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Byproduct Valorisation: Incorporating Millet Milk Residue in Laddu

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Abstract
The growing demand for plant-based beverages such as millet milk has led to increased generation of processing byproducts, which are often underutilized despite their nutritional potential. Valorising these byproducts provides an opportunity to reduce food waste and develop value-added foods. The present study explored the incorporation of millet milk residue into *laddu*, a traditional Indian sweet, and evaluated its functional, nutritional, and storage properties. Millet milk byproduct was stabilized through hot air oven drying and milled into flour, which was used to formulate composite flours by replacing refined wheat flour (20–90%). Sensory evaluation revealed that laddus prepared with a 60% substitution (T_2) were most acceptable, scoring well in terms of taste, texture, and overall acceptability. Functional characterization indicated that byproduct flour exhibited higher water absorption (178.15%) and oil absorption capacities (105.55%) compared to refined wheat flour, reflecting its high fibre and fat-binding ability. Proximate analysis of laddus showed that incorporation of byproduct flour increased fibre (6.24%) and ash content (1.02%), while protein and carbohydrate levels decreased, resulting in a slightly lower energy value than the control. Storage studies conducted over 30 days demonstrated a gradual increase in moisture, water activity, FFA, and TBA values, along with microbial growth and texture hardening. However, T_2 samples consistently exhibited better oxidative and microbial stability than the control. These findings highlight the potential of millet milk byproducts as sustainable functional ingredients for developing nutritious, fibre-rich traditional foods, thereby promoting waste valorisation and circular economy approaches in the food industry.

Keywords: Byproduct, valorisation, millet milk, laddu, texture analysis, storage study

1. Introduction

Utilizing food waste that is lost at any point in the food supply chain is known as waste management utility, and the majority of this waste often originates from the food processing sector. Waste utilization, usually done in the form of animal feed or product formulation (Sumalatha & Niharika, 2020) [23]. Food waste must be managed properly for food systems to flourish in a way that is beneficial for the economy, nutrition, and the health of the world. Byproducts, traditionally considered as waste, have been shown to possess significant nutritional and bioactive properties that can be harnessed for the benefit of the food industry. The utilization of these byproducts not only reduces the environmental impact of waste disposal but also presents an opportunity to create value-added ingredients that can be incorporated into new food products (Dadhaneeya *et al*., 2024) [8]. Processing them further yields a product that presents less of a disposal problem or that has some marginal economic value (Ayala-Zavala *et al*., 2011) [4].

According to the most recent data provided by the FAO, the worldwide production of fruit, vegetable, and cereal products has achieved surprisingly high values in the last decades, and food demand will continue to grow (OECD & FAO, 2019) [14]. The great productions are accompanied by a parallel loss and waste occurring in all phases of the supply chain. Cereals contributing high production as staple crops produce husk, bran, and germ as their main byproducts (Barba *et al*., 2019) [5].

Millet is a nutrient-dense and inexpensive cereal cultivated mainly in India, but is highly overlooked and underutilised due to a lack of awareness. But "The International Year Millets" brought huge demand to these "Nutri cereals" and led to the development of many novel products, and one such is millet milk (Nesari *et al.* 2023) [13]. They are associated with numerous health benefits like hypoglycemic, hypocholesterolaemia, laxative effects and

delay in gastric emptying (Bembem & Agrahar-Murugkar, 2020) [6]. As plant-based milks continue to gain demand, millet milk has emerged as one of the innovative products gaining popularity in the food industry. The residue left after extracting the water-soluble fraction from ground millet, used for producing millet milk, serves as a by-product that can be effectively utilized (Li *et al*., 2012) [12]. Byproducts obtained after millet milk processing usually contains husk, bran and little starch and good source dietary fibre content. There are research going on sustainable valorisation strategies for waste and by-products generated during grain processing emphasizing the importance of minimizing waste and maximizing resource utilization, aligning with the principles of a circular economy (Chen *et al*., 2019) [7].
Traditional foods are developed through the ages, invented, modified, utilized and evolved to overcome the monotony in the diet. The traditional food of India has been widely appreciated for its extensive use of locally grown crops (Ananthanarayan *et. al*., 2019) [1]. Hence, traditional foods are a great choice for fortification to reach a bigger population. Laddu is an Indian sweet made from a mixture of flour, sugar, shortening, and other ingredients that vary by recipe, which is shaped into a ball. It is a popular sweet in the Indian subcontinent. Has a long shelf life and is often served at festivals, family events, and religious occasions in India (Gautam *et al*., 2025) [9]. Hence, the present study was taken up to develop laddu incorporated with byproducts obtained from millet milk processing.

2. Materials and methods

2.1 Preparation of Byproduct flour: The millet milk was extracted by grinding germinated millets with water (1:2) in a mixer (Sheela *et al*., 2018) [21]. The byproduct was extracted after millet milk processing. It had more moisture content. Therefore, the stabilization process was crucial in enhancing the shelf life of the byproduct by reducing its moisture content and inactivating lipolytic enzymes. It was heat-stabilized and dehydrated by drying in a hot air oven at 60ºC for 8 hours (Santos *et al*. 2019) [18]. At industrial levels where stabilization with a microwave oven is not feasible due to its significant initial capital investment, hot air oven treatment can be utilized. The suitability of the hot air oven for stabilisation is presented in several studies (Santos *et al*., 2019; Sudha *et al*., 2011) [18, 22]. After drying, it was sieved in a 6mm mesh and packed in a polyethylene bag for further use.

2.2 Formulation of Laddu

Table 1: Formulation of laddu

Ingredients	Control	Type 1	Type 2	Type 3
Refined wheat flour(g)	100	80	40	10
Byproduct flour(g)	0	30	60	90
Ghee(g)	50	50	50	50
Jaggery(g)	50	50	50	50

Method

1. The ghee was melted in a pan.
2. Flour was added to the ghee and roasted for 10-15mins till golden colour appear
3. Then it was poured into a bowl for cooling
4. Then grounded jaggery was added and mixed well
5. It was then made into round shape balls of uniform size.
6. Total cooked weight of recipe was recorded.

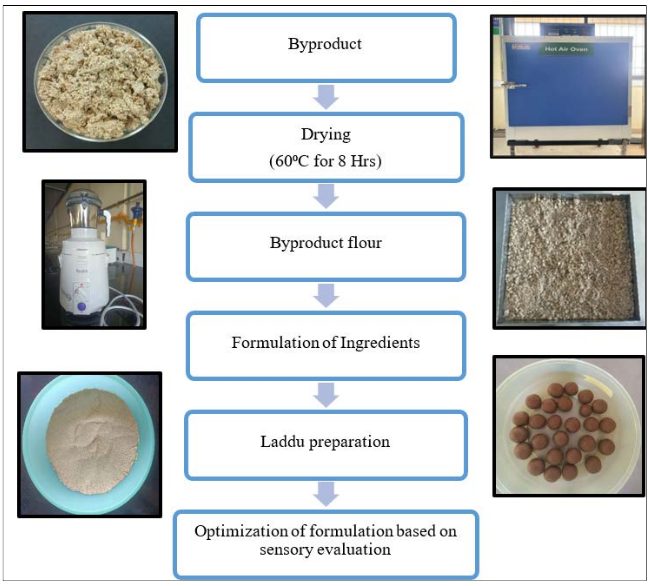

Fig 1: Schematic representation of drying byproduct flour and its utilization in laddu preparation

Fig 2: Formulation of laddu by incorporating different proportions of flour

2.3 Average weight of laddu and roundness of laddu

The average weight of laddu was recorded, and the roundness of laddu was measured by digital vernier callipers

$$\text{Average weight of laddu(g)} = \frac{\text{Total weight of laddus}}{\text{Number of laddus}}$$

Fig 3: Digital vernier caliper

2.4 Optimization of sample based on sensory evaluation
Sensory evaluation was done using a 9-point hedonic scale by 20 panel members. The panellists were asked to score products for colour and appearance, texture, flavour, taste and overall acceptability

2.5 Physicochemical and Functional properties of flour
Composite flour (3parts byproduct flour: 2 parts refined wheat flour) and Refined wheat flour (as control) were assessed for their physicochemical and functional properties.

2.6 Water absorption capacity (WAI) and Water Solubility Index (WSI)

The method outlined by Zhang (2020) [26] was employed for conducting the measurements. Accurately weighed (1g) flour mix was added to distilled water (30 ml) and mixed thoroughly. Further, the mixture was kept still at room temperature (30°C) and then centrifuged (3000 rpm for 30 minutes). The supernatant was decanted carefully into a previously weighed Petri plate (W1), and the sample was weighed to analyse the absorbed water. Further, for the water solubility index, the petri plate was dried at 100 °C, and after drying weight was recorded (W2). Water absorption capacity and water solubility were calculated and expressed as %.

$$\text{Water absorption capacity (\%)} = \frac{\text{W2} - \text{W1}}{\text{Weight of sample}} \times 100$$

$$\text{Water solubility (\%)} = \frac{\text{W3} - \text{W4}}{\text{Weight of sample}} \times 100$$

Where,
W1 - weight of tube with sample
W2 - weight of tube with sample after draining off water
W3- weight of petriplate with aliquot before drying
W4- weight of petriplate with aliquot after drying

2.7 Oil absorption capacity (OAC)
Oil absorption capacity was assessed by using the method developed by Kakar (2022) [11]. The centrifuge tube was weighed (W1) to which 1 gram of flour and 10 ml of refined oil were added and stirred for 1 min for the complete dispersion of the sample. The sample was centrifuged for 25 min at 3000 rpm. The oil that was separated was removed, and the remaining oil was drained off by inverting the tube on an absorbent paper before reweighing (W2). The absorption capacity was calculated using a formula.

$$\text{Oil absorption capacity (\%)} = \frac{\text{W2} - \text{W1}}{\text{Weight of sample}} \times 100$$

Where,
W1 - weight of tube with sample
W2 - weight of tube with sample after draining off oil

2.8 Flowability: The flowability of flour is expressed as Carr Index (CI) in terms of tapped density and bulk density as described by Jinapong (2008) [10].

$$\text{Flowability (\%)} = \frac{\text{Tapped density} - \text{Bulk density}}{\text{Tapped density}} \times 100$$

Table 2: Classification of Flour Flowability based on Carr Index

CI%	Flowability
<15	Very good
15-20	Good
20-35	Fair
35-45	Bad
>45	Very bad

2.9 Cohesiveness (Hausner Ratio)
Cohesiveness of the flour was evaluated in terms of the Hausner ratio (HR), calculated from bulk density (pB) and tapped density (pT) as suggested by Jinapong (2008) [10].

$$\text{Cohesiveness(HR)} = \frac{\text{Tapped density}}{\text{Bulk density}} \times 100$$

Table 3: Classification of Cohesiveness based on Hauser ratio

Hauser Ratio	Cohesiveness
<1.2	Low
1.2-1.4	Intermediate
>1.4	High

2.10 Bulk density
The bulk density is the weight of grains per unit volume and it is expressed in g/cc, g/ml or kg/m^3. 5-10 g weighed grain sample were chosen and transferred into the 25 ml measuring cylinder. The experiment was carried out in triplicates for more accuracy and precision. The volume of grains was noted and the bulk density of the grains were calculated using the equation:

$$\text{Bulk density (g/ml)} = \frac{\text{Weight of the sample}}{\text{Volume of the sample}} \times 100$$

2.11 Tapped bulk density
Tapped bulk density (g/ml): Tapped bulk density was measured by taking a standard graduated cylinder of 100ml capacity. Initially, the empty measuring cylinder was measured and noted, to it about 20 g of flour was added and tapped 20-25 times to tightly pack the flour materials and the volume of the weighed sample was recorded. The tapped bulk density (TBD) of flour was determined by following the formula (Jinapong, 2008) [10].

$$\text{Tapped density (g/ml)} = \frac{\text{Weight of the sample}}{\text{Recorded volume of the sample}} \times 100$$

2.12 Proximate analysis
The proximate composition was determined following standard analytical procedures (AOAC, 2019) [2], which included moisture content by the gravimetric method, fat by the Soxhlet extraction method, protein by the Micro-Kjeldahl method, crude fiber using Fibra Plus equipment, ash using a muffle furnace, and carbohydrate content calculated by difference. Energy value was also calculated.

2.13 Texture analysis
The hardness of laddu was analysed by Stable Microsystem Texture Analyzer Model (TA-H di England) using settings given in Table 4. The texture analysis has two basic components-hardware (load cell with sample platform to hold the sample and a moving head for holding the probe) and software (Texture Expert) for recording and interpreting the results for the particular texture parameter. Before the

test was conducted on the sample, the machine was calibrated for load and distance. After calibrating the machine, the sample was placed on the sample platform, and the command 'RUN TEST'

Table 4: The settings of the system for texture analysis

Parameters	Laddu
Test	Compression
Probe	P by 75
Speed	1 mm/sec
Pretest speed	2 mm/sec
Post-test speed	10 mm/sec
Distance	5 mm
Force	100g

3. Storage study
Laddus were made manually and packed in transparent plastic containers, and stored for quality analysis at room temperature for 30 days. Different analysis was done at an interval of 10 days.

3.1 Water activity
The water activity of the samples was measured using a Lab Touch advanced water activity meter (Make: Novasina).

3.2 Free fatty acid value
Free fatty acids (FFA) were analysed following the method of Ranganna (2000) [16]. Five grams of the sample were extracted with 50 ml of benzene for 30 min and filtered through Whatman No. 1 filter paper. A 5 ml aliquot of the extract was mixed with 5 ml benzene, 10 ml of 95% ethanol, and phenolphthalein indicator, and titrated against 0.02 N KOH until a light pink endpoint appeared. FFA was calculated using the formula as given below.

$$\text{FFA}(\%) = \frac{282 * 0.02\text{N KOH} * \text{Alkali used} * \text{Dilution factor}}{1000 * \text{Weight of the sample}} \times 100$$

3.3 Thiobarbituric acid (TBA) value
The extent of fat oxidation in laddu was assessed by the TBA value using the method of Zeb, & Ullah (2016) [25] with slight modifications. A 2 g sample was blended with 50 ml of 20% TCA and 50 ml of distilled water, left for 10 min, and filtered through Whatman No. 1 paper. From the filtrate, 5 ml was mixed with 5 ml of 0.01 M 2-thiobarbituric acid and incubated in a boiling water bath for 30 min to develop colour. After cooling, absorbance was measured at 532 nm against a blank prepared with distilled water. Results were expressed as absorbance per unit weight of sample.

3.4 Colour value
Photos were analysed using ImageJ® freeware (http://imagej.nih.gov/ij). The RGB image was first converted to LAB format (Image → Type → Lab Stack), splitting it into L, a, and b* channels. A grid (2000 pixels/point) was overlaid (Analyse → Tools → Grid), and a rectangular selection was made at the center of the teeth. The L*, a*, and b* values were obtained by selecting Analyse → Measure, and the mean values displayed in the results window were recorded

3.5 Microbial analysis: The pour plate method was used for assessing the microbial quality of the sample as per the procedure described by Ranganna (2008) [17]. Aerobic plate count was assessed using nutrient agar after incubation at 37 °C for 24–48 hours. Potato Dextrose Agar PDA incubated at 25 °C for 48–72 hours for enumeration of yeast and mold counts. Coliforms were analysed on MacConkey agar plates incubated at 37 °C for 24–48 hours.

3.6 Statistical analysis
All tests were performed in triplicate, and the results were expressed as mean ± standard deviation. Statistical analysis was done using CRD (Completely Randomized Design) for the storage study.

4. Results and discussion
4.1 Sensory analysis: Average weight of laddu was 10.13, and the roundness of laddu was 30.35 mm. Sensory analysis is an integral part of any product development study. The mean sensory scores for control laddu, i.e., without incorporating byproduct flour and different types of laddu (T1, T_2, T3) prepared by the replacement of refined wheat flour with byproduct (20-60%), are given in Table 5.

Table 5: Sensory evaluation of laddu incorporated with different proportions of flour

Attributes	Control	T1	T_2	T3
Colour and appearance	8.45±1.03	8.39±0.79	7.79±0.28	7.64±0.56
Texture	8.23±0.61	8.16±0.53	8.02±0.59	8.24±0.54
Flavour	7.89±0.68	7.98±0.60	7.87±0.52	7.78±0.66
Taste	7.82±0.31	8.06±0.42	8.34±0.46	8.27±0.49
Overall acceptability	8.05±0.42	8.13±0.61	8.61±0.21	8.43±0.37

Sensory analysis revealed that T_2 (60% supplementation of byproduct) was most acceptable. Even 90% supplementation received a bit good response from the panellist, but it was reported that some panellists experienced a sandiness while consuming T3. Similar results were reported by Sharma & Yammer (2022) [19] and Wang *et al.* (2023) [24]. Hence, we can conclude that higher supplementation can also be made with slight modifications to have good acceptability.

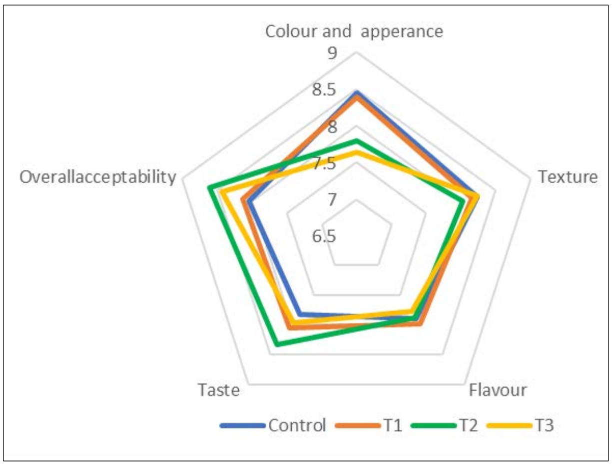

Fig 4: Radar chart representing the results of sensory evaluation

4.2 Physicochemical and Functional properties of flour:
The results obtained are presented in Table 4 below. There was significant variance in the flours' functional characteristics. In comparison to RWF and CPF, BPF demonstrated the highest water absorption capacity (178.15%) and oil absorption capacity (105.55%), suggesting improved hydration and fat-binding capabilities.

Compared to RWF (1.01%) and CPF (1.12%), BPF has a marginally better water solubility index (1.27%). While RWF had the highest bulk density (0.53 g/ml) and BPF had the lowest (0.44 g/ml), BPF also had the lowest tapped density (0.22 g/ml) in comparison to RWF (2.51 g/ml) and CPF (1.68 g/ml). Compared to RWF and CPF, BPF demonstrated superior flowability (CI: 66.41%) and lower cohesion (HR: 4.63). The Flowability of all flour was very less because of its more cohesive property. But Cohesiveness slightly decreased on addition of BPF to RWF, resulting in bit increase in flowability. The obtained results were in good agreement with Santos *et al*. (2019) [18] and Sharma *et al*. (2024) [18].

Table 6: Physicochemical and functional properties of flour

Sample	WAC (%)	WSI (%)	OAC	BD	TD	Cohesiveness (HR)	Flowability (CI%)
RWF	76.81	1.01	94.32	0.53	2.51	4.73	78.87
BPF	178.15	1.27	105.55	0.44	0.22	4.63	66.41
CPF (3:2)	113.06	1.12	97.56	0.46	1.68	3.65	73.68

Here**,** RWF-Refined wheat flour, BPF- Byproduct flour, CPF-Composite flour, WAC-Water absorption capacity, WSI- Water solubility index, OAC- Oil absorption capacity, BD-Bulk density, TD -Tapped density

4.3 Proximate analysis of laddu

Table 7: Proximate composition of laddu

Parameter	Control	T_2
Moisture Content (%)	7.56	8.35
Carbohydrates (%)	56.60	54.54
Protein (%)	10.05	5.12
Fat (%)	24.26	25.73
Crude Fibre (%)	0.97	6.24
Ash (%)	0.56	1.02
Energy value	484.94	470.21

The proximate composition showed notable differences between the control and T_2 and results are represented in Table 5. Moisture (8.35%), fat (25.73%), crude fibre (6.24%), and ash (1.02%) were higher in T_2 compared to the control (7.56%, 24.26%, 1.97%, and 0.56%, respectively). However, carbohydrates (52.54%) and protein (5.12%) were lower than in the control (56.60% and 10.05%). Consequently, the energy value of T_2 (470.21 kcal/100 g) was slightly reduced compared to the control (484.94 kcal/100 g). Hence, the optimized sample had a good amount of fibre and ash content compared to the control. But it had slightly less amount of protein compared to the control sample. The results obtained were in good agreement with Asiyanbi-Hammed *et al.* (2018) [3] and Santos *et al*. (2019) [18].

4.4 Storage study

Over the course of 30 days, the storage research showed that both the control and T_2 samples underwent progressive alterations. Moisture content and water activity gradually increased, with slightly higher values in T_2 indicating stronger water retention. Although there was a slight decrease in lightness (L*) and redness (a*), colour characteristics (L, a, b*)** remained rather constant, with yellowness (b*) exhibiting minimal fluctuation, suggesting that storage had little effect on appearance. While Thiobarbituric acid (TBA) readings also increased, indicating ongoing lipid oxidation, free fatty acid (FFA) values grew continuously, demonstrating lipid hydrolysis during storage. Significantly, T_2 showed lower TBA and FFA values than the control, indicating improved oxidative stability. Throughout the investigation, T_2 continuously demonstrated lower microbial growth in comparison to the control, and microbial counts (APC) rose with storage duration but stayed below safe bounds. Microbial counts were within the specifications. In case of yeast and molds and *E. coli* the colonies were too low to count. The product matrix hardened over time, as seen by the notable increase in textural profile (TPA) values. Overall, T_2 exhibited comparatively greater stability in terms of lipid quality, microbiological safety, and texture as compared to the control, even though both samples deteriorated during storage. The similar findings were reported by Pandey & Sangwan (2019) [15].

5. Conclusion

The study was conducted to utilize the byproduct obtained after millet milk processing effectively to formulate value-added product (laddu) and evaluate its functional properties and nutritive value after incorporation into product. The study reveals that we can successfully incorporate more than 50% of the byproduct flour to the without affecting its organoleptic properties and also improving its nutritional profile. Hence, we can conclude that Byproduct from millet milk can be effectively used for formulating different value-added products.

Table 8: Quality characteristics of laddu during storage period

Storage study																		
Days	Water activity		Moisture content		Colour value						FFA		TBA		Microbial count (APC)		TPA	
	C	T_2	C	T_2	C			T_2			C	T_2	C	T_2	C	T_2	C	T_2
					L*	a*	b*	L*	a*	b*								
0	0.203^{d}	0.205^{d}	1.233^{d}	1.09^{d}	82.983^{a}	1.860^{b}	21.544^{a}	79.123^{a}	5.289^{b}	33..984^{b}	1.147^{d}	1.230^{d}	0.206^{d}	0.219^{d}	2.967^{d}	2.653^{d}	2.133^{d}	2.247^{d}
10	0.221^{C}	0.224^{C}	1.403^{C}	1.22^{C}	82.963^{b}	1.890^{b}	20.813^{b}	78.978^{b}	5.465^{b}	33.984^{b}	2.443^{c}	2.510^{c}	0.268^{c}	0.279^{c}	3.643^{c}	3.167^{c}	2.290^{c}	2.457^{c}
15	0.226^{b}	0.241^{b}	1.643^{b}	1.527^{b}	82.961^{b}	1.887^{b}	20.812^{b}	78.978^{b}	5.465^{b}	33.983^{b}	3.880^{b}	3.927^{b}	0.288^{b}	0.335^{b}	4.853^{b}	3.970^{b}	2.547^{b}	2.833^{b}
30	0.258^{a}	0.264^{a}	1.883^{a}	1.677^{a}	82.957^{b}	1.883^{a}	20.812^{b}	78.977^{b}	5.465^{a}	34.303^{a}	4.573^{a}	4.617^{a}	0.323^{a}	0.381^{a}	5.023^{a}	5.013^{a}	2.817^{a}	3.32^{a}
SEm±	0.000	0.000	0.001	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.001	0.000	0.000	0.003	0.003	0.000	0.002
CV	0.61	0.865	0.749	1.068	0.01	0.012	0.001	0.001	0.049	0.01	0.525	0.42	0.878	0.252	0.49	0.557	0.708	0.583
CD $_{0.05}$	0.003	0.004	0.002	0.028	0.016	0.343	0.004	0.002	0.005	0.004	0.030	0.024	0.004	0.001	0.038	0.039	0.033	0.030

Here Sem± is Standard mean error, CV is Coefficient of variance and CD -Critical difference at 5% level of significance. Values followed by different letters in the same column having different significant difference at 5%(p,0.05). Here C- Control, T_2- Optimized treatment or formulation, FFA- Free fatty acid, TBA- Thio barbituric acid value, APC- Aerobic plate count in logCfu/ml, TPA- Texture profile analysis

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