Hindawi
Journal of Food Processing and Preservation
Volume 2023, Article ID 1925913, 11 pages
https://doi.org/10.1155/2023/1925913

Research Article

The Application of Raw Chickpeas and Nuts in the Development of Plant-Based Cheese Snack: Ideal Nutrition and Texture Properties

Ying Nie,[1,2] **Yaqun Liu**,[1,2] **Qiulan Luo**,[1,2] **Yisheng Huang**,[1,2] **Lei Hu**,[1,2] **Xianghui Zou**,[1,2] **Yuzhong Zheng**,[1,2] **Biansheng Li**,[3] **and Yongping Huang**[1,2,3]

[1]*School of Food Engineering and Biotechnology, Hanshan Normal University, Chaozhou 521041, China*
[2]*Guangdong Provincial Key Laboratory of Functional Substances in Medicinal Edible Resources and Healthcare Products, Chaozhou 521041, China*
[3]*College of Food Science and Engineering, South China University of Technology, Guangzhou 510640, China*

Correspondence should be addressed to Ying Nie; 529279619@qq.com and Yongping Huang; 20190001@hstc.edu.cn

Received 13 May 2023; Revised 5 July 2023; Accepted 22 August 2023; Published 8 September 2023

Academic Editor: Néstor Gutiérrez-Méndez

Human and global health would be greatly improved by replacing animal-based foods with plant-based alternatives. This transition would be facilitated when more affordable, convenient, sustainable, nutritious, and tasty plant-based foods are available on the market. Interest in related research has surged these years, and dozens of plant-based cheese (PBC) products have been introduced to the market. However, studies found that most PBCs are far from comparable with dairy cheese in nutritional value, and the texture and sensory properties are still hurdles to the widespread consumption of PBCs. This paper focused on the "tissue disruption route" and adopted chickpeas and nuts as the main ingredients to form a cheese snack. Test results showed that our samples were high of nourishment value compared to the cheese sample and even healthier than the cheese in the terms of energy (709.37 ± 1.35 vs. 865.63 ± 0.49 kJ/100 g, $p < 0.01$), K/Na ratio ($142.00 \pm 0.82/13.33 \pm 0.12$ mg/100 g vs. $121.67 \pm 2.05/44.23 \pm 0.05$ mg/100 g, $p < 0.01$), DF (6.99 ± 0.01 g/100 g vs. N/A, $p < 0.01$), and cholesterol (8.81 ± 0.25 vs. 207.30 ± 3.35 mg/100 g, $p < 0.01$). From the order of magnitude, the PBC samples are similar to the cheese sample in the aspects of cohesiveness ($p < 0.05$) in texture test, and the fermentation process improved the imitation of texture properties in terms of hardness and cohesiveness (both $p < 0.05$). The volatile compounds were similar between the two PBC samples; however, the fermentation process could increase the species of the volatile compounds and make the PBC a little more similar to the dairy cheese. Overall, the observed properties of our PBC snack using raw chickpeas and nuts make the "plant-based cheese substitutes" extremely promising because of their nutritional value, sensory, and texture properties.

1. Introduction

Plant-based cheese (PBC), also known as cheese analogue (CA), can be described as a cheese-mimicking product originated from vegetable substances rather than milk sources, as well as food additives such as emulsifying salts, hydrocolloids, preservatives, acidifying agents, and sometimes cheese flavouring agents [1]. The first PBC was produced and consumed in China as fermented tofu, which could be traced back to the 17th century and was called "Furu" following the meaning of "spoiled milk." Modern industrialized PBC products were called "fake cheese" and accused of deceiving customers. However, this attitude has changed drastically over the past few years with increasingly more consumers seeking out and purchasing plant-based foods. Plant-based dairy alternatives are expanding to a tremendous degree and are expected to reach a global market size of more than 52 billion USD by 2028 [2]. The reasons for this change are numerous but include considerations of food intolerance, environmental sustainability, health, and animal welfare, as well as social trends. Moreover, the PBC products available on the market are continuing to increase, which also

accounts for the increasing acceptance and adoption of these products [3].

PBCs are designed to be similar to dairy cheese in nutrition, appearance, texture, mouthfeel, and flavour [4]. Following this concept, the design principle of PBC is to aim for the physicochemical and sensory properties of a specific cheese product, such as cheddar, mozzarella, or other processed cheese, which should be achieved by using different combinations of raw materials and processing techniques depending on the properties needed. However, many experiments have found that these mimic designs have difficulties in practice because there is no casein in the plant materials. Plant proteins have larger molecular sizes and more complex quaternary structures than casein, which plays a vital role in the formation of cheese due to its ability to form compact gel networks.

Another consideration of PBC is its nutritional value. Evidence showed that a higher intake of plant-based foods is associated with a lower risk for type 2 diabetes, and this is mainly because of the nonprotein components such as fibers and phytochemicals in the plant [5]. Therefore, it is easy to believe that plant source foods are healthier. An article comparing the micro- and macronutrients between plant-based foods and their counterparts found that the contents of salt, iron, and vitamins E and K were of higher value in plant-based foods, while their protein contents were generally lower [6]. Another study investigated all the nutritional properties of PBC products sold in the Spanish market and suggested that 85% of them are based on coconut oil and cannot be considered healthy foods because of their high content of saturated fats and salt [7]. In other words, it is naive to simply consider PBC a healthy food without in-depth research on the combination of raw materials and processing methods.

Although there have been several studies on the development of plant-based cheese analogues mainly from soybean, pea, and coconut, to the best of our knowledge, data is still lacking regarding the use of chickpea (*Cicer arietinum*) and nuts to produce PBC [8–10]. Among all the dry legumes, the content of proteins and Ca in chickpea is relatively high (its protein content could reach 46.5 g/100 g) [11], and it also has a good heat stability and a minimum beany flavour; hence, the objective of this study was to evaluate the suitability of raw chickpea and nuts inspired by the processing of "tofu" to develop a PBC snack compared to a commercialized product. Under the common consideration of nutrition and health as well as the concept of green, sustainable development, and environmental protection, only if we choose the right path in the research and development of plant-based cheese will the products simulate a variety of cheese counterparts and the future market for plant-based cheese will be booming.

2. Materials and Methods

2.1. Materials

2.1.1. Preparation of Chickpea Tofu. Fifty grams of chickpeas was soaked overnight and then mixed with water (1 : 7 *w*/*w*) in a high-speed blender to grind into soymilk. The milk was further boiled, and the foam on the surface was removed. When the liquid cooled to 80°C, 2 g of gluconolactone was added to the mixture to form the solid condensate. After 1 h of storage in a 4°C refrigerator, the excess water was then removed, and the chickpea tofu was ready for the next step.

2.1.2. Preparation of Macadamia Nut/Water Mix and Cashew Nut/Water Mix. Macadamia nuts and cashew nuts were soaked for 0.5 hours and then mixed with water (1 : 2 *w*/*w* and 1 : 3 *w*/*w*, respectively) in a high-speed blender. Filtration was then performed using an 80-mesh sieve.

2.1.3. Preparation of the PBC Sample. Prepared chickpea tofu, macadamia nut/water mix, and cashew nut/water mix were mixed with sunflower seed oil, sugar, zein, monoglyceride stearin, tricalcium phosphate, calcium lactate, and potassium sorbate according to the portion in Table 1 in a high-speed mixer (12000 rpm, 85°C) for 3 min. Following by adding xanthan gum : locust bean gum : carrageenan = 1 : 1 : 1 several separate times, the high-speed mixer (12000 rpm, 85°C) was turned on again for 4 min. When the mixture cooled to 50°C, approximately 16 drops of thick frankincense were added to the mixture (600 g). The last step was to transfer the mixture into a container and leave it to set until it clots.

2.1.4. Preparation of the Fermented PBC Sample. Before the mixing of the 3 kinds of gums, the unfinished PBC mixture was first mixed with 2% more sugar to accelerate the reproduction of the added 0.05% (*w*/*w*) plant *Lactobacillus plantarum* (Lp-G18, Biogrowing Co. Ltd., Shanghai, China). The fermentation temperature was set to 38°C, and the whole process lasted for 3 hours. The fermented mixture was pasteurized in an 85°C hot water bath for 30 min and then blended with a mixture of xanthan gum : locust bean gum : carrageenan = 1 : 1 : 1 as well as thick frankincense in equal amounts with the last unfermented sample.

2.2. Method of Characterization

2.2.1. Nutrition Test. The protein content was determined using an automatic protein analyzer (Flash EA 1112, Thermo Scientific, USA) following GB 5009.5-2016, and the result shown on the device multiplied by 6.25 was the protein content. The fat content was determined after extraction with petroleum ether in a complex system (Soxtec AVANTI, Sweden) according to GB5009.6-2016. The total dietary fiber (TDF) content was analyzed according to GB5009.88-2014 using a cellulose automatic tester (FIWE ADVANCE, VELP, Italy). The carbohydrate content was calculated as the difference between 100 and the sum of moisture, ash, protein, fat, and total dietary fiber content. The phosphorus content was determined by the molybdenum blue spectrophotometric method following the instructions of GB5009.87-2016 (UV1900i, Shimadzu, Japan), and the calcium content was tested using atomic absorption spectroscopy (280FS AA, Agilent, USA) following the instructions of GB5009.92-2016. The cholesterol content

Table 1: The recipe for the preparation of PBC.

Ingredient	Brands/sources	Amount (% in mass) in unfermented PBC
Chickpea tofu	October Fields/Xinjiang, China	30.00
Macadamia nut/water mix	Three Squirrels/Yunnan, China	26.00
Cashew nut/water mix	Three Squirrels/Xinjiang, China	30.00
Sunflower seed oil	Duoli/Xinjiang, China	2.00
Sugar	Sugarman/Guangdong, China	4.00
Zein	Hubei Yuancheng Technology, China	6.00
Monoglyceride stearin	Guangzhou Jialong Chemistry, China	0.20
Xanthan gum : locust bean gum : carrageenan = 1 : 1 : 1	Shanghai Peng Jia-er New Materials, China	1.00
Tricalcium phosphate	Jiangsu Ke Lun-duo Food Additives, China	0.08
Calcium lactate	Jiangsu Ke Lun-duo Food Additives, China	0.03
Potassium sorbate	Jiangsu Ke Lun-duo Food Additives, China	0.07
Thick frankincense	Huabao/Shanghai, China	0.62

was tested using a spectrophotometer (UV1900i, Shimadzu, Japan) following the instructions of GB5009.128-2016.

2.2.2. Texture Properties. A texture analyzer (TA. XTC, Bosin Tech., China) was used to perform texture profile analysis (TPA) on the different samples following the method used in the study of Mattice and Marangoni [12]. Samples were prepared by cutting 15 mm diameter cylindrical sections from the gels. The AC temperature was set to 25°C, and all the samples reached this temperature equilibrium prior to analysis and were further analyzed on a modified platform. The hardness was reported as the peak maximum force upon first compression. Cohesiveness was calculated as the area under the 2nd compression peak divided by the area under the 1st compression peak. Gumminess was calculated as hardness times cohesiveness. The adhesiveness was equal to the negative area from the first compression. Springiness was calculated as the time to reach peak during the 2nd compression divided by the time to reach peak during the 1st compression, and chewiness was equal to gumminess times springiness.

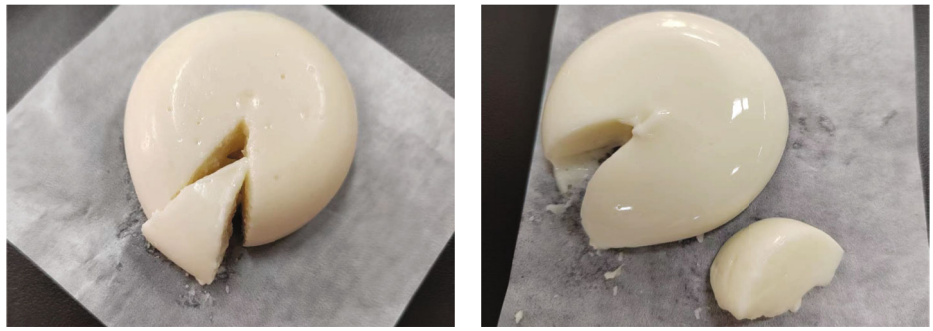
2.2.3. Volatile Compound Detection. The cheese sample was weighed (5 g) and finely dispersed in 50 mL of ultrapure water. Homogenization was performed using a bench dispersing machine (DR500 Std, DISRAD, USA) for 1 min. Two milliliters of the mixture was then filled into a vial and conditioned at 37°C for 30 min in a thermostatic bath to establish volatile equilibrium between the mixture sample and the headspace. Volatile compounds (VOCs) were extracted from the headspace using the solid-phase microextraction (SPME) method. For fiber exposition, 30 min was required to establish the volatile compound equilibrium between the headspace and fiber solid phase. The fiber was preconditioned before initial use by inserting it into the injector port of a GC-MS instrument for 1 h at 225°C. The fiber was reconditioned at the same temperature for 5 min before each analysis. For the identification of the VOCs, a GC–MS system (Agilent 7890A Series and Agilent 5975C Mass Selective Detector, USA) was utilized. An HP-5 capillary column (30 m × 0.25 mm ID × 0.25 μm film thickness, Agilent Technologies, USA) was set in the GC machine. The chromatographic operating conditions were as follows: splitless injector at 220°C and oven at 150°C for 30 min. Helium pressure (carrier gas) was fixed at 13.6 psi, and the gas flow was 1.0 mL·min^{-1}. The mass selective detector was operated in scan mode, 5.15 scan·s^{-1}, with 70 eV IE. The identification of the obtained peaks was carried out by comparison of the mass spectra with the bibliographic data from the Wiley 175 library (Wiley & Sons, Inc., Germany).

2.2.4. Statistical Analysis. The results of the previously mentioned tests obtained from each sample were expressed as the mean ($n = 3$, triplicate analysis from two independent trials) ± standard deviation (SD). The data on the proximate composition were presented on a wet basis (wb). One-way ANOVA and Tukey's post hoc test were used to determine significant differences between samples in each trial and differences between PBCs and the references. The significance level was set at <0.05. Statistical analyses were performed using SPSS (version 26.0).

3. Results and Discussion

3.1. Nutritional Value of PBC and Fermented PBC Samples. Plant-based cheese and fermented plant-based cheese were prepared following the method introduced in Section 2. Both of them were off-white colors with no significant difference when compared to the cheese sticks sold on the market. The PBC sample was polyporous inside due to the process of high-speed mixing, while the fermented PBC sample was more fine, smooth, and tender at first sight (see Figure 1).

Both samples together with a dairy cheese snack sample called "a cup of cheese" (produced by MILKANA, France) were all sent for a nutrition test, including the content of protein, fat, carbohydrates, phosphorus, calcium, potassium, sodium, dietary fiber, and cholesterol as well as the total energy. The results showed that both PBC and fermented PBC samples had high nourishment values compared to



(a) (b)

Figure 1: Appearance of PBC cheese sample (a) and fermented PBC sample (b).

Table 2: The results of the nutrition test.

Item	Cheese sample	PBC sample	Fermented PBC sample
Energy (kJ/100 g)	865.63 ± 0.49	709.37 ± 1.35	799.00 ± 2.45
Protein (g/100 g)	5.99 ± 0.03	3.30 ± 0.02	3.09 ± 0.02
Fat (g/100 g)	13.17 ± 0.05	11.33 ± 0.05	10.50 ± 0.33
Carbohydrates (g/100 g)	16.33 ± 0.12	10.40 ± 0.29	11.37 ± 0.21
Dietary fiber (g/100 g)	N/A	6.99 ± 0.01	6.47 ± 0.01
Cholesterol (mg/100 g)	207.30 ± 3.35	8.81 ± 0.25	11.36 ± 0.99
Ca (mg/kg)	853.33 ± 25.04	628.33 ± 2.62	628.00 ± 8.29
P (mg/100 g)	59.33 ± 0.25	66.80 ± 1.07	66.63 ± 0.46
K (mg/100 g)	121.67 ± 2.05	142.00 ± 0.82	139.00 ± 0.82
Na (mg/100 g)	44.23 ± 0.05	13.33 ± 0.12	16.20 ± 0.22

the cheese sample and were even healthier than the cheese in terms of energy, K/Na ratio, DF, and cholesterol. The specific results can be further identified in Table 2 and Figure 2.

3.2. Texture Profile Analysis Results. The PBC, fermented PBC, and cheese samples were further analyzed using a texture analyzer following the manufacturer's instructions. Figures displayed on the screen of each sample are shown in Figure 3, and the results of six characteristic indexes, including hardness, cohesiveness, gumminess, adhesiveness, springiness, and chewiness of the three samples, are shown in Table 3. From the order of magnitude, we could easily draw the conclusion that PBC samples are similar to the cheese sample only except for the gumminess, and the fermentation process could improve the imitation of texture properties.

3.3. Volatile Compound Results. The PBC, fermented PBC, and cheese samples were analyzed using GC–MS in order to discover the compositional difference in volatile compounds between the PBC samples and the dairy cheese. 21, 32, and 29 kinds of compounds were identified using the library search in the NIST database in the PBC, fermented PBC, and cheese samples, respectively (shown in Table 4). The composition differences were further analyzed using the R package (version 4.0). From the compound list, it can be seen clearly that the characteristic volatile compounds were 2,3-butanedione, 3-hydroxy-2-butanone, 2-heptanone, caproic acid, sorbic acid, caprylic acid, and vanillin in the cheese sample, while those in both PBC samples were very different except sorbic acid. The characteristic volatile compounds in both PBC samples were n-hexal, n-hexanol, sorbic acid, and 1,3-diacetin. In particular, 1,3-diacetin accounts for approximately 35%-60% of the total amount of volatile compounds using the peak area normalization method, while the corresponding number in the cheese sample is only 0.79%. In addition, there are three more coexisting compounds in the three samples with lower amounts, namely, ethyl caprate, hexal, and butyl-decalactone. The total ion chromatography of the three samples is shown in Figure 4, and from the PCA plot (Figure 5), it is clear that the volatile compounds were similar between the two PBC samples; however, the fermentation process could increase the species of the volatile compounds and make the PBC slightly more similar to the dairy cheese.

4. Discussions

It is a general consensus that human and global health would be greatly improved by replacing animal-based foods with plant-based alternatives [13]. This transition would be facilitated by the availability of more plant-based foods that are affordable, convenient, sustainable, nutritious, and tasty. However, hurdles, especially technological ones due to the

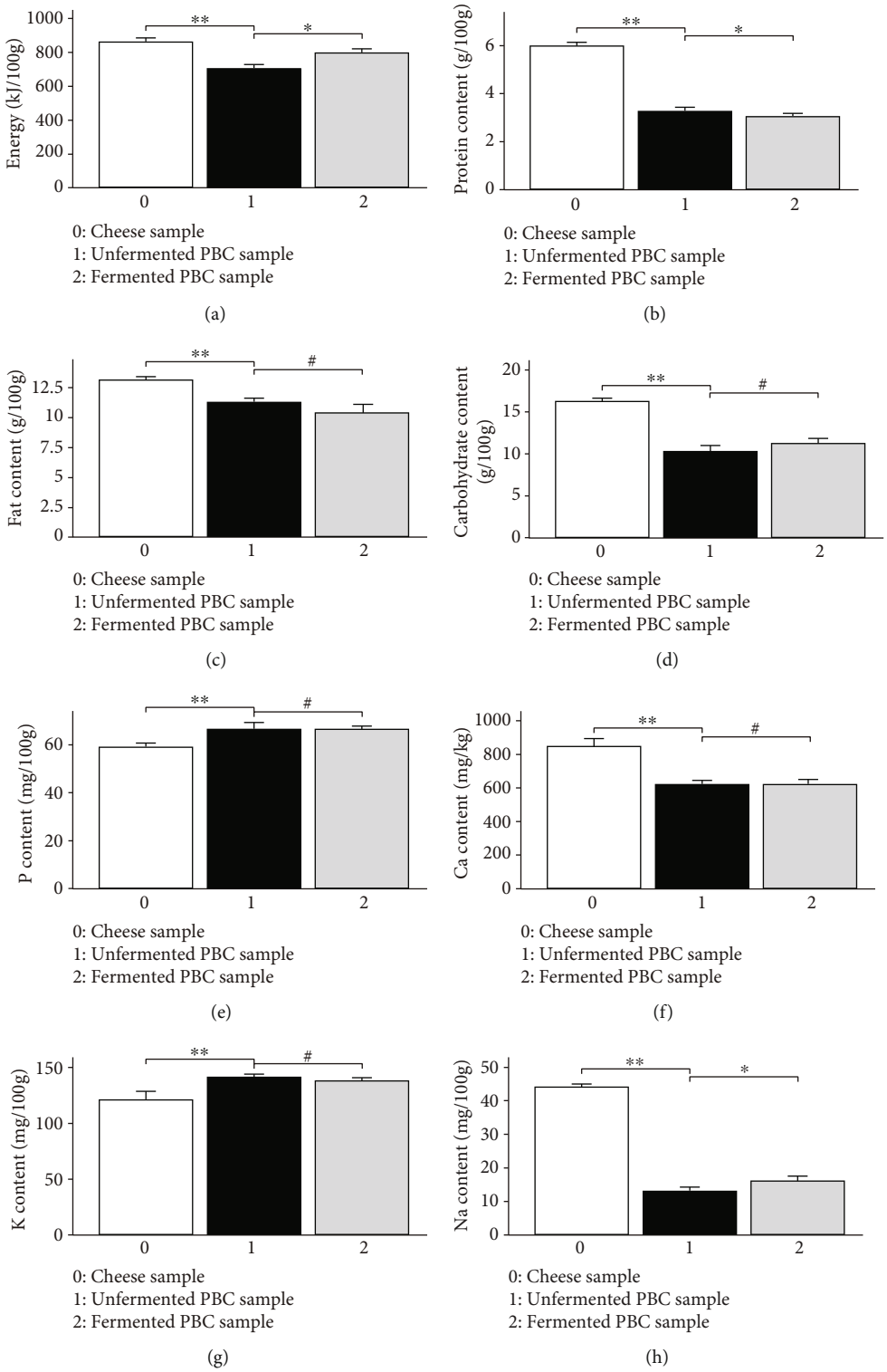


Figure 2: Continued.

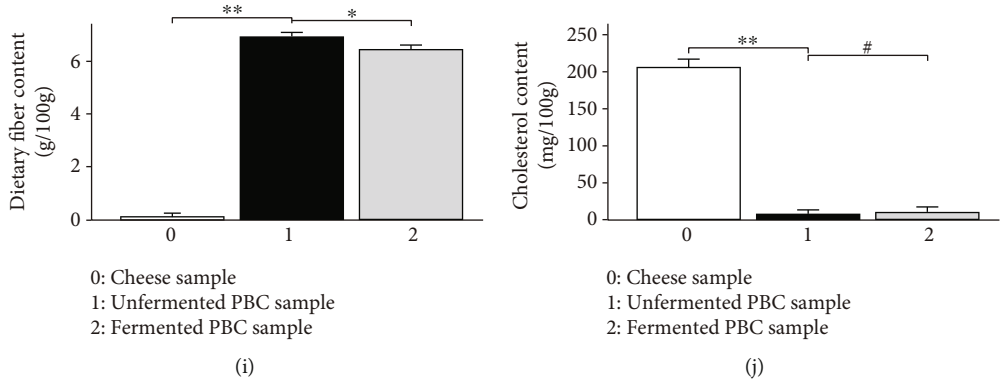


Figure 2: Nutrition test results: (a) energy barplot; (b) protein content barplot; (c) fat content barplot; (d) carbohydrate content barplot; (e) P content barplot; (f) Ca content barplot; (g) K content barplot; (h) Na content barplot; (i) dietary fiber content barplot; (j) cholesterol content barplot.

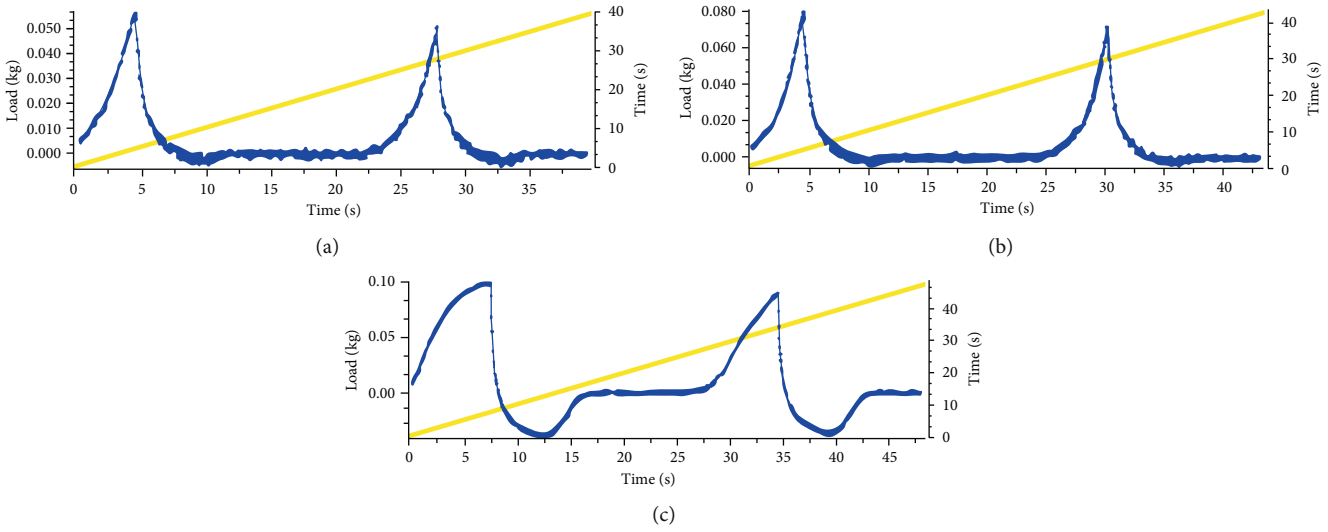


Figure 3: TPA test curve: (a) test curve of PBC sample; (b) test curve of fermented PBC sample; (c) test curve of cheese sample.

Table 3: The texture profile analysis results of all the samples.

Name	Cheese sample	PBC sample	Fermented PBC sample
Hardness (kg)	0.099 ± 0.009^{a}	0.056 ± 0.007^{b}	0.080 ± 0.008^{a}
Gumminess (kJ)	4.40 ± 0.14^{a}	0.15 ± 0.03^{b}	0.19 ± 0.03^{c}
Cohesiveness	0.60 ± 0.06^{a}	0.70 ± 0.08^{a}	0.75 ± 0.08^{a}
Springiness (mm)	12.94 ± 0.46^{a}	7.84 ± 0.39^{b}	8.23 ± 0.42^{b}
Adhesiveness (kg)	0.0596 ± 0.006^{a}	0.0392 ± 0.004^{b}	0.0598 ± 0.008^{a}
Chewiness (mJ)	7.57 ± 0.29^{a}	3.62 ± 0.16^{b}	4.83 ± 0.18^{c}

huge compositional difference between plant and animal ingredients, must be addressed through a deep understanding of the relationship between the structure and properties of the two categories of ingredients [4]. This is also our purpose to study a proper method to develop a nutritious and tasty plant-based cheese snack, and most of the tested results showed that the method might be a prominent path worthy of further research.

From previous studies on PBC, the processing could be divided into two kinds: "fractionation route" and "tissue disruption route." The majority of studies adopt the first route because it is easier to understand the contribution of each plant ingredient [8–10, 12]; however, it is suggested that the "tissue disruption route" is more energy efficient because it only employs two phase transitions in the whole process [3]. In our experiment, we chose plant materials with high

Table 4: The VOCs discovered in all the samples.

Sample name	Retention time (min)	Peak area	Amount (%)	Name	CAS
PBC sample	3.807	5961138	0.34%	1-Aziridineethanamine	4025-37-0
	4.192	10198552	0.58%	Ethanol	64-17-5
	5.691	644437	0.04%	Ethyl acetate	141-78-6
	7.292	774142	0.04%	Acetic acid,2-chloro-,2-butoxyethyl ester	5330-17-6
	8.757	16697788	0.94%	Pentanol	71-41-0
	9.42	115737442	6.53%	Hexal	66-25-1
	10.719	88414433	4.99%	Hexanol	111-27-3
	11.092	9549061	0.54%	Methyl thiobutyrate	2432-51-1
	12.603	12095254	0.68%	2-Pentylfuran	3777-69-3
	13.118	2057044	0.12%	Isopinocarveol	6712-79-4
	13.995	239728725	13.52%	Sorbic acid	110-44-1
	14.059	128274888	7.25%	Sorbic acid	110-44-1
	14.991	1028080	0.06%	3-Ethyl-5-(2-ethylbutyl)octade	55282-12-7
	15.115	68296970	3.85%	Ethyl maltol	4940-11-8
	16.309	1053613522	59.44%	1,3-Diacetin	25395-31-7
	16.802	901136	0.05%	Ethyl caprate	110-38-3
	16.909	3342922	0.19%	2-(5-Methylthiazol-4-yl)ethyl acetate	94021-41-7
	17.716	723764	0.04%	6-Methyloctadecane	10544-96-4
	17.822	10591019	0.60%	5-Decanolide	705-86-2
	18.446	860421	0.05%	Ethyl laurate	106-33-2
	19.485	1287437	0.07%	Delta-Dodecalactone	713-95-1
Fermented PBC sample	4.194	32719041	0.82%	Ethanol	64-17-5
	7.225	27042781	0.68%	2,3-Pentanedione	600-14-6
	7.507	22391612	0.56%	3-Hydroxy-2-butanone	513-86-0
	8.188	1791598	0.04%	Propylene glycol	57-55-6
	8.758	11915371	0.30%	1-Pentanol	71-41-0
	9.419	63172305	1.59%	Hexanal	66-25-1
	10.724	132330655	3.32%	Hexanol	111-27-3
	11.091	11376413	0.29%	Methyl thiobutyrate	2432-51-1
	11.179	1256141	0.03%	Styrene	100-42-5
	11.279	951472	0.02%	Heptaldehyde	111-71-7
	11.851	686225	0.02%	N-[4-(Trimethylsiloxy)benzoyl]glycine methyl ester	55638-48-7
	12.148	679961	0.02%	Pentanol, 4-methyl-4-nitro-	
	12.301	3014145	0.08%	Benzaldehyde	100-52-7
	12.448	15123154	0.38%	Trisiloxane, 3-butoxy-1,1,1,5,5,5-hexamethyl-3-[(trimethylsilyl)oxy]- (9CI)	87867-97-8
	12.604	11920805	0.30%	2-Pentylfuran	3777-69-3
	12.759	1050613	0.03%	Octanal	124-13-0
	12.828	740083	0.02%	3-Trifluoroacetoxypentadecane	
	13.077	478871	0.01%	2-Ethyl-1-hexanethiol	7341-17-5
	13.118	1507526	0.04%	(Endo,endo)-9-oxabicyclo[4.2.1]nonane-2,5-diol	19740-86-4
	13.182	281802	0.01%	Neodihydrocarveol	18675-33-7
	13.249	1378026	0.03%	1-Cyclopentene-1-methanol, 5-methyl-	88125-84-2
	13.471	950585	0.02%	3-Trifluoroacetoxypentadecane	—
	13.586	3608612	0.09%	Decyl alcohol	112-30-1
	13.994	279864340	7.02%	Sorbic acid	110-44-1

Table 4: Continued.

Sample name	Retention time (min)	Peak area	Amount (%)	Name	CAS
	14.174	647726573	16.26%	Sorbic acid	110-44-1
	14.378	984957864	24.72%	Sorbic acid	110-44-1
	15.148	152224848	3.82%	Ethyl maltol	4940-11-8
	16.33	1542296203	38.71%	1,3-Diacetin	25395-31-7
	16.808	4118106	0.10%	Ethyl caprate	110-38-3
	16.921	5597880	0.14%	2-(5-Methylthiazol-4-yl)ethyl acetate	94021-41-7
	17.825	17555751	0.44%	δ-Decalactone	705-86-2
	18.447	1427782	0.04%	Ethyl laurate	106-33-2
Cheese sample	4.196	11284463	2.04%	Lactamide	2043-43-8
	4.394	3288538	0.60%	Acetone	67-64-1
	5.32	37875478	6.86%	2,3-Butanedione	431-03-8
	5.415	30840226	5.59%	2,3-Butanedione	431-03-8
	7.044	1148257	0.21%	2-Pentanone	107-87-9
	7.277	2411989	0.44%	Isovaleraldehyde	590-86-3
	7.52	175889878	31.87%	Acetoin	513-86-0
	8.193	6888628	1.25%	(R)-(-)-1,2-Propanediol	4254-14-2
	8.788	5308107	0.96%	1-Phenyl-2-propanol	698-87-3
	9.365	3863940	0.70%	Butyric acid	107-92-6
	9.43	1852082	0.34%	Hexanal	66-25-1
	11.059	40581877	7.35%	2-Heptanone	110-43-0
	12.595	70682574	12.81%	Caproic acid	142-62-1
	13.698	29967968	5.43%	Sorbic acid	110-44-1
	13.824	8840254	1.60%	2-Nonanone	821-55-6
	13.993	2341905	0.42%	Nonanal	124-19-6
	14.727	43124271	7.81%	Caprylic acid	124-07-2
	15.126	1193163	0.22%	Naphthalene	91-20-3
	15.729	8315403	1.51%	p-Anisaldehyde	123-11-5
	16.235	4374660	0.79%	1,3-Diacetin	25395-31-7
	16.523	3513042	0.64%	Decanoic acid	334-48-5
	16.734	732903	0.13%	1-Fluoro-1-hex-1-ynyl-2,2-dimethyl-cyclopropane	—
	16.801	679298	0.12%	Ethyl caprate	110-38-3
	16.868	481995	0.09%	Behenyl behenate	17671-27-1
	17.03	48709273	8.83%	vanillin	121-33-5
	17.715	892420	0.16%	2,6,10-trimethyltetradecane	14905-56-7
	17.818	4719465	0.86%	5-Decanolide	705-86-2
	19.484	549268	0.10%	10-Methylundecan-5-olide	—
	19.886	247141	0.04%	3-Trifluoroacetoxydodecane	—

nutritional value and adopted the "tissue disruption route" to make a cheese snack analogue.

A study compared the nutritional content of 109 kinds of cheese alternatives sold on the UK market with dairy equivalents and found that there was a significant difference between the two parties: all cheese had approximately 20% more declared fat content than PBCs, while PBCs mainly made from oil had 3-9 times more declared carbohydrate. The protein and calcium content of dairy cheese was also higher, while the PBCs usually had a higher level of salt content [14]. Our PBC samples are consistent with this research in the comparison of protein and calcium content; however, much less fat content was discovered in our PBC than in the PBC made mainly from oil. The salt (Na) content of our PBC is also very different from that in this research, namely, our Na content is much lower than that of the cheese sample. Another study analyzed 245 nondairy PBCs using their nutritional fact labels and found that only 3% of them had reached 5 g/100 g protein, which is consistent with our sample.

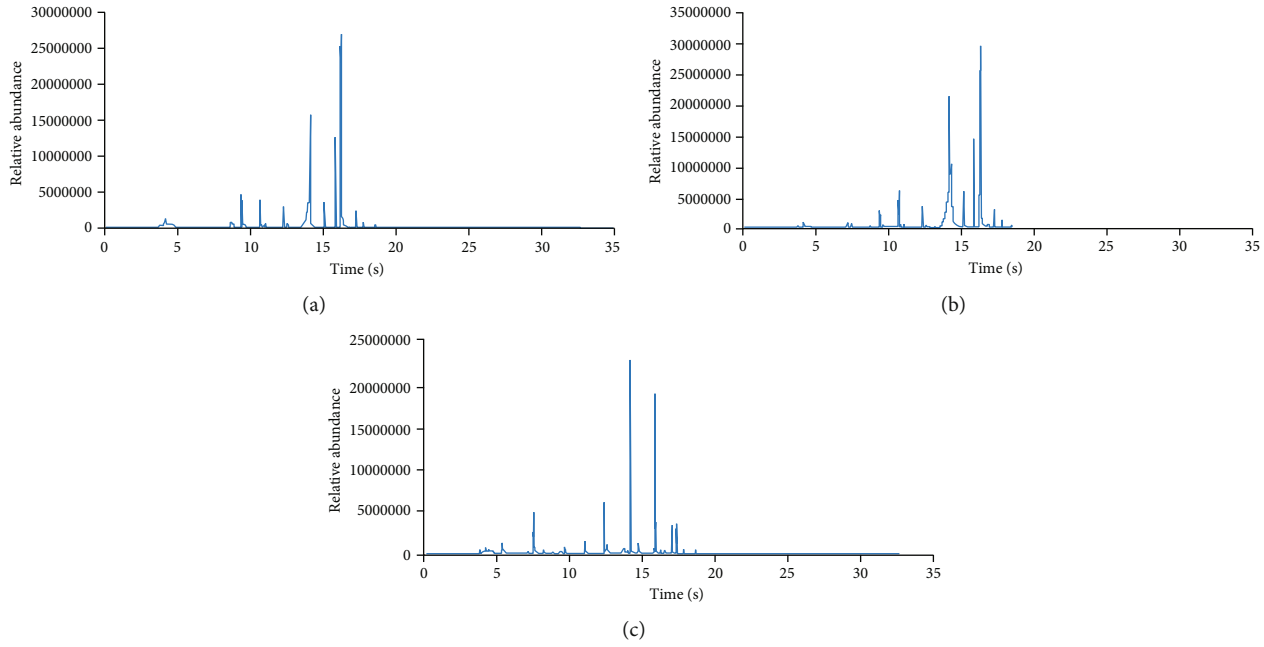


Figure 4: TIC curve of the GC: (a) TIC curve of PBC sample; (b) TIC curve of fermented PBC sample; (c) TIC curve of cheese sample.

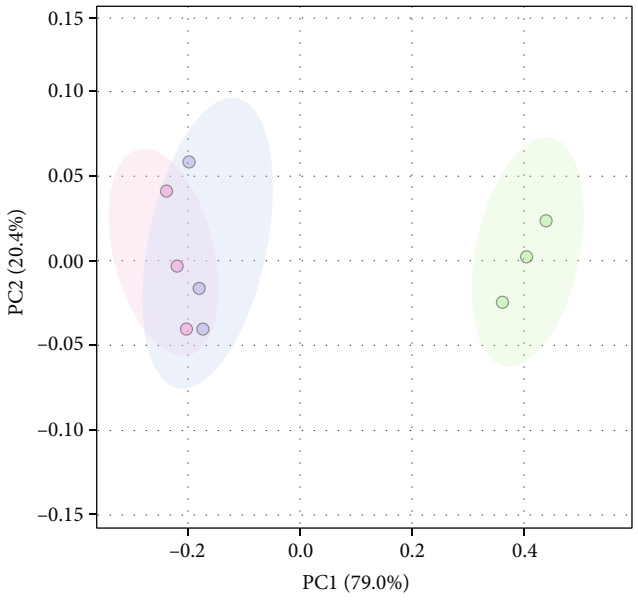


Figure 5: PCA plot of the three samples.

The study further suggested that almost 60% had high levels of saturated fat because of the use of coconut instead of cashew, while only 15% had low sodium levels [15]. Our sample is thus advantageous in terms of the content of saturated fat and sodium, although we did not run the saturated fat test. Further, it is necessary to increase the content of protein in our formula because 30% of consumers would be encouraged to have more dairy substitutes if the products contained more protein [16]. Legume proteins have good technological properties and are low in price, which gives them strong commercial potential to be used in PBC products. However, few legume proteins have been explored in the formulation, development, and manufacture of vegan cheese because of their undesirable properties: heat stability, antinutritional factors, and a beany flavour [11]. Our trial chose chickpea as the main source of protein, which could be a clue for future PBC research because very little bean flavour was found in our sample.

It is common sense that lactic acid bacteria- (LAB-) fermented foods are recognized as healthy due to their probiotic effect and their metabolites, such as exopolysaccharides (EPS) and SCFAs, produced during food fermentation or after food digestion. LAB-fermented foods such as yogurt and cheese and plant-based products such as sauerkraut and kimchi all have a long history and have become more popular because of their unique flavour and health effects [17]. The molecular mechanisms during fermentation by LAB in dairy products are well understood, such as proteolysis of casein into peptides and amino acids and the utilization of carbohydrates to form lactic acid and exopolysaccharides, which are the basis for forming the flavour and texture of fermented cheese. However, the differences in fermentation processes in plant-based alternatives are poorly understood [18]. Differences in the structures of proteins in plants and dairy suggest that the in-depth knowledge of proteolysis in dairy is not directly translatable to plant-based analogues. From the previous data, it is often the case that flavour profiles of PBCs limit their acceptance [19, 20]. With the goal of producing more valuable and tasty products, precise fermentation can help improve the sensory profiles, nutritional properties, texture, and microbial safety of PBC [19, 21]. Studies further suggested that a mixture of fermentation strains may be more effective in modifying flavour and texture as well as lowering allergenicity and other antinutritional factors [11]. From the above, conclusion could be drawn that the texture and sensory properties of PBC would be improved when the fermentation process

was adopted. This conclusion could also be reflected in our experiment. The variation in the content of the main nutritional components is not very obvious, while the improvement in the appearance, texture, and volatile compounds of the fermentation of PBC could all be easily recognized. However, the mechanism still needs further investigation. Compared to dairy fermentations, our knowledge of strain properties in different plant-based substrates is still limited [22].

5. Conclusions

Overall, the observed properties of our PBC sample using raw chickpeas and nuts are comparable to those of the dairy cheese snack sample, making this processing route very promising because of its nutritional value, sensory, and texture properties. Our samples were high in nourishment value compared to the cheese sample and even healthier than the cheese in terms of energy, K/Na ratio, DF, and cholesterol. In addition, the nutritional value of our PBC sample is also better than other reported PBCs, especially those made mainly from coconut and oils. The PBC samples are similar to the cheese sample in the aspects of hardness, cohesiveness, springiness, adhesiveness, and chewiness in the texture test, and the fermentation process could improve texture properties to a certain degree. The volatile compounds were similar between the two PBC samples, and those of the cheese sample were quite different with our PBC samples; however, the fermentation process could increase the species of the volatile compounds and make the PBC slightly more similar to the dairy cheese. Future studies could pay more attention to the plant protein source with the aim of increasing protein content and reduce the undesirable flavour and taste. Meanwhile, the imitation of volatile compounds in cheese also needs to be strengthened. This might be achieved by a deep understanding of the fermentation process of LABs as well as other bacterial strains on plant ingredients. In addition, when more specific food additives, including essences for each kind of cheese, are available, it will accelerate the development of PBCs.

Data Availability

All data supporting the findings of this study are available within the paper.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Acknowledgments

We acknowledge the experimental materials supported by Shantou Happy Food Ltd., China. This research was funded by the Guangdong Provincial Key Laboratory of Functional Substances in Medicinal Edible Resources and Healthcare Products (grant number 2021B1212040015), Guangdong University Foundation (grant number 2019KQNCX079), Hanshan Normal University (grant number QN202019), Chaozhou Branch of Chemistry and Chemical Engineering Guangdong Laboratory (grant number HJL202202B009), and Postdoctoral Project of Wuqiong Food Co., Ltd.

References

[1] R. Kamath, S. Basak, and J. Gokhale, "Recent trends in the development of healthy and functional cheese analogues-a review," *LWT*, vol. 155, article 112991, 2022.

[2] Global Dairy Alternatives Market Size & Trends Report, *Dairy Alternatives Market Size, Share & Trends Analysis Report By Source (Soy, Almond, Coconut, Rice, Oats), By Product (Milk, Yogurt, Cheese, Ice-cream, Creamers), By Distribution Channel, And Segment Forecasts, 2022 - 2030*, Global Dairy Alternatives Market Size & Trends Report, 2021, Report ID: GVR-1-68038-070-5.

[3] L. Grossmann and D. J. McClements, "The science of plant-based foods: approaches to create nutritious and sustainable plant-based cheese analogs," *Trends in Food Science & Technology*, vol. 118, pp. 207–229, 2021.

[4] D. J. McClements and L. Grossmann, "A brief review of the science behind the design of healthy and sustainable plant-based foods," *NPJ Science of Food*, vol. 5, no. 1, p. 17, 2021.

[5] K. B. Comerford and G. Pasin, "Emerging evidence for the importance of dietary protein source on glucoregulatory markers and type 2 diabetes: different effects of dairy, meat, fish, egg, and plant protein foods," *Nutrients*, vol. 8, no. 8, p. 446, 2016.

[6] M. Pointke and E. Pawelzik, "Plant-based alternative products: are they healthy alternatives? Micro- and macronutrients and nutritional scoring," *Nutrients*, vol. 14, no. 3, p. 601, 2022.

[7] U. Fresan and H. Rippin, "Nutritional quality of plant-based cheese available in Spanish supermarkets: how do they compare to dairy cheese?," *Nutrients*, vol. 13, no. 9, p. 3291, 2021.

[8] F. Ferawati, M. Hefni, K. Ostbring, and C. Witthoft, "The application of pulse flours in the development of plant-based cheese analogues: proximate composition, color, and texture properties," *Foods*, vol. 10, no. 9, p. 2208, 2021.

[9] C. Masia, P. E. Jensen, I. L. Petersen, and P. Buldo, "Design of a functional pea protein matrix for fermented plant-based cheese," *Foods*, vol. 11, no. 2, p. 178, 2022.

[10] M. Mefleh, A. Pasqualone, F. Caponio et al., "Spreadable plant-based cheese analogue with dry-fractioned pea protein and inulin-olive oil emulsion-filled gel," *Journal of the Science of Food and Agriculture*, vol. 102, no. 12, pp. 5478–5487, 2022.

[11] M. Mefleh, A. Pasqualone, F. Caponio, and M. Faccia, "Legumes as basic ingredients in the production of dairy-free cheese alternatives: a review," *Journal of the Science of Food and Agriculture*, vol. 102, no. 1, pp. 8–18, 2022.

[12] K. D. Mattice and A. G. Marangoni, "Physical properties of plant-based cheese products produced with zein," *Food Hydrocolloids*, vol. 105, article 105746, 2020.

[13] U. A. Saari, C. Herstatt, R. Tiwari, O. Dedehayir, and S. J. Mäkinen, "The vegan trend and the microfoundations of institutional change: a commentary on food producers' sustainable innovation journeys in Europe," *Trends in Food Science & Technology*, vol. 107, pp. 161–167, 2021.

[14] M. E. Clegg, A. R. Tarrado, R. Reynolds et al., "A comparative assessment of the nutritional composition of dairy and plant-based dairy alternatives available for sale in the UK and the

implications for consumers' dietary intakes," *Food Research International*, vol. 148, article 110586, 2021.

[15] W. J. Craig, A. R. Mangels, and C. J. Brothers, "Nutritional profiles of non-dairy plant-based cheese alternatives," *Nutrients*, vol. 14, no. 6, p. 1247, 2022.

[16] S. Jeske, E. Zannini, and E. K. Arendt, "Past, present and future: the strength of plant-based dairy substitutes based on gluten-free raw materials," *Food Research International*, vol. 110, pp. 42–51, 2018.

[17] V. Castellone, E. Bancalari, J. Rubert, M. Gatti, E. Neviani, and B. Bottari, "Eating fermented: health benefits of LAB-fermented foods," *Foods*, vol. 10, no. 11, p. 2639, 2021.

[18] A. R. Harper, R. C. Dobson, V. K. Morris, and G. J. Moggre, "Fermentation of plant-based dairy alternatives by lactic acid bacteria," *Microbial Biotechnology*, vol. 15, no. 5, pp. 1404–1421, 2022.

[19] C. Tachie, I. D. Nwachukwu, and A. N. Aryee, "Trends and innovations in the formulation of plant-based foods," *Food Production, Processing and Nutrition*, vol. 5, no. 1, pp. 1–14, 2023.

[20] D. Plamada, B. E. Teleky, S. A. Nemes et al., "Plant-based dairy alternatives—a future direction to the milky way," *Foods*, vol. 12, no. 9, p. 1883, 2023.

[21] M. Tangyu, J. Muller, C. J. Bolten, and C. Wittmann, "Fermentation of plant-based milk alternatives for improved flavour and nutritional value," *Applied Microbiology and Biotechnology*, vol. 103, no. 23-24, pp. 9263–9275, 2019.

[22] W. Engels, J. Siu, S. van Schalkwijk, W. Wesselink, S. Jacobs, and H. Bachmann, "Metabolic conversions by lactic acid bacteria during plant protein fermentations," *Foods*, vol. 11, no. 7, p. 1005, 2022.