oats. *Biochem. Eng. J.* **2010**, *52*, 199–204. [CrossRef]
14. Mousavi, Z.E.; Mousavi, S.M.; Razavi, S.H.; Hadinejad, M.; Emam-Djomeh, Z.; Mirzapour, M. Effect of Fermentation of Pomegranate Juice by *Lactobacillus plantarum* and *Lactobacillus acidophilus* on the Antioxidant Activity and Metabolism of Sugars, Organic acids and Phenolic Compounds. *Food Biotechnol.* **2013**, *27*, 1–13. [CrossRef]
15. Liu, W.; Pu, X.; Sun, J.; Shi, X.; Cheng, W.; Wang, B. Effect of *Lactobacillus plantarum* on functional characteristics and flavor profile of fermented walnut milk. *LWT* **2022**, *160*, 113254. [CrossRef]
16. Balestra, G.; Misaghi, I. Increasing the efficiency of the plate counting method for estimating bacterial diversity. *J. Microbiol. Methods* **1997**, *30*, 111–117. [CrossRef]
17. Zheng, H.; Zhang, Q.; Quan, J.; Zheng, Q.; Xi, W. Determination of sugars, organic acids, aroma components, and carotenoids in grapefruit pulps. *Food Chem.* **2016**, *205*, 112–121. [CrossRef] [PubMed]
18. Chen, C.; Lu, Y.; Yu, H.; Chen, Z.; Tian, H. Influence of 4 lactic acid bacteria on the flavor profile of fermented apple juice. *Food Biosci.* **2019**, *27*, 30–36. [CrossRef]
19. Wu, Y.; Li, S.; Tao, Y.; Li, D.; Han, Y.; Loke-Show, P.; Wen, G.; Zhou, J. Fermentation of blueberry and blackberry juices using *Lactobacillus plantarum*, Streptococcus thermophilus and Bifidobacterium bifidum: Growth of probiotics, metabolism of phenolics, antioxidant capacity in vitro and sensory evaluation. *Food Chem.* **2021**, *348*, 129083. [CrossRef] [PubMed]
20. Csepregi, K.; Kocsis, M.; Hideg, É. On the spectrophotometric determination of total phenolic and flavonoid contents. *Acta Biol. Hung.* **2013**, *64*, 500–509. [CrossRef]
21. Granato, D.; Shahidi, F.; Wrolstad, R.; Kilmartin, P.; Melton, L.D.; Hidalgo, F.J.; Miyashita, K.; Van Camp, J.; Alasalvar, C.; Ismail, A.B. Antioxidant activity, total phenolics and flavonoids contents: Should we ban in vitro screening methods? *Food Chem.* **2018**, *264*, 471–475. [CrossRef]
22. Wang, L.; Wu, J.; Wang, H.; Li, S.; Zheng, X.; Du, H.; Xu, Y.; Wang, L. Composition of phenolic compounds and antioxidant activity in the leaves of blueberry cultivars. *J. Funct. Foods* **2015**, *16*, 295–304. [CrossRef]
23. Sethi, S.; Joshi, A.; Arora, B.; Bhowmik, A.; Sharma, R.; Kumar, P. Significance of FRAP, DPPH, and CUPRAC assays for antioxidant activity determination in apple fruit extracts. *Eur. Food Res. Technol.* **2020**, *246*, 591–598. [CrossRef]
24. Gao, Q.; Wu, C.; Wang, M.; Xu, B.; Du, L. Effect of drying of jujubes (*Ziziphus jujuba* Mill.) on the contents of sugars, organic acids, α-tocopherol, β-carotene, and phenolic compounds. *J. Agric. Food Chem.* **2012**, *60*, 9642–9648. [CrossRef]
25. Gokbulut, I.; Karabulut, I. SPME–GC–MS detection of volatile compounds in apricot varieties. *Food Chem.* **2012**, *132*, 1098–1102. [CrossRef]
26. Gong, Y.; Kerrihard, A.L.; Pegg, R.B. Characterization of the volatile compounds in raw and roasted Georgia pecans by HS-SPME-GC-MS. *J. Food Sci.* **2018**, *83*, 2753–2760. [CrossRef]
27. Kaprasob, R.; Kerdchoechuen, O.; Laohakunjit, N.; Sarkar, D.; Shetty, K. Fermentation-based biotransformation of bioactive phenolics and volatile compounds from cashew apple juice by select lactic acid bacteria. *Process Biochem.* **2017**, *59*, 141–149. [CrossRef]
28. Tkacz, K.; Chmielewska, J.; Turkiewicz, I.P.; Nowicka, P.; Wojdyło, A. Dynamics of changes in organic acids, sugars and phenolic compounds and antioxidant activity of sea buckthorn and sea buckthorn-apple juices during malolactic fermentation. *Food Chem.* **2020**, *332*, 127382. [CrossRef] [PubMed]
29. Wu, Z.; Tu, M.; Yang, X.; Xu, J.; Yu, Z. Effect of cutting and storage temperature on sucrose and organic acids metabolism in postharvest melon fruit. *Postharvest Biol. Technol.* **2020**, *161*, 111081. [CrossRef]

30. Fu, L.; Yang, J.; Shang, H.; Song, J. Changes of characteristic sugar, fatty acid, organic acid and amino acid in jujubes at different dry mature stages. *J. Food Compos. Anal.* **2021**, *104*, 104104. [CrossRef]
31. Tofalo, R.; Schirone, M.; Fasoli, G.; Perpetuini, G.; Patrignani, F.; Manetta, A.C.; Lanciotti, R.; Corsetti, A.; Martino, G.; Suzzi, G. Influence of pig rennet on proteolysis, organic acids content and microbiota of Pecorino di Farindola, a traditional Italian ewe's raw milk cheese. *Food Chem.* **2015**, *175*, 121–127. [CrossRef]
32. Freire, A.L.; Ramos, C.L.; Schwan, R.F. Effect of symbiotic interaction between a fructooligosaccharide and probiotic on the kinetic fermentation and chemical profile of maize blended rice beverages. *Food Res. Int.* **2017**, *100*, 698–707. [CrossRef] [PubMed]
33. Ye, M.; Yue, T.; Yuan, Y. Evolution of polyphenols and organic acids during the fermentation of apple cider. *J. Sci. Food Agric.* **2014**, *94*, 2951–2957. [CrossRef]
34. Zheng, B.; Zhao, L.; Jiang, X.; Cherono, S.; Liu, J.; Ogutu, C.; Ntini, C.; Zhang, X.; Han, Y. Assessment of organic acid accumulation and its related genes in peach. *Food Chem.* **2021**, *334*, 127567. [CrossRef]
35. Chen, R.; Chen, W.; Chen, H.; Zhang, G.; Chen, W. Comparative evaluation of the antioxidant capacities, organic acids, and volatiles of papaya juices fermented by *Lactobacillus acidophilus* and *Lactobacillus plantarum*. *J. Food Qual.* **2018**, *2018*, 9490435. [CrossRef]
36. Zhang, H.; Zhou, F.; Ji, B.; Nout, R.M.; Fang, Q.; Yang, Z. Determination of organic acids evolution during apple cider fermentation using an improved HPLC analysis method. *Eur. Food Res. Technol.* **2008**, *227*, 1183–1190. [CrossRef]
37. Barboni, T.; Cannac, M.; Chiaramonti, N. Effect of cold storage and ozone treatment on physicochemical parameters, soluble sugars and organic acids in Actinidia deliciosa. *Food Chem.* **2010**, *121*, 946–951. [CrossRef]
38. Kwaw, E.; Ma, Y.; Tchabo, W.; Apaliya, M.T.; Wu, M.; Sackey, A.S.; Xiao, L.; Tahir, H.E. Effect of lactobacillus strains on phenolic profile, color attributes and antioxidant activities of lactic-acid-fermented mulberry juice. *Food Chem.* **2018**, *250*, 148–154. [CrossRef]
39. Wei, M.; Wang, S.; Gu, P.; Ouyang, X.; Liu, S.; Li, Y.; Zhang, B.; Zhu, B. Comparison of physicochemical indexes, amino acids, phenolic compounds and volatile compounds in bog bilberry juice fermented by *Lactobacillus plantarum* under different pH conditions. *J. Food Sci. Technol.* **2018**, *55*, 2240–2250. [CrossRef]
40. Filannino, P.; Cavoski, I.; Thligene, N.; Vincentini, O.; De Angelis, M.; Silano, M.; Gobbetti, M.; Di Cagno, R. Correction: Lactic acid fermentation of Cactus Cladodes (*Opuntia ficus-indica* L.) generates flavonoid derivatives with antioxidant and anti-inflammatory properties. *PLoS ONE* **2016**, *11*, e0155156. [CrossRef]
41. Mokrani, A.; Krisa, S.; Cluzet, S.; Da Costa, G.; Temsamani, H.; Renouf, E.; Mérillon, J.; Madani, K.; Mesnil, M.; Monvoisin, A.; et al. Phenolic contents and bioactive potential of peach fruit extracts. *Food Chem.* **2016**, *202*, 212–220. [CrossRef]
42. Fan, X.; Jiao, W.; Wang, X.; Cao, J.; Jiang, W. Polyphenol composition and antioxidant capacity in pulp and peel of apricot fruits of various varieties and maturity stages at harvest. *Int. J. Food Sci. Technol.* **2018**, *53*, 327–336. [CrossRef]
43. Bakar, M.F.A.; Mohamed, M.; Rahmat, A.; Fry, J. Phytochemicals and antioxidant activity of different parts of bambangan (*Mangifera pajang*) and tarap (*Artocarpus odoratissimus*). *Food Chem.* **2009**, *113*, 479–483. [CrossRef]
44. Pedersen, C.; Kyle, J.; Jenkinson, A.; Gardner, P.; McPhail, D.; Duthie, G. Effects of blueberry and cranberry juice consumption on the plasma antioxidant capacity of healthy female volunteers. *Eur. J. Clin. Nutr.* **2000**, *54*, 405–408. [CrossRef]
45. Nazzaro, F.; Fratianni, F.; Sada, A.; Orlando, P. Synbiotic potential of carrot juice supplemented with *Lactobacillus* spp. and inulin or fructooligosaccharides. *J. Sci. Food Agric.* **2008**, *88*, 2271–2276. [CrossRef]
46. Zhou, Y.; Wang, R.; Zhang, Y.; Yang, Y.; Sun, X.; Zhang, Q.; Yang, N. Biotransformation of phenolics and metabolites and the change in antioxidant activity in kiwifruit induced by *Lactobacillus plantarum* fermentation. *J. Sci. Food Agric.* **2020**, *100*, 3283–3290. [CrossRef]
47. Hur, S.J.; Lee, S.Y.; Kim, Y.-C.; Choi, I.; Kim, G.-B. Effect of fermentation on the antioxidant activity in plant-based foods. *Food Chem.* **2014**, *160*, 346–356. [CrossRef]
48. Kachouri, F.; Ksontini, H.; Kraiem, M.; Setti, K.; Mechmeche, M.; Hamdi, M. Involvement of antioxidant activity of *Lactobacillus plantarum* on functional properties of olive phenolic compounds. *J. Food Sci. Technol.* **2015**, *52*, 7924–7933. [CrossRef]
49. Li, T.; Jiang, T.; Liu, N.; Wu, C.; Xu, H.; Lei, H. Biotransformation of phenolic profiles and improvement of antioxidant capacities in jujube juice by select lactic acid bacteria. *Food Chem.* **2021**, *339*, 127859. [CrossRef]
50. Bai, L.; Ruxianguli, M.; Liang, W. Effects of four individual lactic acid bacteria on the physical and chemical and antioxidant properties of Kuqa apple juice during fermentation. *J. Food Process. Preserv.* **2021**, *45*, e15385. [CrossRef]
51. Pellegrini, N.; Vitaglione, P.; Granato, D.; Fogliano, V. Twenty-five years of total antioxidant capacity measurement of foods and biological fluids: Merits and limitations. *J. Sci. Food Agric.* **2020**, *100*, 5064–5078. [CrossRef]
52. Qi, J.; Huang, H.; Wang, J.; Liu, N.; Chen, X.; Jiang, T.; Xu, H.; Lei, H. Insights into the improvement of bioactive phytochemicals, antioxidant activities and flavor profiles in Chinese wolfberry juice by select lactic acid bacteria. *Food Biosci.* **2021**, *43*, 101264. [CrossRef]
53. Xu, X.; Bao, Y.; Wu, B.; Lao, F.; Hu, X.; Wu, J. Chemical analysis and flavor properties of blended orange, carrot, apple and Chinese jujube juice fermented by selenium-enriched probiotics. *Food Chem.* **2019**, *289*, 250–258. [CrossRef]
54. Kati, K.; Kaisa, P.; Karin, A. Influence and Interactions of Processing Conditions and Starter Culture on Formation of Acids, Volatile Compounds, and Amino Acids in Wheat Sourdoughs. *Cereal Chem.* **2004**, *81*, 598–610. [CrossRef]
55. Cheng, L.; Luo, J.; Li, P.; Yu, H.; Huang, J.; Luo, L. Microbial diversity and flavor formation in onion fermentation. *Food Funct.* **2014**, *5*, 2338–2347. [CrossRef]

56. Di Cagno, R.; Filannino, P.; Gobbetti, M. Lactic acid fermentation drives the optimal volatile flavor-aroma profile of pomegranate juice. *Int. J. Food Microbiol.* **2017**, *248*, 56–62. [CrossRef] [PubMed]
57. Garcia-Alcega, S.; Nasir, Z.A.; Ferguson, R.; Whitby, C.; Dumbrell, A.J.; Colbeck, I.; Gomes, D.; Tyrrel, S.; Coulon, F. Fingerprinting outdoor air environment using microbial volatile organic compounds (MVOCs)–A review. *TrAC Trends Anal. Chem.* **2017**, *86*, 75–83. [CrossRef]
58. Melgarejo, P.; Calín-Sánchez, Á.; Vázquez-Araújo, L.; Hernández, F.; Martínez, J.J.; Legua, P.; Carbonell-Barrachina, Á.A. Volatile Composition of Pomegranates from 9 Spanish Cultivars Using Headspace Solid Phase Microextraction. *J. Food Sci.* **2011**, *76*, S114–S120. [CrossRef]
59. Dongmo, S.N.; Procopio, S.; Sacher, B.; Becker, T. Flavor of lactic acid fermented malt based beverages: Current status and perspectives. *Trends Food Sci. Technol.* **2016**, *54*, 37–51. [CrossRef]
60. Michlmayr, H.; Nauer, S.; Brandes, W.; Schümann, C.; Kulbe, K.D.; Andrés, M.; Eder, R. Release of wine monoterpenes from natural precursors by glycosidases from Oenococcus oeni. *Food Chem.* **2012**, *135*, 80–87. [CrossRef]
61. Liang, H.Y.; Chen, J.Y.; Reeves, M.; Han, B.Z. Aromatic and sensorial profiles of young Cabernet Sauvignon wines fermented by different Chinese autochthonous Saccharomyces cerevisiae strains. *Food Res. Int.* **2013**, *51*, 855–865. [CrossRef]