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Incorporation of Kombucha Bacterial Cellulose to Produce Tomato Leathers via Cast-Tape Drying

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ABSTRACT

Bacterial cellulose from kombucha production is a by-product with a slight sour taste and potential food applications. The current research aimed to produce tomato leathers by cast-tape drying (CTD) incorporating kombucha bacterial cellulose (KBC), specifically investigating its impact on rheological properties, drying performance, and product physicochemical properties and acceptability. Tomato leathers were dried using a Teflon support at 98°C and air velocity of $1.0 \pm 0.1\ \mathrm{m\,s^{-1}}$ with a relative humidity of 60% and a temperature of 24.5°C. The substitution of tomato puree by KBC (1%–2% w/w) increased the viscosity of systems, yet it still allowed uniform spreading during the CTD process. However, the drying time increased from 7 to 9 min when KBC was added to the tomato puree. Tomato leathers showed homogeneous aspects and were completely soluble in water. Furthermore, the substitution of tomato puree by KBC did not modify the antioxidant properties (DPPH inhibition around 20%) of tomato leathers and reconstituted leather acceptability (mean score of approximately 6) due to KBC's antioxidant properties and its similar sour taste to tomato puree, respectively. These results demonstrated that KBC can be used as a natural additive in tomato leathers without altering their functional properties and acceptability.

1 | Introduction

Tomatoes (*Solanum lycopersicum* L.) are widely consumed as fresh fruits because of their sensory attributes and nutrients such as vitamins, minerals, fiber, protein, essential amino acids, monounsaturated fatty acids, carotenoids, and phytosterols (Ali et al. 2020). Furthermore, tomatoes can be processes into value-added products such as ketchup, sauce, paste, juice, puree, and leathers (Basdemir et al. 2024; Roy et al. 2024).

Tomato leathers are an alternative for processing tomatoes, it is a flexible strip or sheet made from the dehydration of tomato juice or puree, with or without other food ingredients (Basdemir et al. 2024). Tomato leathers have commonly been produced by hot air drying (Basdemir et al. 2024; Fiorentini et al. 2015). However, this drying process results in undesirable quality parameters due to the employed drying conditions, that is, relatively high air temperature and long processing times.

An alternative technique to produce tomato leathers is the cast-tape drying (CTD), also known as refractance window drying or conductive hydro-drying (Cuq et al. 2011). According to da Silva Simão et al. (2020), the use of CTD allows for the drying of products in short times and with less nutrient degradation. In this technique, a thin layer of a viscous fluid is uniformly spread over a flexible support whose bottom surface is heated by water or steam (Cichella Frabetti et al. 2021). CTD enables dehydrating fruit or vegetable purees or juices at moderate product temperatures (around 70°C) in a few minutes (da Silva Simão et al. 2021; Parisotto et al. 2020; Simão et al. 2024; Waghmare 2021).

The production of tomato leathers allows for the incorporation of new ingredients that improve their sensory attributes. Nowadays, food wastes are considered as sources of new natural ingredients and the valorization of food waste contributes to achieving the United Nations' Sustainable Development Goals (Ahmad et al. 2024). Several food wastes are matrices with high contents of bioactive compounds and macromolecules, chemical compounds with potential food applications (Ahmad et al. 2024; Valencia et al. 2021).

Among various food wastes, the bacterial cellulose from kombucha (KBC) has been highlighted as a promising food ingredient. KBC is a by-product of kombucha beverage production with no economic value. However, this by-product contains significant bioactive compounds with high antioxidant activity (Gagliardi et al. 2025). In addition, KBC has a slightly acidic flavor reminiscent of vinegar, typical of kombucha beverages, and can be used as a natural food flavoring in food products like tomato. Recently, KBC was used to stabilize oil-in-water emulsions and as a texturizer in mango jam (Chong et al. 2025; Li et al. 2023; de Farias Nascimento et al. 2025). Nevertheless, to the best of our knowledge, no study has explored the use of KBC as an additive in tomato puree. Therefore, the purpose of this research was to evaluate the use of KBC as an additive in tomato puree and its effect on the: (a) rheological properties of tomato puree; (b) kinetics of CTD for producing tomato leathers; and (c) physicochemical properties and sensory evaluation of leathers and their reconstituted purees in water, respectively.

2 | Materials and Methods

2.1 | Materials

Tomato puree (Passata rústica, Sacciali, Brazil) was purchased from the local market (Florianópolis. SC, Brazil). This tomato puree was based on 100% tomato and its chemical composition was: carbohydrates (5.4 g/100 g), sugars (4 g/100 g), proteins (1.9 g/100 g), fibers (1.4 g/100 g), and sodium (17 mg/100 g). The tomato puree characterization is informed in Sections 3.2 and 3.3. KBC was obtained from a local source in Florianópolis, Brazil. Hexane (P.A. grade, Êxodo científica, Brazil), acetone (P.A. grade, Neon, Brazil), ethanol (99.5% P.A. Neon, Brazil), 2,2-Diphenyl-1-picrylhydrazyl (DPPH, Sigma–Aldrich, Brazil), and 2,2′-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) (ABTS, Sigma–Aldrich, Brazil) were of analytical grade. Distilled water was used as the universal solvent.

2.2 | KBC Conditioning and Characterization

KBC was washed several times with distilled water and dried in a forced-air convection oven (model, Solidsteel, Brazil) at 25°C for 24 h to remove water and traces of alcohol. In sequence, KBC was frozen at −18°C and then freeze-dried (Liotop L 101, Liobras, Brazil) for 48 h. After drying, the resulting material was milled in a stainless-steel knife mill (TE-147, TECNAL, Brazil) and stored in the absence of light at 25°C.

The main strains in KBC were identified by high-throughput sequencing technologies using MiSeq Sequencing System (Illumina Inc., USA) by Neoprospecta Microbiome Technologies (Florianópolis, Brazil).

The particle size distribution of dried KBC was determined by image analysis. KBC was spread onto a white surface, and images were captured by a stereoscope (LFZ, Optech, Germany) coupled with a digital camera (Nikon D5500, Nikon Corporation, Japan) and using TSView v.73.1.7 software (Tucsen Imaging inc, USA). One hundred particles were measured using the ImageJ v 1.54 g software (National Institute Health, USA).

2.3 | Preparation and Characterization of Tomato Puree Incorporated With KBC

Tomato puree containing KBC was prepared at 20°C by substituting the puree by KBC (1% and 2% w/w). Systems were stirred using a mechanical stirrer (RW 20 digital, IKA, Germany) at 400 rpm for 10 min. Tomato puree without KBC was considered the control sample. KBC concentrations above 2% (w/w) were not considered based on preliminary experiments, as tomato suspensions with high viscosity were obtained, leading to non-homogeneous flow from the spreader (data not shown).

The samples' pH and soluble solids content were measured using a pH meter (PHS3BW, BEL, Brazil) and a manual refractometer (PAL-BX/RI, ATAGO, Japan), respectively.

Flow curves of tomato suspensions were obtained using a digital viscosimeter (MVD-30 LO, Marte Científica, Brazil) operating with the spindles L0, L1, and L2. Rheological analyses were performed at 20°C, using rotation from 5 to100 rpm and a full torque scale of 20%–90%. The viscosity was recorded for 60 s for each shear rate. The Power law (Equation 1) was used to calculate the rheological parameters of the shear stress (τ) vs. shear rate ($\dot{\gamma}$):

$$\tau = K\dot{\gamma}^{n} \tag{1}$$

where K is the flow consistency index (Pa s^n) and n is the flow behavior index (dimensionless) (Hauswirth et al. 2020).

2.4 | Drying Procedure

The batch-scale CTD system used to produce tomato leathers was previously described by da Silva Simão et al. (2019). Tomato suspensions were uniformly spread over the 0.25 mm-thick fiberglass film coated with Teflon (Lençol Armalon Standard, Indaco, Brazil) using a doctor blade with a 1.5 mm gap. The bottom surface of the Teflon-coated support was maintained in contact with steam produced by hot water at 98°C ± 1°C. The evaporated water from the material during drying was removed by an exhaustion/ventilation tunnel at an average air velocity of 1.0 ± 0.1 m s^{-1}. The experiments were performed under ambient conditions, with a relative humidity of 60% ± 2% and a temperature of 24.5°C ± 1.0°C.

The temporal evolution of moisture content (drying kinetics) and water activity of the samples throughout the drying process was evaluated by sampling three regions of the spread suspension at predefined intervals. The moisture content was determined gravimetrically using an air-circulation oven at 105°C.

The water activity (a_w) was measured using a water activity analyzer (AquaLab 4TE, METER Group, USA). The Page model (Equation 2) was used to understand the drying kinetics of samples by adjusting this model to the experimental data of moisture content versus drying time.

$$\frac{X_t - X_{eq}}{X_0 - X_{eq}} = e^{-k' t^{n'}} \tag{2}$$

where X_t, X_0 and X_{eq} are the moisture content at time t (dry basis, d.b.), the initial moisture content (d.b.), and the equilibrium moisture content (d.b.), respectively; t is the drying time (min), and k' (min^{-1}) and n' are constants of the model (Simpson et al. 2017).

The surface temperature distribution of the samples was measured using a thermographic camera (T360, FLIR, Sweden) positioned 100 cm above the drying support. Thermographic images were analyzed using the FLIR QuickReport 1.2 SP2 software (FLIR, Sweden). The emissivity of tomato suspensions was assumed 0.96 due to their initial high-water content (Durigon et al. 2016).

2.5 | Physicochemical Characterization of Tomato Leathers

2.5.1 | Visual Aspect, Morphology, Thickness, and Color

The visual aspect of the leathers was registered using a high-resolution digital camera (Nikon D5500, Nikon Corporation, Japan). The leather morphology was analyzed using the stereoscope previously described (Section 2.2). Leather thickness was assessed by measuring dried samples at 40 different points using a digital micrometer (MDC-Lite, Mitutoyo, Japan) with a precision of 1 μm.

The leather color was measured using a colorimeter (Delta Vista 450G, Delta Color, Brazil), operating with the CIELab scale and represented by L^*, a^*, and b^* (Ramos et al. 2025). A white plate ($L^*_{\text{standard}} = 89.55$, $a^*_{\text{standard}} = -0.15$, and $b^*_{\text{standard}} = 4.81$) was used to calibrate the equipment. The color difference (ΔE^*) was calculated using Equation (3):

$$\Delta E^* = \sqrt{\left(L^*_{\text{standard}} - L^*_{\text{sample}}\right)^2 + \left(a^*_{\text{standard}} - a^*_{\text{sample}}\right)^2 + \left(b^*_{\text{standard}} - b^*_{\text{sample}}\right)^2} \tag{3}$$

where the color parameters of the control leather (0% KBC) were used as the standard.

2.5.2 | Lycopene Content and Antioxidant Activity

The spectrophotometric method was used to determine the lycopene concentration (LC) in tomato leathers according to the methodology proposed by Basdemir et al. (2024). Samples (1 g) were dissolved in 50 mL of distilled water using a shaker (SL-222, Solab, Brazil) at 200 rpm for 24 h. Subsequently, 25 mL of a hexane:acetone:ethanol solution (2:1:1) was added to the reconstituted tomato puree for lycopene extraction. The resulting mixture was vortexed (K45-2820, Kasvi, Brazil) for 2 min and then kept in the dark for 10 min to obtain the upper hexane phase. The absorbance was measured in a UV–Vis spectrophotometer (METASH, UV-5100 UV–VIS Spectrophotometer, Shanghai Metash Instruments Co. LTD, China) at 503 nm, using hexane as the blank. The LC was determined according to Equation (4).

$$LC = A_{503} \times 171.7 / \text{m} \tag{4}$$

where A_{503} is the absorbance at 503 nm, 171.7 mM^{-1} is the extinction coefficient for lycopene in hexane, and m is the mass of the sample (g) (Basdemir et al. 2024).

The antioxidant properties of KBC and tomato leathers were assessed by the DPPH method as proposed by dos Santos Alves et al. (2022). In summary, 100 mg of the sample was mixed with 5 mL of distilled water in a magnetic stirrer (SP Labor, Brazil) at 500 rpm for 15 min. Afterward, 0.1 mL of tomato extract was mixed with 2.9 mL of an ethanolic DPPH solution (0.06 mM). The mixture was kept in a dark place and at room temperature for 30 min and then analyzed using a UV–Vis spectrophotometer (METASH, UV-5100 UV–VIS Spectrophotometer, Shanghai Metash Instruments Co. Ltd, China) at 515 nm. The antioxidant capacity was calculated by Equation (5) and expressed as a percentage of DPPH inhibition (%).

$$\text{Inhibition}\ (\%) = \frac{Abs_{\text{control}} - Abs_{\text{sample}}}{Abs_{\text{control}}} \times 100 \tag{5}$$

where Abs_{control} and Abs_{sample} are the absorbances at 515 nm of the control and sample, respectively.

Furthermore, the antioxidant properties of tomato samples were investigated by the free radical ABTS+ methodology as proposed by dos Santos Alves et al. (2024). In summary, an aliquot of 30 μL of each leather was transferred to test tubes with 3.0 mL of the ABTS+ radical and homogenized in a vortex. The samples were kept in the dark at room temperature for 6 min and the absorbance value was read in the same UV–Vis spectrophotometer at a wavelength of 734 nm. Free radical ABTS+ results were expressed as mg of Trolox per 100 g of leather. The quantification was done using a calibration curve made with concentrations varying between 0 and 1500 mg/mL ($y = -0.0003\times + 0.6931$, $R^2 = 0.9978$).

2.6 | Reconstitution of Tomato Leathers

Tomato leathers were dispersed in water to obtain a puree similar to that used before drying. Tomato leather with different KBC concentrations was reconstituted with distilled water to attain a soluble solids content similar to the original tomato puree. The reconstitution was carried out at 20°C by stirring the samples in a magnetic stirrer (SP Labor, Brazil) at 100 rpm for 30 min.

2.7 | Physical and Sensory Evaluation

Visual aspects and color characterizations of reconstituted purees were performed following the same methodologies described in Section 2.5.1.

Sensory evaluation was carried out in reconstituted tomato samples; this evaluation was conducted by a panel of 10 trained consultants, aged 20–40, following ISO 6564 guidelines (ISO 6564 1985). The evaluated sensory attributes were color, taste, texture, and general acceptability using a 9-point structured hedonic scale (1: dislike extremely to 9: like extremely) (dos Santos Araujo et al. 2025).

2.8 | Statistical Analysis

Results are reported as means ± standard deviation and were obtained from at least three independent experiments. Analyses of variance (ANOVA) and Tukey test of multiple comparisons were accomplished with a significance level of 5% using the Statistica software v 13.5.0.17 (TIBCO Statistica, Germany).

3 | Results and Discussion

3.1 | KBC Characterization

Several acetic acid bacteria, such as *Acetobacter malorum, Acetobacter persici, Acetobacter bacterium, Afipia genosp, Blastococcus aggregatus, Chroococcidiopsis* sp., *Gluconacetobacter entanii, Komagataeibacter hansenii*, and *Paracoccus carotinifaiens*, as well as a bacterium associated with cellulose production (*Komagataeibacter rhaeticus*) were identified in KBC. These microorganisms are typical in the kombucha production (Içen et al. 2023; Leonarski et al. 2021; Machado et al. 2016), suggesting that the KBC used in the current research has a microbiological profile comparable to those reported in the literature.

The dried KBC had a monomodal distribution with particle sizes between 0.4 and 5.7 mm and irregular shapes (Figure 1). These particle sizes were correlated with the aggregates of cellulose, indicating that the milling process did not separate the cellulose chains. In the current research, characterization of KBC particle size is an important factor since particle size can affect rheological properties of tomato purees.

3.2 | Tomato Puree Characterization

The pH and soluble solids content (SSC) of the tomato puree were 4.1° and 8.9° Brix, respectively (Table 1). These values are typical of tomato puree and agree with those informed in the literature (Abd El-Salam 2003; Basdemir et al. 2024). The pH of the tomato puree remained constant after KBC incorporation ($p > 0.05$). In the literature, foods with a pH ≤ 4.6 are classified as low-acid foods and are generally safer from bacterial contamination (Featherstone 2015). Therefore, the microbiological safety of the tomato puree was not altered after KBC incorporation. On the other hand, the incorporation of this additive increased the SSC progressively due to the dispersion of KBC in the tomato puree (Table 1).

Tomato puree exhibited a shear-thinning behavior (Figure 2a and Table 1), without thixotropy, which is crucial for spreading

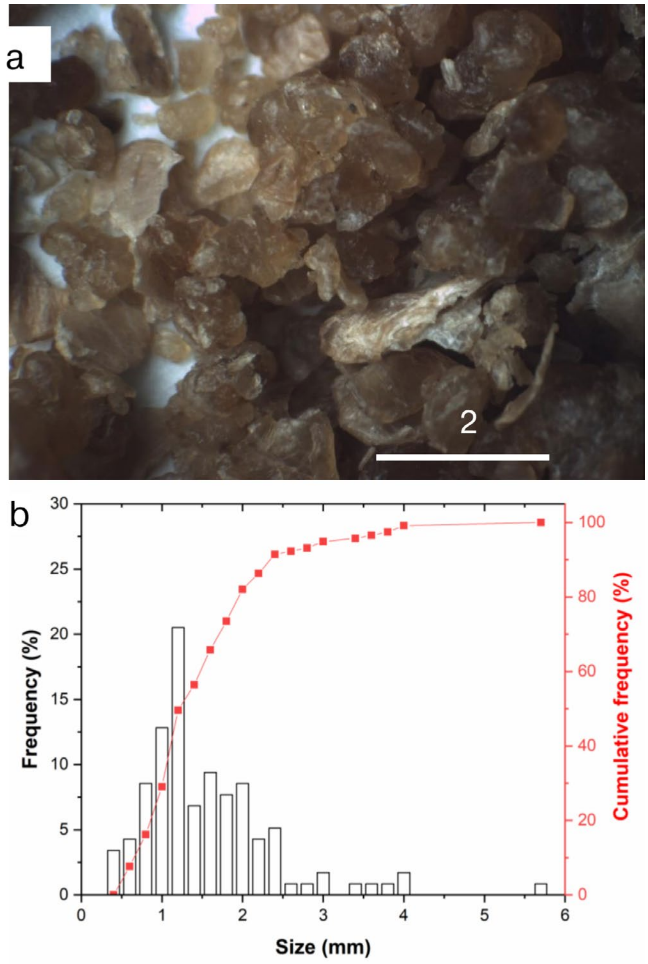

FIGURE 1 | Visual aspect and particle size distribution of dried kombucha bacterial cellulose (KBC).

TABLE 1 | pH, soluble solids content (SSC), and rheological parameters of tomato puree incorporated with kombucha bacterial cellulose (KBC).

	KBC (%)		
Parameter	**0**	**1**	**2**
pH	4.1 ± 0.2^a	4.0 ± 0.2^a	3.9 ± 0.2^a
SSC (°Brix)	8.9 ± 0.1^c	9.4 ± 0.1^b	10.0 ± 0.1^a
k (Pa s^n)	1.02 ± 0.23^c	1.31 ± 0.07^b	1.83 ± 0.07^a
n	0.37 ± 0.06^b	0.37 ± 0.08^b	0.64 ± 0.06^a
R^2	≥ 0.986	≥ 0.975	≥ 0.953

Note: Values are expressed as arithmetic means ± standard deviation of at least 3 individual test results. Different lowercase letters in the same row indicate that the means are significantly different ($p \leq 0.05$), according to Tukey's test.

suspensions in CTD (Cichella Frabetti et al. 2021; de Moraes et al. 2013). The pseudoplastic behavior of tomato puree has been correlated with the presence of particles in the suspension, such as cells, cellular walls, fibers, sugars, proteins, and soluble polysaccharides. In this system, particle orientation and their interactions are responsible for the viscosity dependence with the shear rate (Kubo et al. 2019). The incorporation of KBC increased the pseudoplasticity of the tomato puree (Figure 2a). In this way, k and n increased from 1.02 to 1.83 Pa s^n and from 0.37 to 0.64, respectively (Table 1), suggesting that KBC interacted with the components of tomato puree, increasing the flow resistance of this food. This result is in concordance with the increase in the SSC of tomato puree after KBC incorporation. Based on rheological results, it is possible to suggest the spread of tomato samples using $\dot{\gamma} \geq 1.25\,s^{-1}$ where τ values of all samples increased slowly (Figure 2a), favoring their application on the Teflon support.

3.3 | CTD Processing

The tomato puree without KBC had an initial moisture content (MC) and water activity (a_w) of around 10.12 g g^{-1} (d.b) and 0.98, respectively (Table 2). These initial values decreased with the incorporation of KBC due to the increase of solid particles, including SSC and their physical interaction between KBC and water molecules of tomato puree (Table 2).

All drying curves showed a decreasing rate which was correlated with the decreasing in water vapor pressure at the sample surface, as indicated by the reduction in a_w of tomato purees (Figure 2b) (Frabetti et al., 2021). The drying time of tomato puree to achieve MC≈0.5 g g^{-1} and a_w≈0.4 was 7 min, increasing to 9 min after KBC incorporation, suggesting that this additive bind water, making its evaporation more difficult (Figure 2b). This increase in the drying time of tomato puree containing KBC was confirmed by the time–temperature evolution at the suspension surface during the drying process (Figure 3).

After spreading, the suspension temperature rapidly increased to around 51°C–61°C in all samples. In sequence, the surface temperature increased continuously reaching temperatures above 80°C at the 7th and 9th min for the tomato without and with KBC, respectively (Figure 3). Similar drying time was informed by Durigon et al. (2016) in tomato juice dried by CTD. In contrast, Basdemir et al. (2024) used a tray dryer operating between 50°C and 70°C to produce tomato leather from tomato

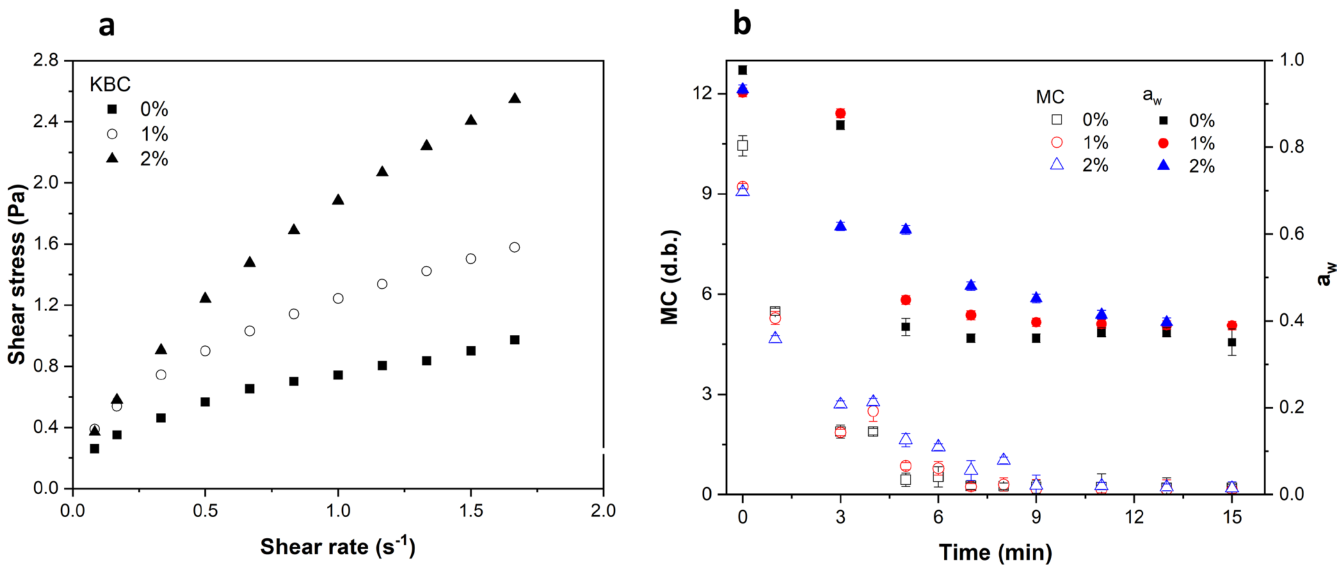

FIGURE 2 | Representatives flow curves (a) and temporal evolution of moisture content (MC) and water activity (a_w) during the drying process (b) of tomato puree incorporated with kombucha bacterial cellulose (KBC).

TABLE 2 | Moisture content (MC), water activity (a_w), and drying parameters of tomato puree incorporated with kombucha bacterial cellulose (KBC).

	KBC (%)		
Parameter	**0**	**1**	**2**
Initial MC (g g^{-1})	10.12 ± 0.03^a	9.31 ± 0.13^b	8.68 ± 0.34^c
Final MC (g g^{-1})	0.20 ± 0.01^a	0.16 ± 0.03^b	0.17 ± 0.03^b
Initial a_w	0.98 ± 0.00^a	0.95 ± 0.02^b	0.92 ± 0.01^c
Final a_w	0.37 ± 0.02^a	0.38 ± 0.01^a	0.40 ± 0.04^a
k' (min^{-1})	0.84 ± 0.21^a	0.66 ± 0.15^{ab}	0.57 ± 0.04^b
n'	0.91 ± 0.24	0.68 ± 0.26	0.61 ± 0.44
R^2	≥ 0.9932	≥ 0.9683	≥ 0.9960

Note: Values are expressed as arithmetic means ± standard deviation of at least 3 individual test results. Different lowercase letters in the same row indicate that the means are significantly different ($p \leq 0.05$), according to Tukey's test.

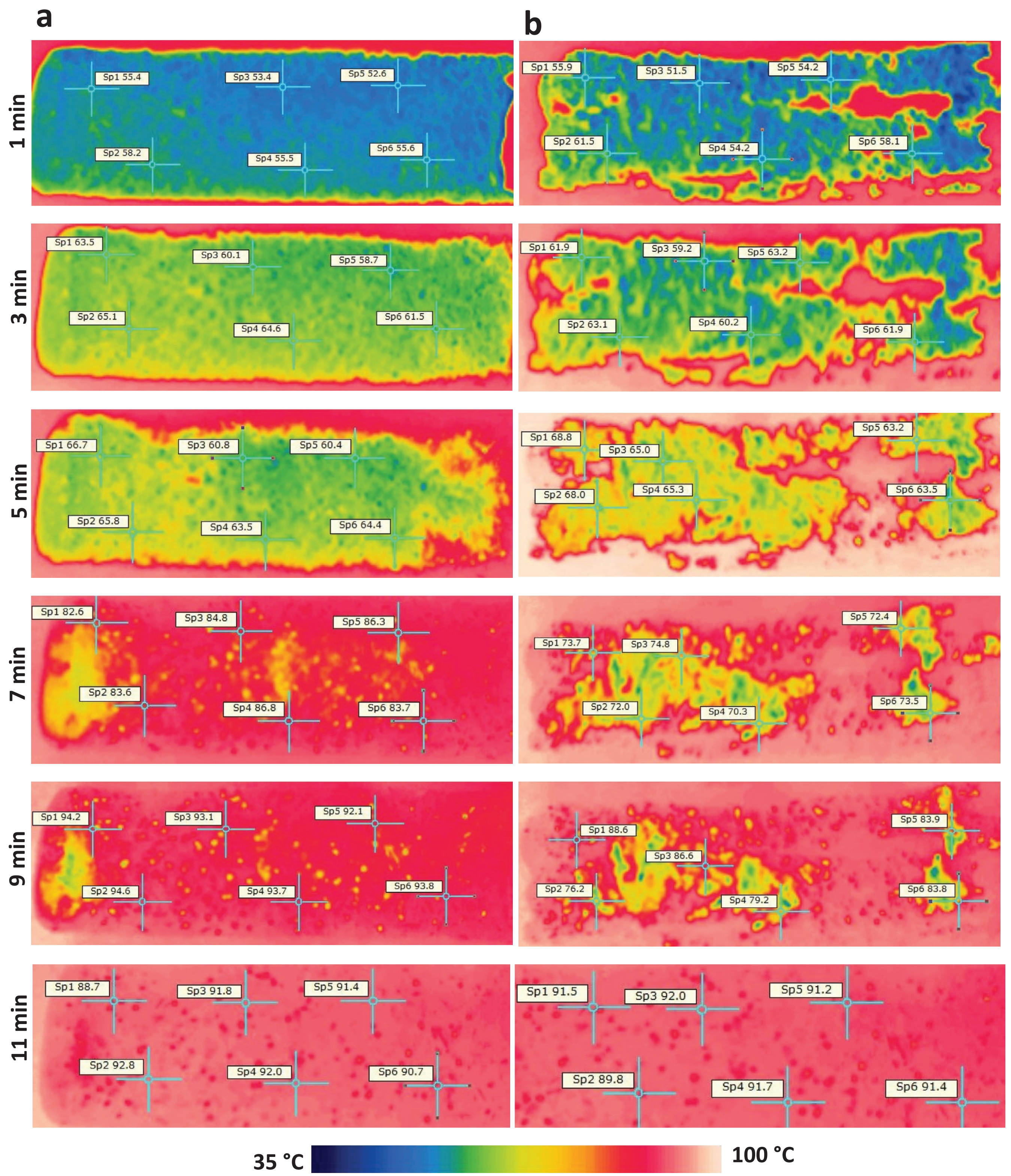

FIGURE 3 | Infrared thermographs throughout the drying process of tomato puree with 0% (a) and 2% (b) of kombucha bacterial cellulose (KBC).

juice. The authors obtained tomato leathers using drying times between 283 and 518 min. These results highlight the use of CTD as a viable alternative to producing dehydrated tomato quickly.

The drying curves had an exponential behavior, which was explained by the empirical Page model (Table 2), which is frequently used to understand the drying process of thin-layer materials (Simpson et al. 2017). The k' and n' parameters from the Page model have been correlated with the diffusion coefficient and the type of diffusion ($n'=1$ pure diffusion, $n'>1$ super diffusion and $n'<1$ sub diffusion) (Bitencourt et al. 2022). In this way, the incorporation of KBC reduced the diffusion coefficient and modified the diffusion mechanism in tomato paste because of cellulose hydration (Table 2).

After drying, all tomato leathers had low a_w values (Table 2), which are ideal for their preservation (Basdemir et al. 2024). In the literature, foods with $a_w \leq 0.60$ are not susceptible to microbial growth and have reduced nonenzymatic and enzymatic reactions (Taoukis et al. 1997).

3.4 | Tomato Leather Properties: Visual Aspect, Morphology, Thickness, and Color

Tomato leathers showed a homogeneous visual aspect, independent of the KBC concentration (Figure 4a–c). However, the incorporation of 2% KBC modified the leather color (Figure 4c), probably due to the dark yellow color of SCOBY (de Farias Nascimento et al. 2025). Optical images confirmed the homogeneous visual aspect of the leathers and revealed the presence of KBC particles with a rod shape, which were well dispersed into the tomato matrix (Figure 4d–f). These results suggest that KBC can be used as an additive (≤2 wt.%) to produce tomato leathers with a homogeneous appearance.

The leather thickness ranged between 0.20 and 0.31 mm with no statistical difference ($p > 0.05$), indicating that KBC did not alter the leather microstructure as previously observed by optical images (Table 3).

The incorporation of KBC modified the leather color. The luminosity (L^*) remained constant, whereas the redness (a^*) and yellowish (b^*) were reduced (Table 3) due to the SCOBY dark yellow color (de Farias Nascimento et al. 2025). According to the literature, color alteration can be detected by the human eye when $\Delta E^* > 3.0$ (Andretta et al. 2019). In this way, tomato leathers containing KBC have a different color than tomato leathers without KBC (0%). This fact is more evident between the tomato leathers with 0% and 2% KBC (Figure 4a,c). Nevertheless, consumers can still accept samples incorporated with KBC even if color differences are visible.

3.5 | Lycopene Content and Antioxidant Properties of Leathers

The lycopene content (LC) and antioxidant activity remained constant without alteration after KBC incorporation (Table 3). In addition, KBC has a DPPH value around 15% ± 1%, confirming its potential as an antioxidant ingredient (de Farias Nascimento et al. 2025). In the current research, LC values are comparable with those informed by Basdemir et al. (2024) in tomato leathers dried using a tray dryer at temperatures between 50°C and 70°C (LC = 193–934 mg/kg) and by Durigon et al. (2016), in tomato leathers dried by CTD at 90°C (LC = 123–515 mg/kg). In addition, the antioxidant properties of tomato leathers remained constant after KBC incorporation (Table 3). This behavior was since KBC also has antioxidant activity (de Farias Nascimento et al. 2025). In the present work, the incorporation of KBC led to a reduction in the amount of tomato paste needed to spread the same mass of sample on the equipment. In this way, a reduction of the tomato mass in the formulation without altering the antioxidant activity of the dried product only was possible because KBC also has antioxidant properties. According to the literature, tomato paste has an inhibition of the DPPH radical values between 41% and 45% (Shahzad et al. 2014) and ABTS values varying between 267 and 616 μmol of TROLOX/100 g (Katırcı et al. 2020). Differences between the inhibition values of the DPPH radical of the tomato paste and those obtained in the reconstituted tomato leathers (≈20%, Table 3) could be due to the

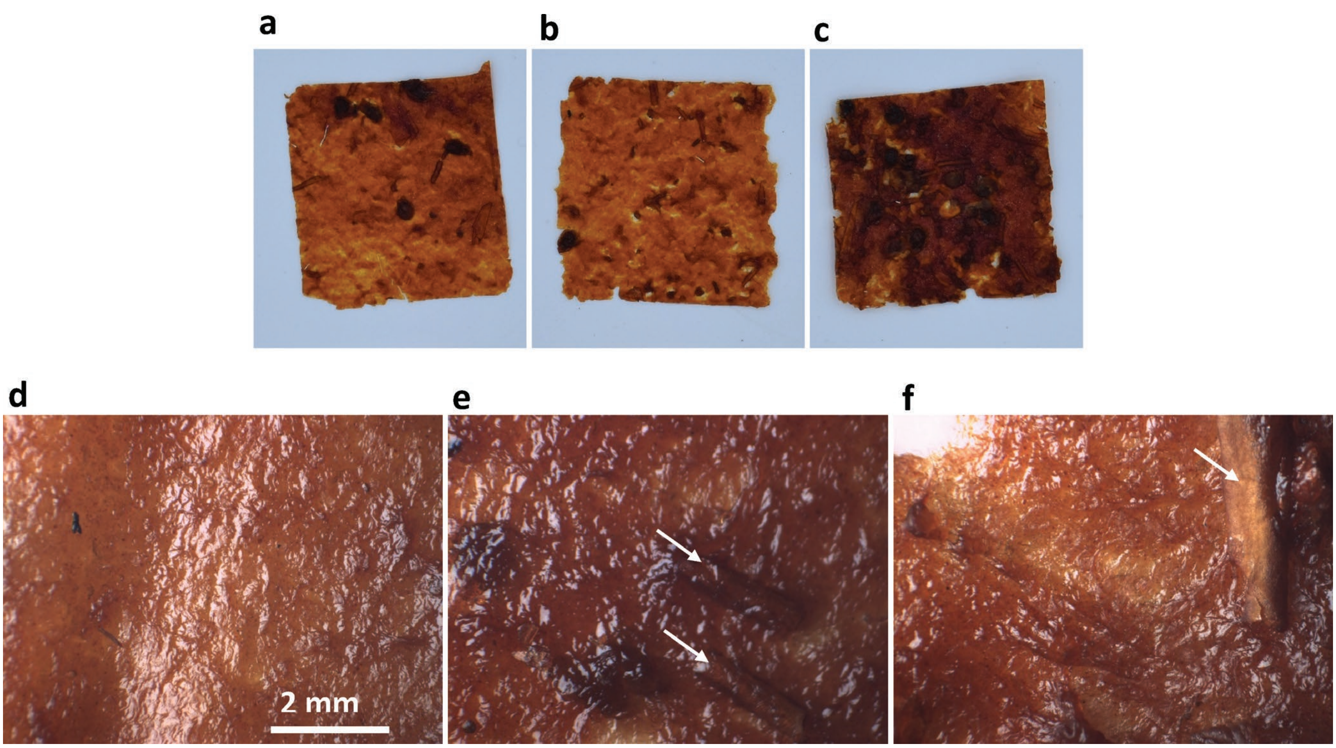

FIGURE 4 | Visual appearance and optical images of tomato leathers with 0% (a, d), 1% (b, e), and 2% (c, f) of kombucha bacterial cellulose (KBC). White arrows indicate the presence of KBC.

TABLE 3 | Color parameters, lycopene concentration (*LC*) and antioxidant activity (DPPH) of tomato leathers containing kombucha bacterial cellulose (KBC).

	KBC (%)		
Parameter	**0**	**1**	**2**
Thickness (mm)	0.20 ± 0.07^{a}	0.31 ± 0.17^{a}	0.24 ± 0.13^{a}
L^*	40.43 ± 0.80^{a}	44.67 ± 4.15^{a}	38.41 ± 4.03^{a}
a^*	32.21 ± 1.85^{a}	28.80 ± 4.75^{ab}	25.09 ± 3.25^{b}
b^*	35.62 ± 3.73^{a}	34.44 ± 2.25^{a}	23.07 ± 3.88^{b}
ΔE^*	0	5.56	14.57
LC (mg/kg)	531.56 ± 5.61^{a}	536.15 ± 2.30^{a}	529.76 ± 5.16^{a}
DPPH (%)	21.07 ± 5.92^{a}	20.43 ± 2.37^{a}	22.73 ± 1.47^{a}
ABTS (μg TROLOX/100 g)	400.15 ± 50.92^{a}	380.43 ± 60.09^{a}	420.85 ± 50.18^{a}

Note: Values are expressed as arithmetic means ± standard deviation of at least 3 individual test results. Different lowercase letters in the same row indicate that the means are significantly different ($p \leq 0.05$), according to Tukey's test.

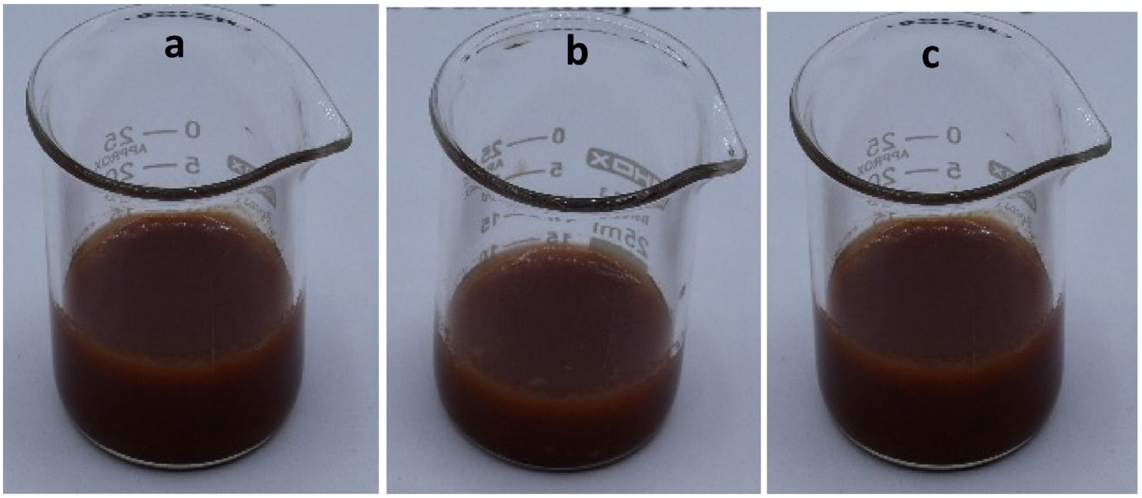

FIGURE 5 | Visual aspect of reconstituted tomato leathers containing 0% (a), 1% (b), and 2% (c) of kombucha bacterial cellulose (KBC).

TABLE 4 | Color parameters and sensory attributes of reconstituted leathers containing kombucha bacterial cellulose (KBC).

	KBC (%)		
Parameter	**0**	**1**	**2**
L^*	19.98 ± 1.77^{a}	18.89 ± 1.33^{a}	18.32 ± 0.57^{a}
a^*	11.60 ± 1.41^{a}	12.27 ± 0.30^{a}	12.04 ± 0.25^{a}
b^*	14.47 ± 2.89^{a}	16.10 ± 1.59^{a}	17.52 ± 0.29^{a}
ΔE^*	0	2.07	3.50
Color	7 ± 1^{a}	6 ± 2^{a}	6 ± 2^{a}
Taste	6 ± 0^{a}	6 ± 2^{a}	6 ± 2^{a}
Texture	6 ± 1^{a}	6 ± 1^{a}	6 ± 1^{a}
General acceptability	6 ± 1^{a}	6 ± 1^{a}	6 ± 1^{a}

Note: Values are expressed as arithmetic means ± standard deviation. Different lowercase letters in the same row indicate that the means are significantly different ($p \leq 0.05$), according to Tukey's test.

thermal degradation of the bioactive molecules during the drying process (Kelebek et al. 2017; Vallverdú-Queralt et al. 2012).

3.6 | Reconstitution, Color, and Sensory Evaluation

All tomato leathers were completely dissolved in water, and the reconstituted systems had a homogeneous visual aspect (Figure 5). In this way, tomato leathers can be consumed as snacks (leathers) or as puree after their reconstitution in water. The reconstituted samples have low L^* values, as well as a^* and b^* values tending toward the red and yellow, respectively (Table 4). Color parameters were similar to those obtained in tomato puree before drying ($L^* = 23.31 \pm 1.41$, $a^* = 13.22 \pm 1.22$, and $b^* = 14.23 \pm 2.69$), suggesting that CTD is an efficient method to obtain tomato leathers with comparable color properties than tomato puree after their reconstitution. Similar L^*, a^*, and b^* values have been informed in the literature for tomato paste (Katırcı et al. 2020). The ΔE^* values of reconstituted leathers containing KBC were lower than 3.5 compared to tomato leather with no KBC (Table 4), indicating that the human eye would have difficulty detecting the color differences between the leathers (Andretta et al. 2019).

Reconstituted tomato leather without KBC showed a good acceptance, with a general acceptability score of 6 and color, taste, and texture scores between 6 and 7 (Table 4). The incorporation of KBC did not alter the acceptability score of tomato leathers, confirming the potential of this ingredient for tomato products (Table 4). In the current research, the trained consultants attributed score values between 6 and 7 due to the sourness of tomato puree as indicated by the consultants. Adding sweeteners into the formulation is an alternative to reduce the sourness of tomato (Gallo et al. 2020).

4 | Conclusions

The current research reports, for the first time, information on the use of kombucha bacterial cellulose (KBC) as an additive in the production of tomato leathers. CTD enabled the production of tomato leathers with a shorter processing time than the conventional method. KBC can be used to modify the flow properties of tomato puree; however, a KBC concentration above 2% (w/w) excessively increased its viscosity, making its spreading during CTD difficult. A KBC concentration of 1% (w/w) was the best concentration to add to tomato puree to avoid significant rheological and color alterations in tomato puree and its leathers. The incorporation of this additive increased the drying time of tomato puree from 7 to 9 min, probably due to a reduction in the diffusion coefficient. Nevertheless, the antioxidant properties of tomato leathers remained constant, and reconstituted leathers had similar consumer acceptance, independent of KBC concentration, due to KBC's antioxidant properties and its similar sour taste to tomato puree, respectively. Further studies investigating the digestibility of tomato leathers containing KBC are recommended.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

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

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