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The Impact of *Flacourtia inermis Roxb* (Tomi-Tomi) Sourdough Prepared Using Different Drying Techniques on the Physicochemical Attributes and Characteristics of Sourdough Bread

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Abstract

The study aimed to produce dried sourdough tomi-tomi (*Flacourtia inermis Roxb*) with 2 different drying methods: Cabinet-driying (CD) and freeze-driying (FD) and investigate the effect of the dried sourdough on the viability of lactic acid bacteria (LAB) and yeast. The tomi-tomi dried-sourdough samples were used in breads production to observe the impact on the bread properties. Satisfactory results were obtained with CD and FD dried sourdough, there was no significant reduction in viability of lactic acid bacteria (LAB), yeast and specific volume of the bread. Nevertheless, the CD and FD dried sourdough significantly reduced the cell density of the bread compared to control. The addition of tomi-tomi juice increased the LAB and yeast production. The result of CD and FD dried sourdough with rehydration may be used for bread-making without bakery's yeast activator addition.

Keywords: Sourdough, Lactic acid bacteria, Yeast, Cabinet-drying, Freeze-drying, Tomi-tomi fruit

Introduction

In recent years, artisanal bakeries have considerably increased consumer's interest and bread made with sourdough has been one of them. Sourdough is one of the oldest natural starters made by spontaneous fermentation of lactic acid bacteria (LAB) and yeast on flour and water. Extra ingredients like fruits are often added in early fermentation steps. A fruit would be a source of microorganisms and substrates for fermentation, which can stimulate sourdough at once [1,2,3].

The addition of fruit (i.e. pear, orange, pineapple, pitaya, grapes and apple) to the sourdough gives a higher volume, softer crumb and also improves the shelf-life of the bread due to the a higher anti-fungal of phenolic acid such as gallic acid, caffeic acid and protocatechuic acid [3,4,5,6]. However, the addition of apple juice and lemon juice on sourdough produced also enhanced the production of lactic acid, acetic acid, acetoin and diacetyl that can lower pH and get the greater acidity that can increase the volume specific of bread and gives the different flavor and texture on bread [1]. In a study by Danila *et al* [4] adding a pineapple as a starter also decreased the pH of sourdough and increase the LAB and yeast on sourdough and makes bread trends to be softer.

Tomi-tomi belongs to genus *Flacourita* of the *Salicaceae* family. It grows widely in eastern Indonesia and is known as tomi-tomi, lobi-lobi or batoko plum [7]. The fruits were chosen for this research because the fruit is more acidic than other fruit, so the addition of tomi-tomi can lower the pH of the starter so can reach the suitable pH faster that others and also can increase the production of yeast and LAB on sourdough and its effect on the texture of bread. However, the effect of tomi-tomi fruits on the technological, microbial properties and impact on the sourdough bread has not been reported.

Due to their potential impacts on nutrition, organoleptic characteristics (bread texture, volume and taste) and better shelf life than commercial yeast bakers [3,8], sourdough with fruit as a starter requires additional cost and continuous care to keep microorganisms active and stable. Therefore, to reduce production costs, maintain sourdough stability, provide longer sourdough shelf life, and a large scale productions, the drying process is recommended [2,9,10]. Freeze-drying (FD) and cabinet-drying (CD) are suitable long-term preservation methods for dried starter cultures. Freeze-drying is an efficient method to preserve the viability of yeast and (LAB) of the sourdough. However, it might reduce bread volume, consumes more energy and requires higher manufacturing costs than oven-dried method [10]. Due to the lower price, shorter time and higher volume specific of bread, the cabinet-drying technique has been used widely. With this technique, the viability of LAB and yeast decreases because of the temperature [11]. Therefore, the present study aims to investigate the potential of tomi-tomi as a sourdough starter and the effect of freeze-drying and cabinet-drying methods on the properties of dried sourdough.

Materials and methods

Materials

Tomi-tomi fruits were obtained on November 2023 from Oki Baru, South Buru Regency, Maluku, Indonesia and transferred to the Biotechnology Laboratory at Universitas Gadjah Mada, Yogyakarta, Indonesia. Whole wheat flour (Naturich Bogasari, Indonesia) and water were used in sourdough making. The ingredients for bread production were whole wheat flour, wheat flour (Indofood Sukses Makmur Inc, Surabaya), sugar, milk, margarine and salt. For counting lactobacilli, the samples were plated on de Man, Rogosa and Sharp (MRS) agar form (Merck, Darmstadt, Germany) and incubated at 37 ° C for 48 h.

Fruit preparation and fermentation

Tomi-tomi fruits were washed with water to remove dust from the surface. The fermentation was executed in 2 steps. First, the washed fruits (200 g) were homogenized with water (500 g) into a liquid using a food blander, and the result liquid was filtered with fruit strainer [6]. Likewise, 200 g of tomi-tomi fruits were chopped and mixed with water (500 g). Both fruits preparations were fermented in separated bottles at 30 °C for 6 days and sampel were taken every 24 h for analysis.

Sourdough production

The *Flacourtia inermis* Roxb sourdough (FS) was prepared by mixing 30 g of fermented liquid with 30 g of whole wheat flour and incubated at 30 °C for 24 h [1]. The mixture was weighed 30 g and was mixed with whole wheat flour and water with a ratio of 1:1:1. After 24 h of fermentation, the sourdough was feeding used back sloped method which used a small amount of a fully fermented sourdough starter to make a new batch of flour and water to helps maintain the health and activity of the sourdough culture over time. Following 2 days of incubation, FS was used for produced sourdough bread (FSB). Control sourdough (CS) was prepared from whole wheat flour and water in the same ratio of FS. CS was fermented until 4 days to make control sourdough bread (CSB). Samples of FS and CS were taken every 24 h for the analysis over 7 days.

Dried sourdough preparation

Prior to the drying, 100 g of whole-wheat flour and 100 mL water were added to 50 g of fresh sourdough to activate bacteria and yeast, and then incubated at 30 °C for 24 h. For the freeze-drying process, activated FS and CS were frozen at −45 °C for 40 h under vacuum at 0.058 mbar. Dried sourdoughs were ground using a blender (Miyako BL-152GF, Indonesia). Samples of freeze-dried sourdough (FD-FS) and freeze-dried control sourdough (FD-CS) were stored in air-tight-capped plastic containers at room temperature for further analysis. The cabinet-drying process of FS and CS was conducted using a food dehydrator (FDH-10, Wiratech Inc, Surabaya). The FS and CS were heated at 30 °C for 24 h. The final product of cabinet-dried sourdough (CD-FS) and cabinet-dried control sourdough (CD-CS) were stored in an air-tight-capped plastic container at room temperature for further analysis.

Bread-making procedure

The bread was prepared according to the method developed by Caglar *et al.* [10] with some modifications. The main ingredients of the bread were 83.3 % (w/w) of wheat flour, 16.67 % (w/w) of whole wheat flour, 63.63 % (w/w) of milk, 12.72 % (w/w) of margarine, 9.09 % (w/w) of sugar and 1.45 % (w/w) of salt. An amount of 54.54 % (w/w) of FS and CS were added, and all the bread ingredients were mixed using an electric mixer for 10 min. The dough was laid on the bread pan for 3 and 6 h for fermentation. The dough of FS and CS was fermented for 3 and 6 h and baked for 50 min at 180 °C.

Determination of titratable acidity and pH

The pH and total titratable acidity (TTA) of the tomi-tomi starter and sourdough were measured on 10 g of sample (the starter, fresh sourdough or freeze-dried/dehydrator powder), homogenized with 90 mL of distilled water. The pH measure was carried out by digital pH meter (Filox, Pavan International, India) and TTA was determined by 0.1 mL/L NaOH until reached pH of 8.2 - 8.5 [3,12,13,14], and expressed as the amount (mL) of NaOH.

Enumeration of total LAB and yeast

For LAB and yeast enumeration, every 10 g samples of the starter, fresh and sourdough, freeze-dried sourdough and cabinet-dried sourdough was mixed with 90 mL of a physiological solution. Serial dilutions of each sample were spread plated, duplicate on media. The media for growth the LAB was MRS agar with $CaCO_3$ 1 % (w/w) for LAB and YPD agar for yeast, and the plates were incubated at 30 °C for 48 h. The plates holding 30 - 300 colonies were selected to determine the colony-forming units per gram of Log CFU/g [10].

The specific volume of the bread

The specific volume of the bread was measured using the seed displacement method [6]. A particular volume of bread (mL/g) was calculated by dividing the volume of the loaf (mL) and the weight of the loaf (g).

The microstructure of bread

The microstructure of the bread was analyzed using a scanning electron microscope (SEM) analysis (Jeol JSM-6510LA, Japan). Bread crumbs were cut and coated with platina and then vacuumed to 3.8 Pa. Subsequently, the samples underwent examination, and images were captured using a scanning electron microscope and were recorded at 50× magnification [6], [15]. The bread's micro-structure was characterized by assessing cell density and the mean cell area [16]. Cell density was calculated by dividing the total number of cells by the mean cell area.

Texture analysis of bread

The bread texture, was measured using a Texture Analyzer TA-XT2i with a 3 cm probe. The bread was compressed to 50 % of its initial height at a cross-head speed of 1.5 mm/s. The texture analysis result of the bread indicated hardness in N, gumminess in N, chewiness in N, springiness, cohesiveness and resiliency [4].

Volatile compounds analysis by GC-MS method

The volatile compounds were determined in sourdough bread by GC/MS coupled with solid-phase micro-extraction (SPME-GC/MS) methods [17]. The 2 g of each sample were transferred and sealed in a 22 mL SPME vial for 45 min. The extraction was performed at 60 °C with SPME fiber DVD/CAR/PDMS (divinylbenzene/ carboxen/polydimethylsiloxane). The sample with SPME fiber was transferred into an XL EI/CI spectrometer for GC/MS. Chromatography separation using capillary column DB-Wax (30 m×250×0.25 μm^2). At the beginning, the temperature of the oven was 50 °C for 5 min, then increased to 210 °C at 5 °C/min for 0 min, and then at 240 °C at the rate of 10 °C/min for 5 min. Carrier gas was helium with a rate of 1 mL/min. The volatile compounds were identified based on reorientation times and mass spectrum comparison with the spectra available in the NIST14 library.

Statistical analysis

Statistical analyses were performed by using SPSS (Version 25.0, SPSS Inc, Chicago, IL, USA). The study results were presented as the mean value ± standard deviation. All analytical determination was performed in triplicate by using a 1-way analysis of variance (ANOVA) with Duncan's multiple range test (significance level $p \leq 0.05$).

Results and discussion

The pH, total titratable acidity (TTA) and microbial profile of tomi-tomi starter

The changes in pH value indicated the amount of strong acid produced by microbial metabolism during the fermentation of the tomi-tomi (*Flacourtia inermis Roxb*) starter. At the same time, TTA reflected the total acidity changes in the starter. The result is shown in

(**Figure 1(a)**). During the fermentation process, the pH of the starter juice or chopped fruits decreased slowly on the first day of fermentation and then decreased more rapidly on day 3 and day 5 for the chopped fruits starter. The pH of the juice starter decreased from 4.22 to 3.22 after 3 days of fermentation, while that of the chopped fruits starter decreased from 4.52 to 3.22 after 5 days. The TTA increased in parallel with the pH value. During the fermentation period, the TTA of the juice starter exhibited a gradual increase, reaching 1.28 mL after 3 days. In contrast, the TTA of the chopped fruits starter demonstrated a significant rise, increasing from 0.6 to 2.16 mL by day 5 of fermentation. This indicated the presence of numerous acid-producing microorganisms in the tomi-tomi starter. A comparable results were observed in the previous studies [3,4,6,18] on the fermentation of pear, orange, dragon fruit and pineapple fruits.

The production of LAB and yeast in the starter was also indicated by the increased growth of lactic acid bacteria and yeast in both juice starters and chopped starters of tomi-tomi. **Figure 1(b)** illustrates the result of the LAB and yeast cell in 6 days fermentation. The initial amount LAB and yeast at the beginning of the juice starter was 2.10 and 4.55 log CFU/g, respectively, and increased over time. In addition, the chopped tomi-tomi starter at day 0 had the highest LAB (2.79 log CFU/g) but the lowest yeast (2.62 log CFU/g). The LAB and yeast for both starters continued to increase until their peak at day 2 and 4, respectively. The different peak times might be due to the disparate treatment of the tomi-tomi juice and chopped starters. This effect may depend on various factors. In terms of nutrient availability, the sugar and other nutrients in the tomi-tomi fruits are easier dissolved in the juice, thus making them more accessible to LAB and yeast as their food source than in the case of chopped tomi-tomi starter [19]. The blending process on tomi-tomi fruits also damaged the fruit cell wall, releasing more internal enzymes and compounds into the liquid. These enzymes facilitate the chemical reactions that increase fermentation speed [20]. In conclusion, the starter of tomi-tomi juice was selected for making dried sourdough.

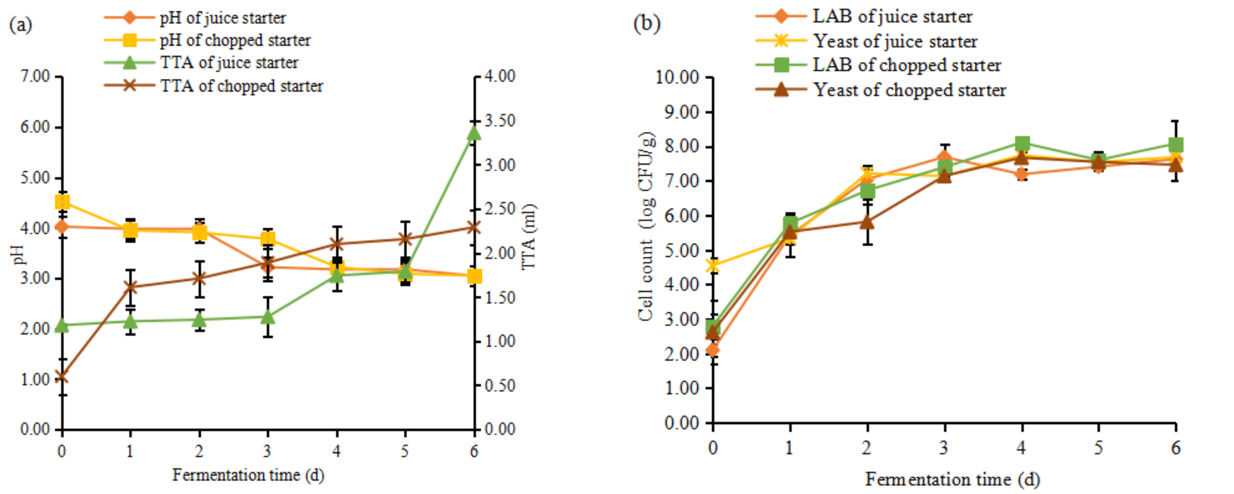

Figure 1 (a) pH and total titratable acidity (TTA) of tomi-tomi (*Flacourtia inermis,Roxb*) starter, (b) LAB and yeast count of tomi-tomi (*Flacourtia inermis,Roxb*) starter.

The pH, total titratable acidity (TTA) and microbial profile of the sourdough

The degree of acidification and the LAB strain of the starter significantly influenced the quality of sourdough [12]. **Figure 2(a)** illustrates the acidification capacity of spontaneous sourdough fermented with tomi-tomi starter. As shown in **Figure 2(a)**, the acid value increased during fermentation. The pH value of FS before fermentation process (day 0) exhibited the lowest pH compared to CS. The pH and TTA values for FS were 4.46 and 2.68 mL, respectively, while the CS started with pH and TTA values of 6.87 and 0.82 mL, respectively. After 2 days, the pH of the fermented FS was 4.1, while the TTA was 5.88 mL. The pH and TTA of the FS reached a peaked on the second day, while the

CS peaked on day 4. The pH value of mature sourdough is 3.4 - 4.9 [9].

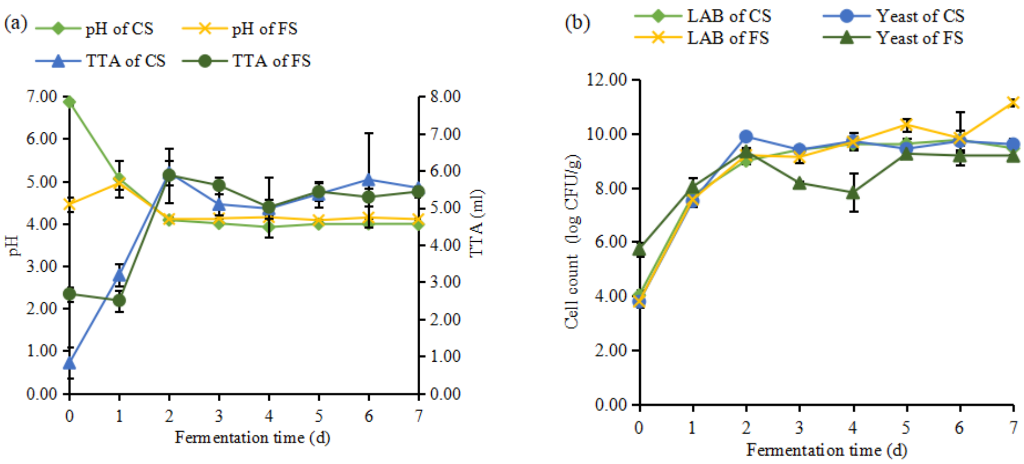

Figure 2 (a) pH and total titratable acidity (TTA) of sourdough tomi-tomi (*Flacourtia inermis Roxb*). (b) LAB and yeast count of sourdough tomi-tomi (*Flacourtia inermis Roxb*). FS: *Flacourtia inermi Roxb* sourdough; CS: Control sourdough.

The TTA of FS and CS increased in sourdough due to the substrate on it, and it can be used by LAB and yeast for metabolic processes [4]. The yeasts and LAB in the sourdough process have important technological properties, making them indispensable during fermentation [21]. **Figure 2(b)** shows the LAB and yeast in FS and CS. The initial cell number of FS LAB and yeast, with the addition of the tomi-tomi starter culture before fermentation, was determined to be 3.80 and 5.74 log CFU/g, respectively. Before fermentation, the viable LAB and yeast of CS were quantified at 4.02 and 3.79 log CFU/g, respectively. After 24 h of fermentation, the LAB of FS increased to 7.56 log CFU/g, while the yeast increased to 8.03 log CFU/g. After 7 days of back-slopped fermentation, FS produced 11.14 log CFU/g of LAB and 9.17 log CFU/g of yeast. During fermentation, the FS peaked LAB and yeast faster than the CS, with a higher LAB count on day 2. Furthermore, the tomi-tomi sourdough on day 2 was used as raw material for dried sourdough, and the CS was produced using the CS sourdough on day 4.

The pH, total titratable acidity (TTA) and microbial profile of dried tomi-tomi

The pH of dried sourdough tomi-tomi was measured before and after drying, and it was found that their acidity level was decreased. The pH value of fresh sourdough tomi-tomi and dried sourdough tomi-tomi between 4.11 and 3.69 (**Figure 3**). CD-FS had the highest pH value among of all the dried samples. These results were in agreement with the findings reported by Ertop *et al.* [11]. During the sourdough fermentation process, a decrease in the pH value of the sourdough samples was accompanied by an increase in the TTA value, which represents the total amount of organic acids produced [12]. **Figure 3** shows the TTA values of the dried sourdough samples, which ranged from 8.70 to 9.76 mL. The observed variation in pH and TTA can be attributed to the raw materials used, the initial chemical composition, the drying methods used and the production process of the sourdough.

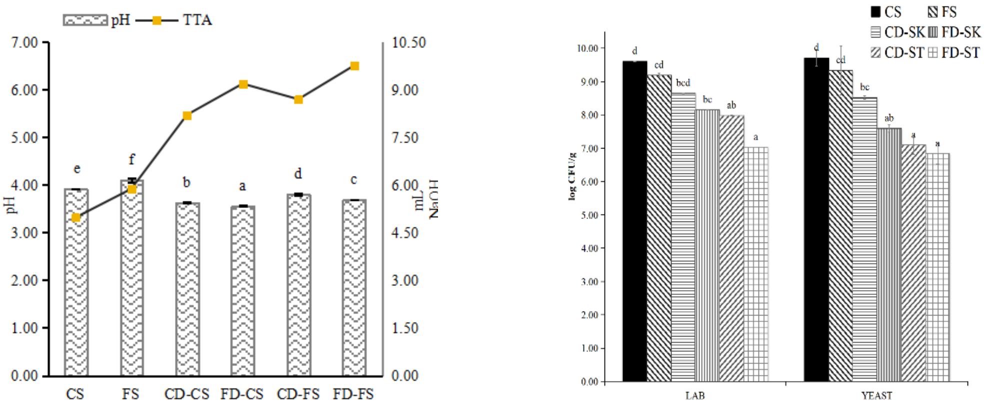

Figure 3 Physicochemical properties of dried sourdough of tomi-tomi FS: *Flacourtia inermis Roxb* sourdough; CS: Control sourdough; CD-CS: Cabinet-dried control sourdough; FD-CS: Freeze-dried control sourdough; CD-FS: Cabinet-dried *Flacourtia inermis Roxb* sourdough; FD-FS: Freeze-dried *Flacourtia inermis Roxb* sourdough. TTA: Total titratable acidity (mL 0.1 N NaOH per 10 g sample). LAB: Lactic acid bacteria. The superscript letters indicate that they are significantly different by Duncan's multiple range test ($p \leq 0.05$). Data are expressed as mean ± standard deviation (n = 3).

As shown in **Figure 3**, the drying process reduced the number of lactic acid bacteria (LAB) and yeast cells in the dried sourdough samples. The freeze-dried sourdough (FDS) was subjected to freeze-drying, while the cabinet-dried sourdough (CDS) exhibited a comparatively lower reduction in LAB and yeast cells. At the same time, the LAB and yeast in the fresh sourdough of the FS were 9.19 and 9.34 log CFU/g, respectively. After freeze-drying process, the FDS exhibited the lowest values for both LAB and yeast. The FSP was then subjected to cabinet-drying, resulting in a further decrease of 2 log cycles, with the LAB value reaching 7.03 log CFU/g and the yeast value reaching 6.84 log CFU/g. The results indicated that the cabinet dryer was more effective than the freeze dryer for both the FDS and CDS in term of the viability of LAB and yeast. This may be attributed to the long drying time, the specific types of LAB and yeast in the sourdough, and the temperature used during the drying process [22].

The specific volume of bread

A crucial parameter for evaluating the visual quality of bread is the specific volume. Previous studies indicated that the incorporation of sourdough in bread production increased the specific volume of bread [11]. **Table 1** illustrates that adding dried sourdough during fermentation can reduce pH conditions and inhibit CO_2 production during proofing, leading to a diminished volume and specific volume of bread. During fermentation, the specific volume of bread was improved to some extent by sourdough fruits, which is consistent with the results obtained in previous studies [1,6,23,24]. In the present study, the bread produced by tomi-tomi sourdough had the highest specific volume compared to that produced by the sourdough control. However, after the drying process, the specific volume of the bread remained relatively high. The FD-FS, CD-FS and FD-CS did not decrease significantly, which may be attributed to the types of LAB and yeast in the FS and CS, the drying process times, the number of lactic acid bacteria and yeast decreasing by 1 - 2 logarithmic cycles after the drying process as a result of injury to the BAL and yeast, and the microbes undergoing inactivation during the drying process. These findings were consistent with Bartkiene *et al.* [12], who studied the effects of spray-drying and freeze-drying sourdough.

In contrast, the specific volume of CD-CS increased from 1.69 to 1.82 mL/g after drying, although this change was not statistically significant ($p > 0.05$). The rehydration of CD-FS may increase the metabolic activity of the yeast, which could generate CO_2 [11]. Furthermore, an acidic environment in sourdough could strengthen gluten structure and improve gas retention [25].

Table 1 Specific volume and microstructure of bread.

Sample (s)	Specific volume (mL/g)	Cell density (µ/mm^2)	Mean cell area (mm^2)
CSB	1.69 ± 0.14^{a}	1.19 ± 0.18^{ab}	0.86 ± 0.13^{ab}
FSB	1.76 ± 0.25^{a}	1.11 ± 0.4^{ab}	0.98 ± 0.31^{ab}
FD-CSB	1.59 ± 0.05^{a}	1.00 ± 0.10^{a}	1.02 ±0.07^{b}
CD-CSB	1.82 ± 0.19^{a}	1.09 ± 0.10^{ab}	0.92 ± 0.84^{ab}
FD-FSB	1.73 ± 0.05^{a}	1.19 ± 0.05^{ab}	0.90 ± 0.05^{ab}
CD-FSB	1.73 ± 0.11^{a}	1.51 ± 0.03^{b}	0.70 ± 0.14^{a}

CS: Control sourdough bread; FS: *Flacourtia inermis Roxb* sourdough bread; FD-CS: Freeze-dried control sourdough bread; CD-CS: Cabinet-dried control sourdough bread; FD-FS: Freeze-dried *Flacourtia inermis Roxb* sourdough bread; CD-FS: Cabinet-dried *Flacourtia inermis Roxb* sourdough bread. The superscript letters indicate that they are significantly different by Duncan's multiple range test ($p \leq 0.05$). Data are expressed as mean ± standard deviation (n = 3).

Microstructure of the bread

The microstructure of the dried sourdough bread is illustrated in **Figure 5**. As stated in Puerta *et al.* [16], the cell density in bread can be expressed as the number of cells or air cavities per centimeter of cross-sectional area in bread or crumb.

The cell density and average cell area of CS bread and FS sourdough bread were not significantly different. Conversely, between bread made from dried sourdough, CD-FSB had the highest cell density and lowest mean cell area compared to others. This might be attributed to using tomi-tomi on sourdough as a source that can lower pH during fermentation. It may affect the structure of the dough down, slow the rate of gas production, and reduce the cell density of the bread.

The Scanning electron microscope (SEM) analysis was applied to reveal a pore difference between breads made with 2 types of dried sourdough with SEM. **Figure 5** shows that of all breads prepared, the most homogeneous pore structure was obtained from breads formulated with FS and dried FDS. As illustrated in **Figure 5**, the control bread had the largest pore size, although the distribution was less homogeneous than that observed in the FS bread. This result was in line with **Figure 4** that there was a significant difference between the frequency of the number of pore areas of CS and FS ($p \leq 0.05$). It might be due to the different types of LAB and yeast present in CS and FS, that after the drying process FSB still has a homogeneous pore size distribution compared to CSB. Furthermore, the observed effect was associated with the gluten structure in the acid dough, which exhibited a superior gas retention capacity [25].

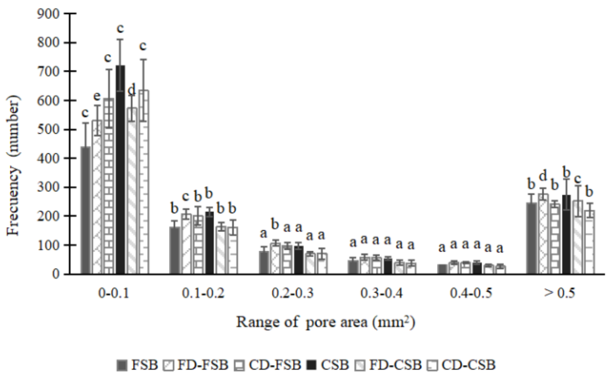

Figure 4 Distribution of pore area sourdough bread. CS-B: Control sourdough bread; FS-B: *Flacourtia inermis Roxb* sourdough bread; FD-CSB: Freeze-dried control sourdough bread; CD-CSB: Cabinet-dried control sourdough bread; FD-FSB: Freeze-dried *Flacourtia inermis Roxb* sourdough bread. Significant differences are indicated by Duncan's multiple range test ($p \leq 0.05$).

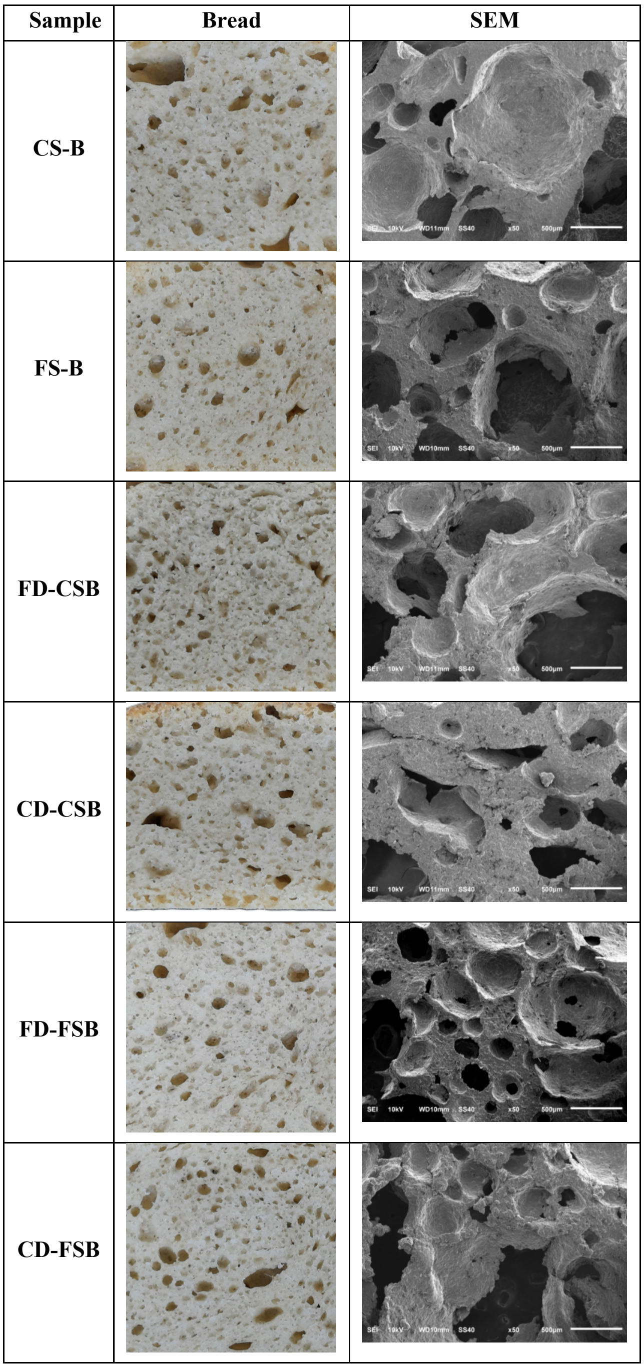

Figure 5 Scanning electron microscope (SEM) 50× images, CS-B: Control sourdough bread; FS-B: *Flacourtia inermis Roxb* sourdough bread; FD-CSB: Freeze-dried control sourdough bread; CD-CSB: Cabinet-dried control sourdough bread; FD-FSB: Freeze-dried *Flacourtia inermis Roxb* sourdough bread.

Texture analysis

The texture analysis of bread is shown in **Table 2**, with texture parameters hardness (N), gumminess (N), chewiness, springiness, cohesiveness and elasticity. Sourdough bread made using FS has a lower hardness, gumminess, chewiness, elasticity and springiness than CS bread [3].

Table 2 Textural properties of bread prepared with dried sourdough.

Texture Parameters	CS-B	FD-CSB	CD-CSB	FD-FSB	CD-FSB
Hardness (N)	65.13 ± 6.82^{c}	36.84 ± 5.79^{ab}	20.11 ± 1.18^{a}	31.97 ± 1.09^{a}	36.70 ± 3.64^{ab}
Gumminess (N)	31.07 ± 5.44^{b}	18.96 ± 4.34^{ab}	8.24 ± 0.37^{a}	11.62 ± 1.32^{a}	18.20 ± 1.10^{ab}
Chewiness	33.18 ± 7.31^{c}	17.45 ± 4.30^{bc}	6.88 ± 0.57^{a}	10.18 ± 1.56^{ab}	16.62 ± 0.99^{abc}
Springiness	1.06 ± 0.20^{b}	0.91 ± 0.01^{ab}	0.82 ± 0.03^{a}	0.88 ± 0.01^{a}	0.91 ± 0.01^{ab}
Cohesiveness	0.46 ± 0.03^{abc}	0.50 ± 0.04^{c}	0.40 ± 0.03^{abc}	0.36 ± 0.04^{ab}	0.49 ± 0.02^{bc}
Elasticity	0.43 ± 0.04^{b}	0.45 ± 0.03^{b}	0.35 ± 0.03^{a}	0.34 ± 0.01^{a}	0.43 ± 0.02^{b}

CS-B: Control sourdough bread; FS-B: Flacourtia inermis Roxb sourdough bread; FD-CSB: Freeze-dried control sourdough bread; CD-CSB: Cabinet-dried control sourdough bread; FD-FSB: Freeze-dried *Flacourtia inermis* Roxb sourdough bread. The superscript letters indicate that they are significantly different by Duncan's multiple range test ($p \leq 0.05$). Data are expressed as mean ± standard deviation (n = 3).

Table 2 shows the hardness, gumminess, cohesiveness and springiness of FS were significantly lower than those of CSB. Furthermore, FD-FSB and CD-CSB showed lower hardness, gumminess and chewiness than CD-FSB and FD-CSB. Additionally, CD-CSB exhibited significantly greater hardness, gumminess and chewiness than FD-CSB, FD-FSB and CD-FS, respectively.

The elasticity of FD-FSB was significantly lower than that of FD-CSB (0.45), CD-CSB (0.35) and CD-FSB (0.43). Dried FS fermentation was observed to have positively affect elasticity, cohesiveness and springiness in comparison to dried CS. Furthermore, the 4 types of bread were found to be similar based on the drying method. As stated by Graça *et al.* [26], the state of the gluten network is the primary determining factor. The different stages of fermentation of sourdough can result in variations in the distribution of acidic substrates within the dough, which significantly affected the formation of the gluten network.

Volatile compounds of sourdough bread

A diversity of microbes influenced the flavor of sourdough and related products. **Table 3** presents the main volatile compounds identified in FS and CS sourdough bread with their respective odors.

Table 3 Volatile compounds of FS and CS bread.

No.	Volatile compound	Area (%)		Odor description [a,b,c]
		FB	CB	
Alcohols				
1	Ethanol	29.93	22.68	Alcoholic, sweet
2	1-Hexanol	0.94	0.93	Ethereal, oil, alcohol, green, fruity, sweet, woody, floral, herbal
3	1-Octanol	0.15	0.11	Waxy, green, orange, aldehydic, rose, citrus,
4	1-Propanol	0.55	0.43	Green, citrus
5	2,4-Decadien-1-ol	0.13	0.11	Alcohol, fermented, musty, fusel
Aldehydes				
6	Acetaldehyde	4.64	3.41	Pungent, aldehydic, fruity, ethereal
7	Hexanal	2.02	1.2	Grass, tallow, fat, fresh, sweaty, green
8	Octanal	0.18	0.18	Fat, soap, lemon, green, melon, grass, floral, orange, citrus, waxy

No.	Volatile compound	Area (%)		Odor description [a,b,c]
		FB	CB	
9	Nonanal	0.57	0.51	Green, fatty, citrus
10	Benzaldehyde	2.29	1.85	Almond, strong, sharp, sweet, cherry, bitter, fruity,
11	Benzeneacetaldehyde	1.9	1.55	Honey, sweet
12	(E,E)-2,4-Nonadienal,	0.22	0.2	Fatty, green, oil, cake, aldehydic
13	(E)-2-Nonenal,	0.62	0.69	Fatty, green, aldehydic, citrus
14	Octanal	0.18	0.18	Melon, grass, floral, orange, fatty, green, aldehydic, citrus
15	Nonanal	0.57	0.51	Aldehydic, rose, citrus, floral
16	(E,E)-2,4-Decadienal,	1.38	1.06	Oil, cucumber, melon, citrus, nutty, meat, fried, pumpkin
Acids				
17	Acetic acid	4.3	4.84	Sour, acid, pungent, vinegar, sharp
Esters				
18	Methyl salicylate	0.2	0.17	Mint, green, peppermint
Furans				
19	Furan, 2,5-dihydro-3-methyl-	0.58	0.33	Caramel, sweet, mildew
20	Furfural, 5-methyl	0.25	0.3	Almond, bread-like, soil, burn roasted, sweet, toasted, caramel, burnt sugar
21	2-Acetylfuran	0.55	0.64	Sweat, balsamic, almond, cocoa, caramel, coffee, burnt
22	2-Furanmethanol	1.18	1.76	Alcohol, bread, coffee, musty, chemical
23	5-Hydroxymethylfurfural	0.06	0.06	Fat, musty, waxy, caramel
24	Furfural	0.25	0.30	Sweet, woody, almond, bread, rancid
Lactones				
25	ɣ-Nonalactone	0.28	0.24	Coconut, peach
Hidrokarbon				
26	Limonene	0.33	0.78	Lemon, orange, citrus
27	Styrene	0.98	1.51	Sweet, floral, plastic, balsamine, rubber
Other				
28	2-Methoxy-4-vinylphenol	0.22	0.17	Wood, amber, wheat

FB: *Flacourtia inermis Roxb*; CB: Control bread; a:[27], b:[28] and c: [29].

The FS bread and CS bread exhibited comparable volatile compound profiles. A slight discrepancy was observed in the percentage area. The compounds in question ranged from simple molecules such as acetaldehyde to more complex ones, including 5-hydroxymethylfurfural. The percentage area presents in FS bread and CS bread included acetaldehyde and ethanol, with significant percentage area. These contributed to the sharp aromas associated with sourdough bread. The aroma of FS bread is more dominant than that in of CS bread, contributing to this perception, including such as acetaldehyde, ethanol, hexanal and phenylethyl alcohol. The aroma of FS bread is perceived as more intense, with notes of fruity, sweet, rose, green and honey. The results indicated that LAB was during bread fermentation, contributing to the sour and spicy flavors observed in the bread [29,30].

Conclusions

The addition of tomi-tomi (*Flacourtia inermis Roxb*) starter increased LAB and yeast population on sourdough faster than CS in this study. However, the dried method with freeze-dried decreased the number of LAB and yeast on sourdough 2 times lower than cabinet-dried. Furthermore, sourdough bread with dried sourdough by freeze-dried and cabinet-dried improved the properties of bread (i.e. volume specific and the texture of bread) better than control sourdough. Due to the lower operational coast, the cabinet-dried would be an efficient method to produced dried tomi-tomi sourdough in the industrial scale. Further research is required to analyze the microbes present in fresh FS and dried FS to find out the significant value of LAB and yeast in drying method and assess dried sourdough's impact on sensory analysis.

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