HDRF Conference 2023:
Next Generation Quality Dairying

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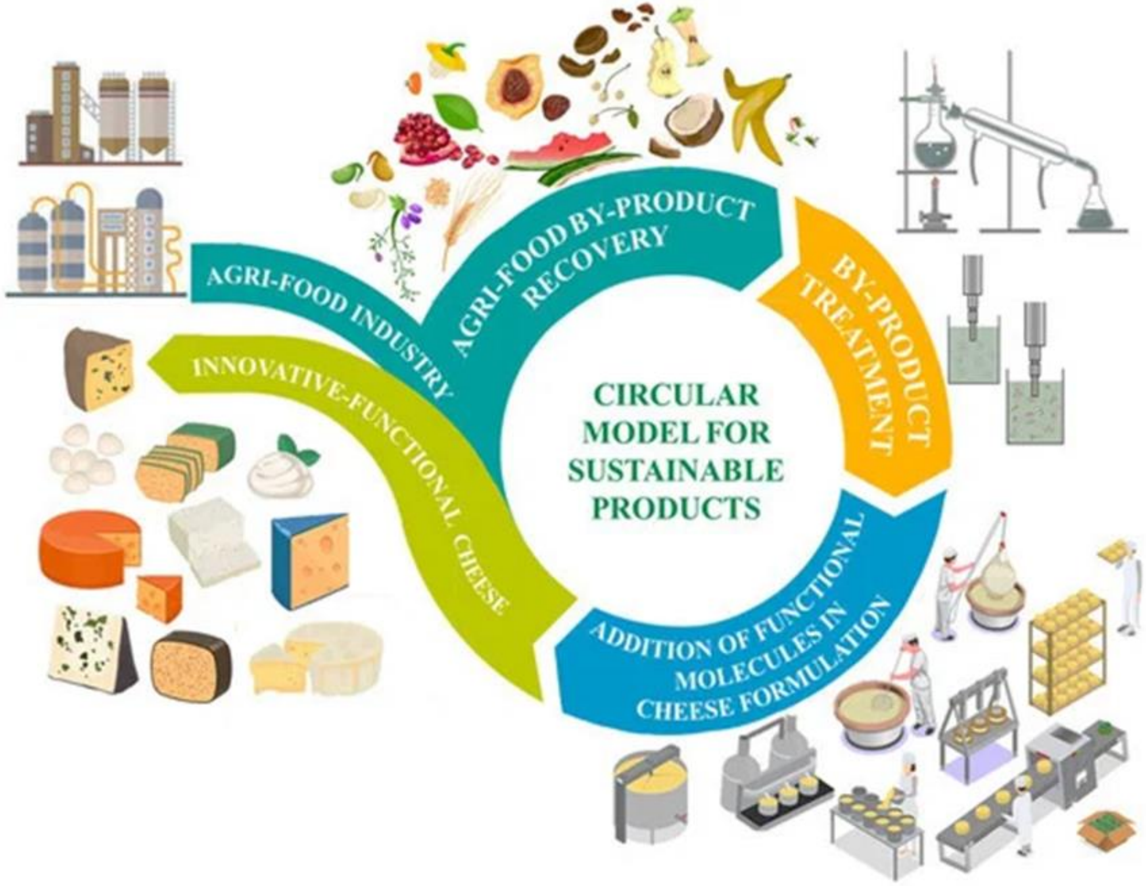
UNIVERSITÀ DEGLI STUDI DI BARI ALDO MORO

Cross-sector circular processing for dairy product quality using agri-food by-products



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antioxidants

Review

Application of Agri-Food By-Products in Cheesemaking

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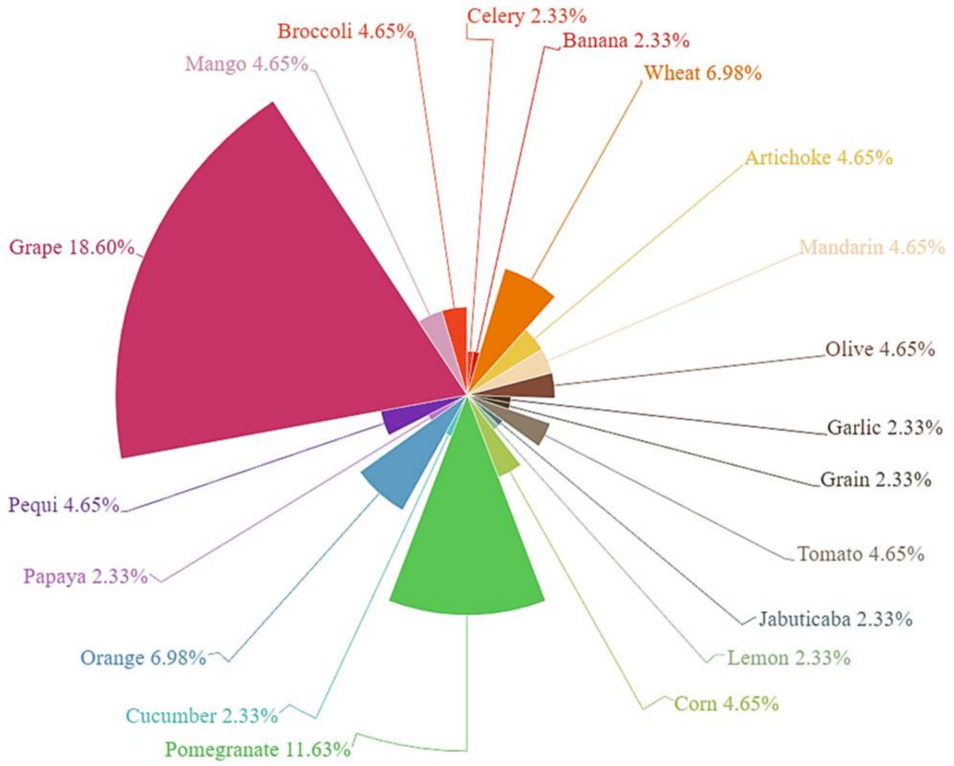
AGRI-FOOD WASTES AND BY-PRODUCTS
BIOACTIVE COMPOUNDS
ANTIOXIDANT AND ANTIMICROBIAL ACTIVITY
EXTENSION OF SHELF-LIFE
24M
TEXTURE AND SENSORY IMPROVEMENT
TECHNOLOGICAL APPLICATION
HEALTH-PROMOTING APPLICATION
PREVENTION OF FOOD-RELATED DISEASES
PREBIOTIC ACTIVITY
BIOACCESIBLE AND BIOAVAILABLE ANTIOXIDANTS
FUNCTIONAL CHEESES

BY-PRODUCTS APPLIED IN THE CHEESEMAKING BY STUDIES IN THE LITERATURE



Difonzo et al., 2023

Table 1. The main agri-food by-products and their bioactive compounds.

Product	By-Product	Bioactive Compounds	Reference
Artichoke	Leaves	Dietary fibers, polyphenols, minerals	[28]
Banana	Peel	Polyphenols, pectins, biogenic amines, phytosterols	[29]
Broccoli	Stem, leaves	Nitrogen–sulphur compounds, polyphenols, vitamins, essential minerals, dietary fibers	[30]
Cardoon	Root	Dietary fibers, minerals, polyphenols, sesquiterpene lactones	[31]
Celery	Leaves	Polyphenols, vitamins, carotenoids, terpenes, coumarins, unsaturated fatty acids	[32]
Chicory	Root	Inulin, chlorogenic acids, cinnarine, lignans, quercetin	[33]
Corn	Bran, germ	Polyunsaturated fatty acids, polyphenols, tocopherols, tocotrienols, phytosterols	[34]
Cucumber	Peel	Dietary fibers, polyphenols, minerals	[35]
Garlic	Leaves	Polyphenols, vitamins, carotenoids, phytoestrogens, minerals	[36]
Grain	Brewers' spent grain	Phenolic acids, noncellulosic polysaccharides, β-glucan	[37]
Grape	Skin, pomace, seed	Polyphenols, vitamins, stilbenes, dietary fibers	[38]
Jabuticaba	Peel	Polyphenols, dietary fibers	[39]
Lemon	Peel	Essential oils, dietary fibers, polyphenols, vitamin C	[40]
Mandarin	Peel	Polyphenols, carotenoids, vitamins, dietary fibers	[40]
Mango	Peel, kernel	PUFAs, polyphenols, carotenoids, minerals, vitamins	[41]
Oat	Bran	Peptides, amino acids, β-glucans, dietary fibers, polyunsaturated fatty acids, vitamins, minerals, polyphenols	[42]
Olive	Water, solid waste	Polyphenols, tocopherols, sterols, minerals, dietary fiber, β-carotene	[43]
Orange	Peel	Essential oils, dietary fibers, carotenoids, polyphenols, vitamin C	[40]
Pequi	Epicarp, mesocarp	Polyphenols, terpenes, flavonoids	[44]
Pomegranate	Peel	Polyphenols, flavonoids, tannins	[45]
Tomato	Peel	Lycopene, β-carotene	[46]
Wheat	Germ	Vitamins, minerals, polyphenols, polyunsaturated fatty acids, carotenoids, sterols	[47]

Difonzo et al., 2023

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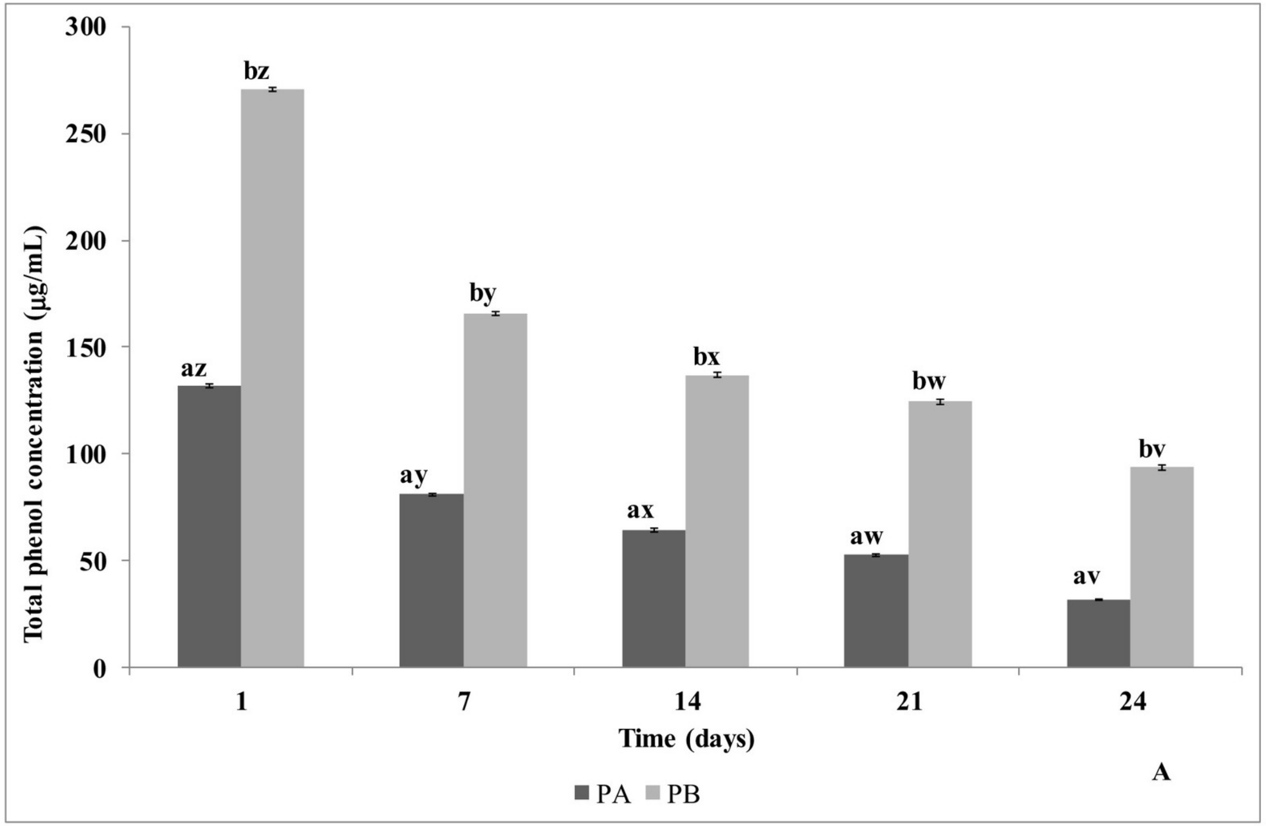
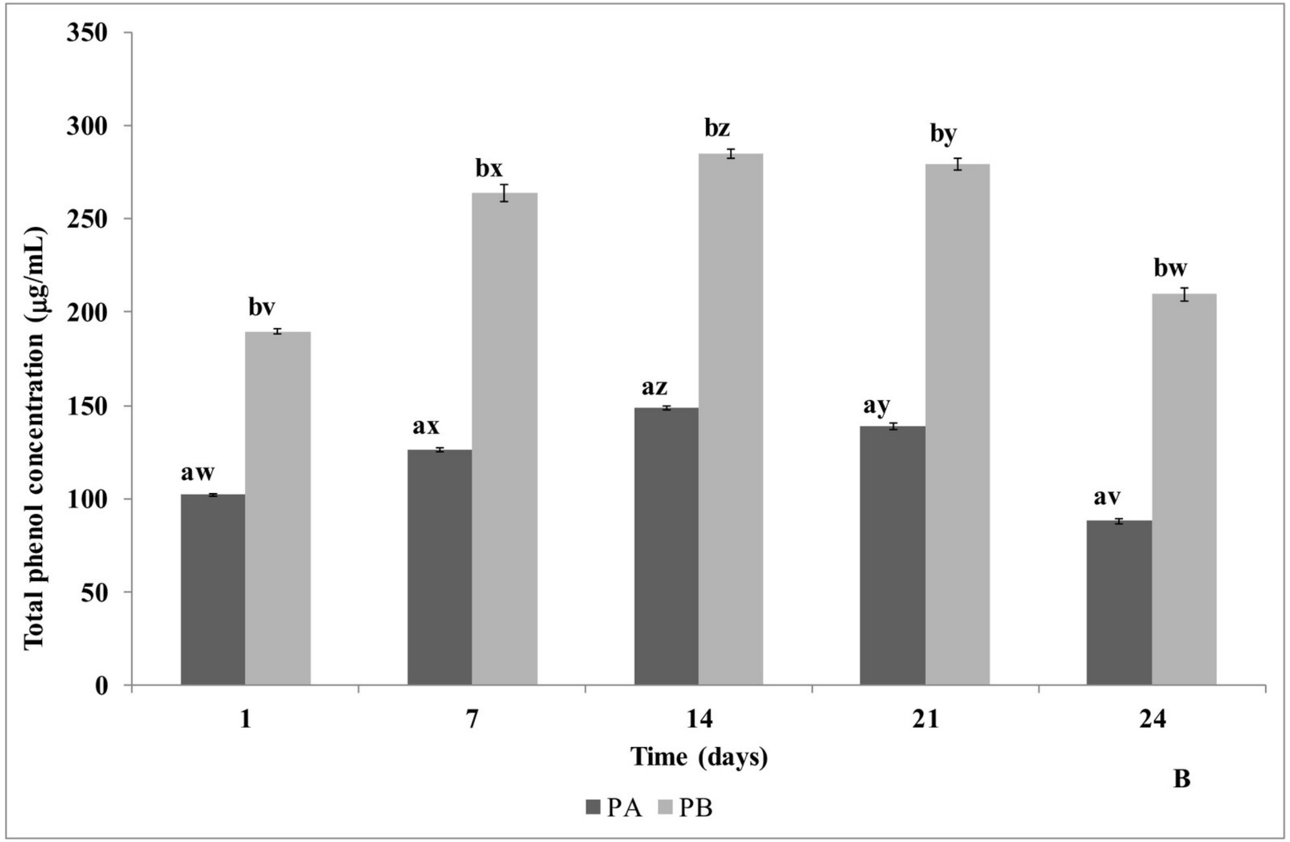
Antimicrobial efficacy of a polyphenolic extract from olive oil by-product against "Fior di latte" cheese spoilage bacteria

Roila et al., 2019



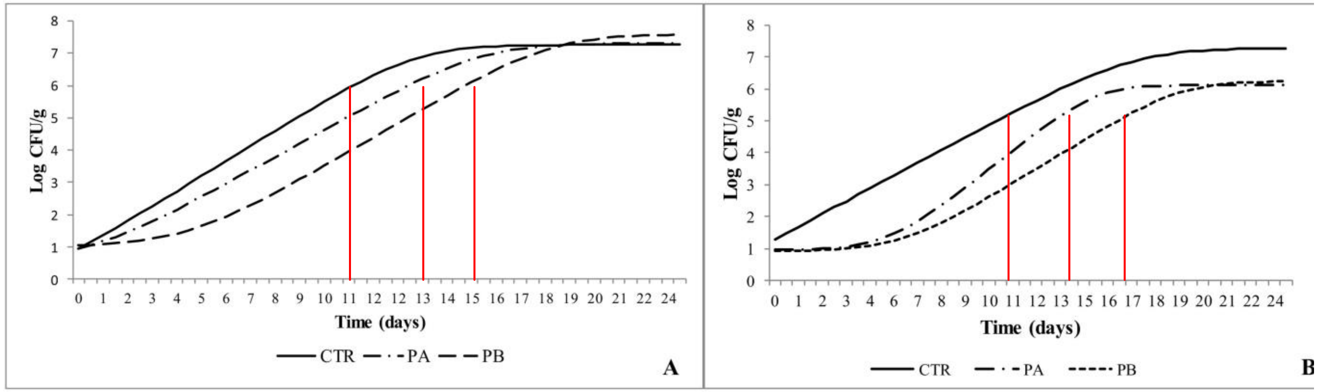


Total polyphenols content in the governing liquid (A) and "Fior di latte" cheeses (B) treated with two different concentrations of olive mill **wastewater** polyphenols extract: (250 µg/mL) PA and (500 µg/mL) PB.

Antimicrobial efficacy of a polyphenolic extract from olive oil by-product against "Fior di latte" cheese spoilage bacteria

106 cfu/g

105 cfu/ml



Estimated growth curves of Pseudomonas fluorescens (A) and of Enterobacteriaceae (B) using the Baranyi and Roberts model, in "Fior di Latte" cheeses treated with two different concentrations of olive oil polyphenols extract (250 μg/mL) PA and (500 μg/mL) PB and CTR samples.

Table 1. Estimated growth dynamic parameters using the Baranyi and Roberts model for *Pseudomonas fluorescens* and *Enterobacteriaceae* growth in "Fior di latte" cheese.

Microorganism and parameters	**CTR**	**PA**	**PB**	**SEM**	***p*-Value**
P. fluorescens					
Initial value (log CFU/g)	0.957	0.971	1.064	0.035	0.087
λ (h)	47.83^{a}	33.75^{a}	103.86^{b}	14.733	0.008
μ_{max} (log CFU/mL/h)	0.0271^{b}	0.0191^{a}	0.0197^{a}	0.001	<0.001
Final value (log CFU/g)	7.235	7.325	7.605	0.142	0.189
Enterobacteriaceae					
Initial value (log CFU/g)	1.047	0.949	0.956	0.062	0.128
λ (h)	0.00^{a}	120.86^{b}	125.81^{b}	19.48	<0.001
μ_{max} (log CFU/mL/h)	0.0175	0.0224	0.0167	0.003	0.245
Final value (log CFU/g)	7.103	6.116	7.075	0.430	0.209

Antimicrobial efficacy of a polyphenolic extract from olive oil by-product against "Fior di latte" cheese spoilage bacteria

Table 2. Estimated sensory shelf life analyses of the "Fior di latte" cheese by Weibull distribution.

Percentage	CTR days	PA days	PB days
1%	2.129	3.630	5.307
5%	4.025	5.996	8.084
10%	5.332	7.484	9.734
1st quartile 25%	7.895	10.197	12.616
Median 50%	11.132	13.368	15.831
3rd quartile 75%	14.595	16.549	18.932
90%	17.795	19.348	21.582
95%	19.722	20.981	23.098
99%	23.331	23.951	25.810

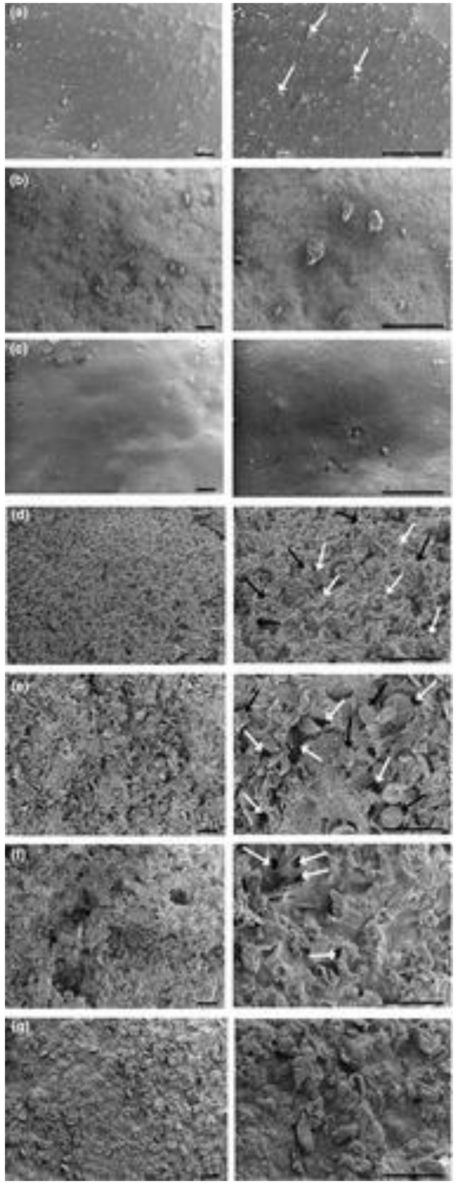
CTR: "Fior di latte" cheese maintained in untreated governing liquid; PA: "Fior di latte" cheese maintained in GL added with polyphenolic extract derived from olive oil by-product to a final concentration of 250 μg total polyphenols/mL; PB: "Fior di latte" cheese maintained in GL added with polyphenolic extract derived from olive oil by-product to a final concentration of 500 μg total polyphenols/mL.

Texture
Flavour
Appearance

Gelatin-starch composite coating containing cucumber peel extract and cumin essential oil: Shelf life improvement of a cheese model

Scanning electron microscopy (SEM)

Esparvarini et al., 2022



Control

CPE

CEO

GS

GS-CPE

GS-CEO

GS-CPE-CEO

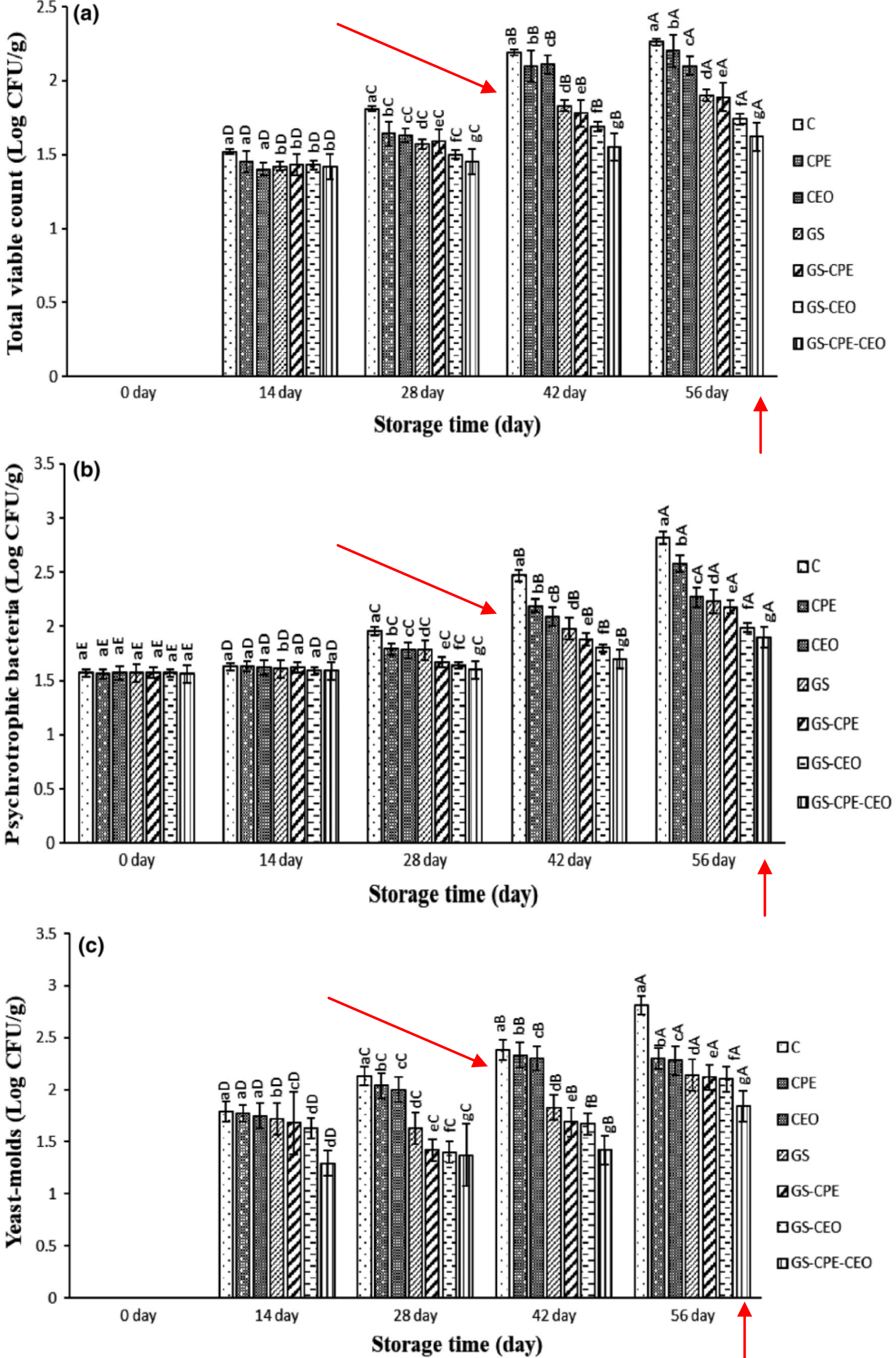
T0

Each slice was sunk for 2 min in the respective solutions. Then, the samples were removed and allowed to drain on a sterilized metal net to form the edible coatings; next, the treated samples were packaged in low-density polyethylene (LDPE) bags.

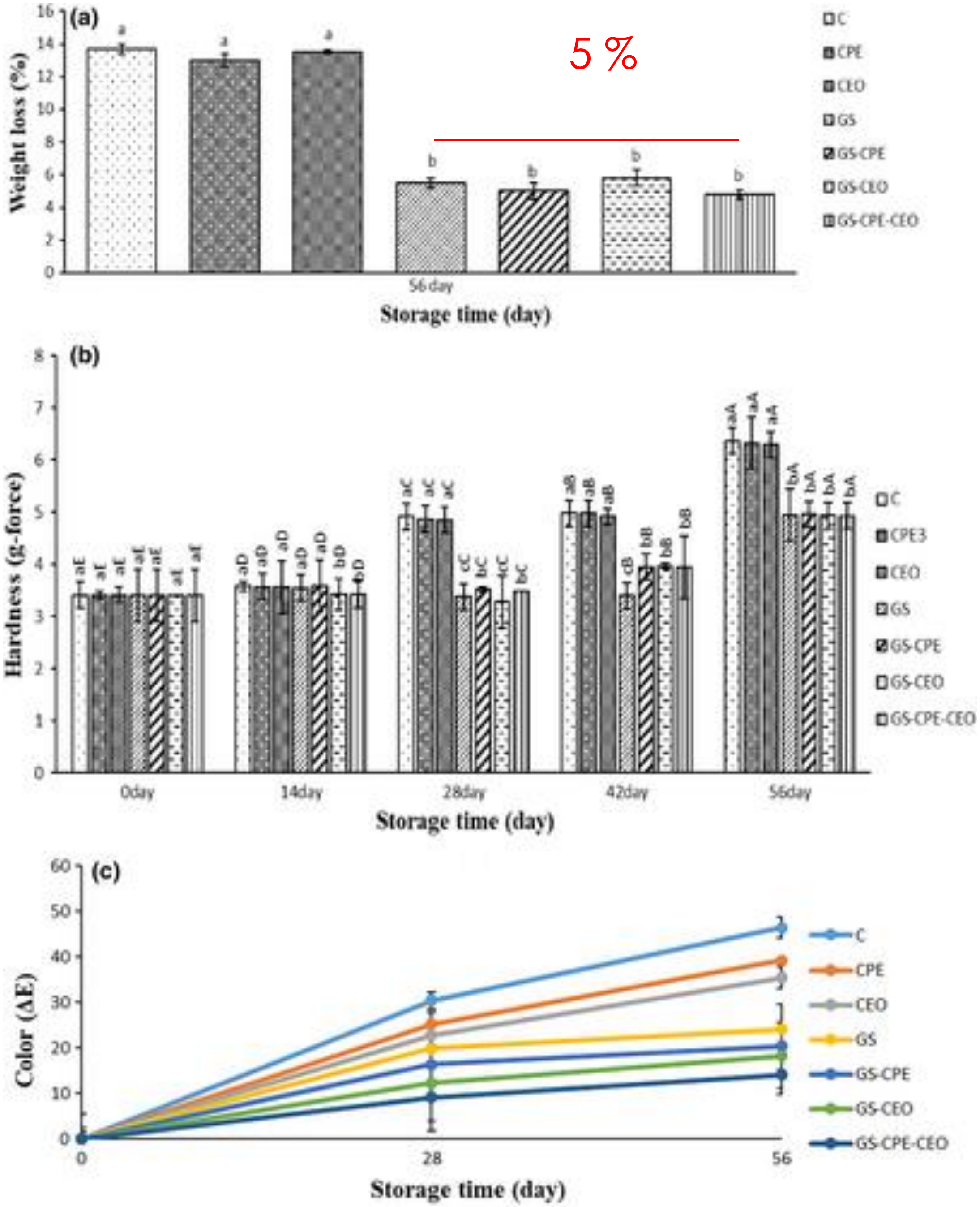
cucumber peel extract (CPE), cumin essential oil (CEO), gelatin-starch edible coating (GS), gelatin-starch edible coating-cucumber peel extract (GS-CPE), gelatin-starch edible coating-cumin essential oil (GS-CEO), and gelatin-starch edible coating-cucumber peel extract-cumin essential oil (GS-CPE-CEO). The images on the left and right show magnifications of 100× and 300×, respectively

Microbiological analysis

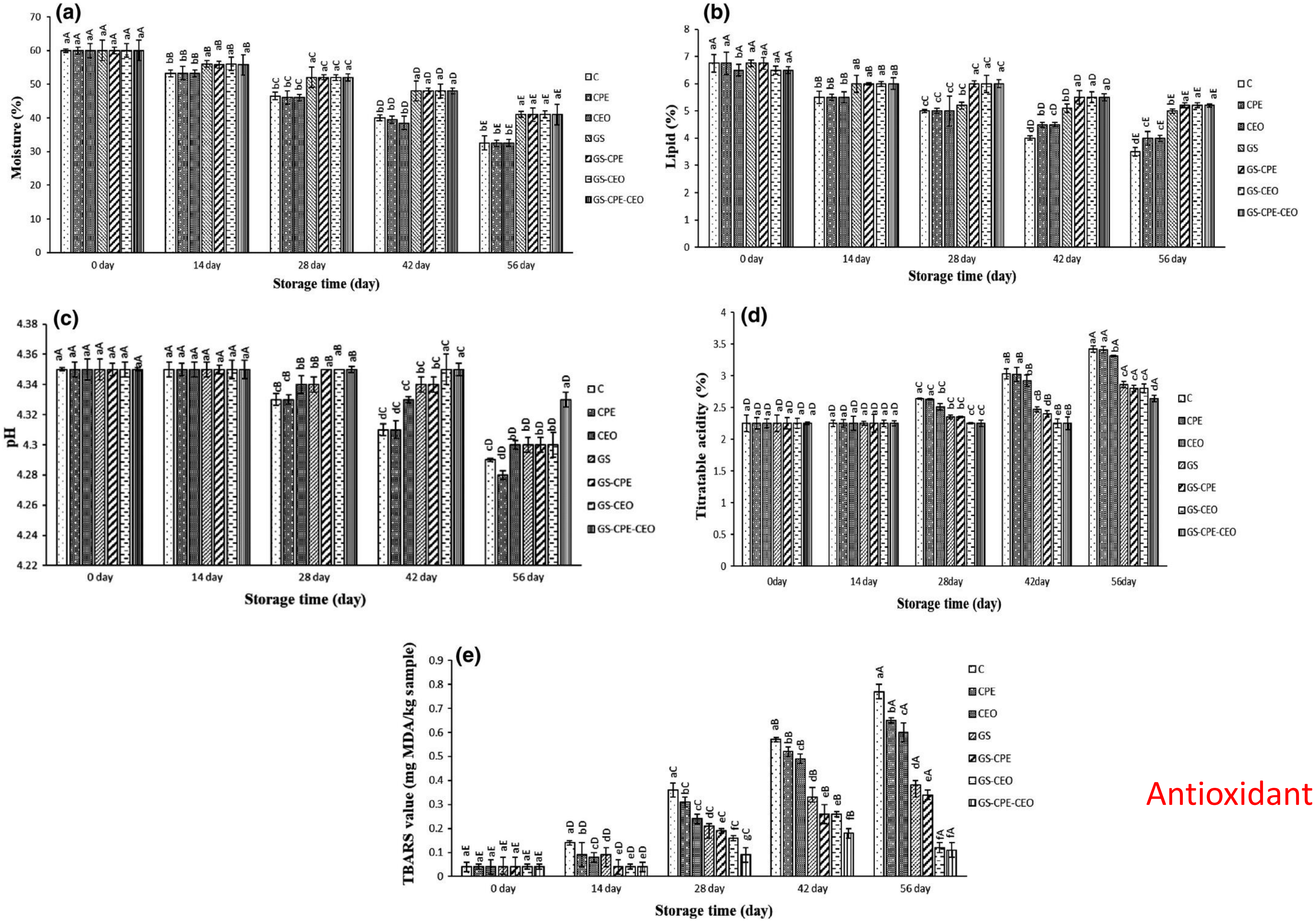
56 days of storage, 4°C



Physical properties



Chemical properties



Antioxidant acivity

Storage period (days)	Treatments	Sensory attributes			
		Taste	Odor	Texture	Overall acceptability
28	C	4.5 ± 0.45^{c}	4.1 ± 0.71^{c}	4.2 ± 0.84^{d}	4.4 ± 0.84^{bc}
	CPE	4.3 ± 0.45^{d}	4.2 ± 0.55^{bc}	4.3 ± 0.45^{c}	4.4 ± 0.45^{bc}
	CEO	4.3 ± 0.45^{d}	4.2 ± 0.55^{bc}	4.3 ± 0.45^{c}	4.4 ± 0.45^{bc}
	GS	4.5 ± 0.45^{c}	4.5 ± 0.45^{b}	4.6 ± 0.45^{b}	4.7 ± 0.45^{b}
	GS-CPE	4.5 ± 0.55^{c}	4.7 ± 0.82^{a}	4.7 ± 0.55^{ab}	4.8 ± 0.71^{a}
	GS-CEO	4.6 ± 0.55^{b}	4.7 ± 0.71^{a}	4.8 ± 0.71^{a}	4.8 ± 0.71^{a}
	GS-CPE-CEO	4.7 ± 0.55^{a}	4.8 ± 0.55^{a}	4.8 ± 0.55^{a}	4.8 ± 0.45^{a}
42	C	4.3 ± 0.71^{d}	4.1 ± 0.71^{c}	3.1 ± 0.71^{bc}	3.6 ± 0.71^{c}
	CPE	4.2 ± 0.45^{e}	4.1 ± 0.55^{c}	3.2 ± 0.55^{b}	3.7 ± 0.55^{c}
	CEO	4.2 ± 0.45^{e}	4.1 ± 0.55^{c}	3.2 ± 0.55^{b}	3.7 ± 0.55^{c}
	GS	4.5 ± 0.55^{c}	4.4 ± 0.55^{b}	4.1 ± 0.45^{ab}	4.2 ± 0.55^{b}
	GS-CPE	4.5 ± 0.55^{c}	4.7 ± 0.82^{ab}	4.1 ± 0.82^{ab}	4.4 ± 0.82^{b}
	GS-CEO	4.6 ± 0.84^{b}	4.8 ± 0.71^{a}	4.1 ± 0.71^{ab}	4.5 ± 0.82^{a}
	GS-CPE-CEO	4.8 ± 0.84^{a}	4.8 ± 0.55^{a}	4.2 ± 0.55^{a}	4.5 ± 0.82^{a}
56	C	—	3.1 ± 0.45^{d}	2.5 ± 0.45^{b}	2.9 ± 0.45^{e}
	CPE	—	3.4 ± 0.55^{cd}	2.5 ± 0.55^{b}	3.0 ± 0.45^{d}
	CEO	—	3.5 ± 0.55^{c}	2.5 ± 0.55^{b}	3.0 ± 0.55^{d}
	GS	3.5 ± 0.55^{d}	4.5 ± 0.82^{b}	3.5 ± 0.82^{a}	4.0 ± 0.82^{c}
	GS-CPE	4.1 ± 0.45^{c}	4.6 ± 0.82^{ab}	3.5 ± 0.82^{a}	4.2 ± 0.82^{b}
	GS-CEO	4.5 ± 0.82^{b}	4.7 ± 0.55^{a}	3.5 ± 0.55^{a}	4.2 ± 0.55^{b}
	GS-CPE-CEO	4.7 ± 0.71^{a}	4.7 ± 0.55^{a}	3.5 ± 0.55^{a}	4.3 ± 0.55^{a}

Note: The significance of the acronyms is the same as in Figure 3. Different letters within the same interval (day) (a, b, c, etc.) indicate a statistically significant difference ($p \leq .05$).

"Simultaneous use of the CPE and GS created an attractive greenish color on the sample surfaces."

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The Concept of Cheese Fortification

The WHO and the United Nations Food and Agriculture Organization (FAO) define fortification as "the practice of deliberately increasing the content of an essential micronutrient in food, to improve the nutritional quality of food supply and provide a benefit to public health with the least health risk".

In the functional food market, fortified dairy products account for 42.9%

It is expected that the fortified dairy product market will reach almost EUR 15,675.03 million by 2027, with a compound annual growth rate of 6.9% during the forecast period

https://www.maximizemarketresearch.com/market-report/global-fortified-dairy-products-market/26835/#details

Fruit and Vegetable By-Products to Fortify Spreadable Cheese

Lucera et al., 2020

Bioactive compounds from vegetable by-products

Spreadable cheese

Cheese samples	TPC (mg GAEs/g_{dw})	TFC (mg QEs/g_{dw})	ABTS (mg TEs/g_{dw})	FRAP (μMol $FeSO_4 \cdot 7H_2O/g_{dw}$)
Control	0.66 ± 0.06^{a}	0.47 ± 0.00^{a}	0.96 ± 0.08^{a}	1.52 ± 0.05^{a}
broccoli	1.78 ± 0.02^{d}	0.79 ± 0.07^{c}	2.09 ± 0.06^{d}	6.65 ± 0.20^{d}
corn brain	0.90 ± 0.04^{b}	0.49 ± 0.03^{a}	1.71 ± 0.09^{c}	4.53 ± 0.47^{c}
artichoke	1.20 ± 0.22^{c}	0.06 ± 0.03^{b}	1.71 ± 0.20^{c}	4.74 ± 0.13^{c}
tomato peel	0.72 ± 0.02^{a}	0.47 ± 0.00^{a}	1.51 ± 0.07^{b}	2.58 ± 0.12^{b}
red grape pomace	2.34 ± 0.15^{e}	0.86 ± 0.08^{d}	3.95 ± 0.19^{e}	26.17 ± 0.72^{e}
white grape pomace	2.74 ± 0.04^{f}	0.89 ± 0.03^{d}	4.00 ± 0.06^{e}	26.45 ± 0.25^{e}

- ✓ red and white grape pomace
- ✓ tomato peel
- ✓ broccoli
- ✓ corn bran
- ✓ artichokes

Fine powders added at 5% in the spreadable cheese

Fruit and Vegetable By-Products to Fortify Spreadable Cheese

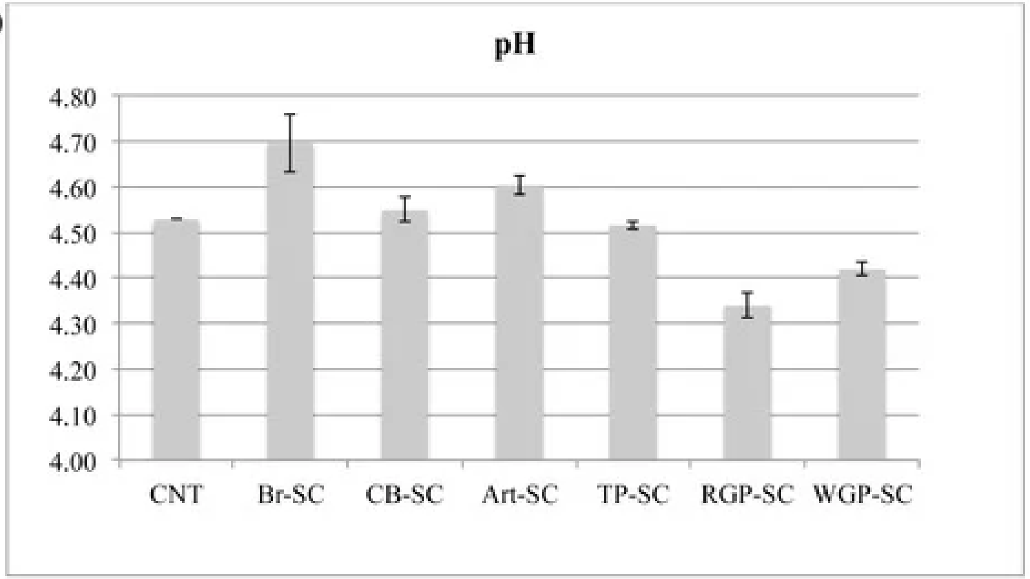
Table 2. Total phenolic content (TPC), total flavonoids content (TFC), and antioxidant activity measured by ABTS and FRAP assays of spreadable cheese enriched with 5% by-products.

	TPC (mg GAEs/g dw)	TFC (mg QEs/g dw)	ABTS (mg TEs/g dw)	FRAP (μMol $FeSO_4 \cdot 7H_2O$/g dw)
CNT	0.66 ± 0.06 [a]	0.47 ± 0.00 [a]	0.96 ± 0.08 [a]	1.52 ± 0.05 [a]
Br-SC	1.78 ± 0.02 [d]	0.79 ± 0.07 [c]	2.09 ± 0.06 [d]	6.65 ± 0.20 [d]
CB-SC	0.90 ± 0.04 [b]	0.49 ± 0.03 [a]	1.71 ± 0.09 [c]	4.53 ± 0.47 [c]
Art-SC	1.20 ± 0.22 [c]	0.06 ± 0.03 [b]	1.71 ± 0.20 [c]	4.74 ± 0.13 [c]
TP-SC	0.72 ± 0.02 [a]	0.47 ± 0.00 [a]	1.51 ± 0.07 [b]	2.58 ± 0.12 [b]
RGP-SC	2.34 ± 0.15 [e]	0.86 ± 0.08 [d]	3.95 ± 0.19 [e]	26.17 ± 0.72 [e]
WGP-SC	2.74 ± 0.04 [f]	0.89 ± 0.03 [d]	4.00 ± 0.06 [e]	26.45 ± 0.25 [e]

CNT: control spreadable cheese; Br-SC: broccoli spreadable cheese; CB-SC: corn bran spreadable cheese; Art-SC: artichoke spreadable cheese; TP-SC: tomato peel spreadable cheese; RGP-SC: red grape pomace spreadable cheese; WGP-SC: white grape pomace spreadable cheese. [a–f]: Data in columns with different superscripts are significantly different ($p < 0.05$). Results are expressed as means ± Standard Deviation for $n = 3$.

Fruit and Vegetable By-Products to Fortify Spreadable Cheese

a)



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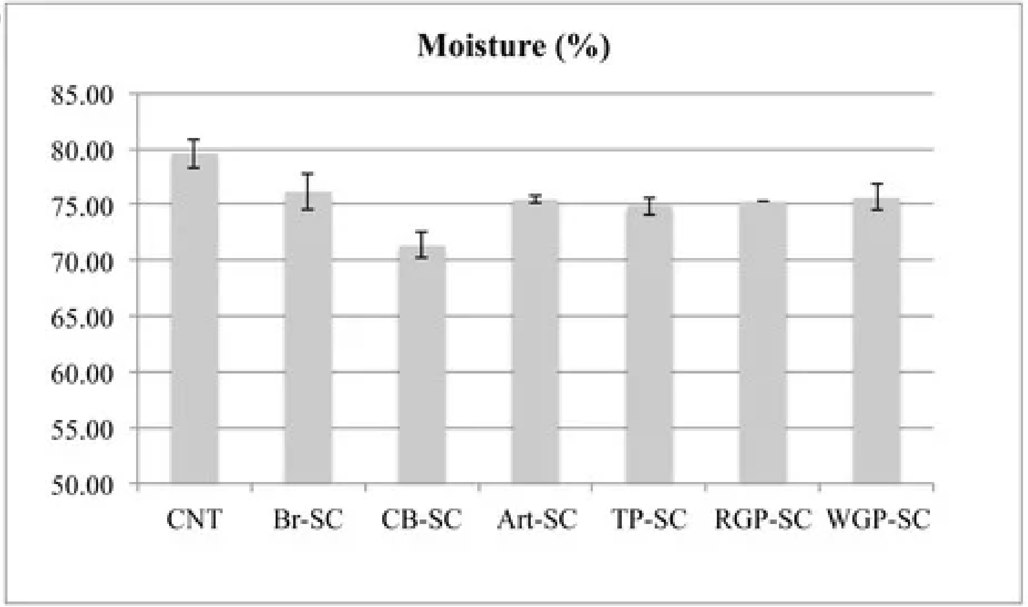


Table 3. Ratings for flavour attributes of seven spreadable cheeses investigated.

	Flavour Attributes (0–7)							
Samples	**Overall Intensity**	**Sweetness**	**Salty**	**Acid**	**Bitter**	**Astringent**	**Aftertaste Intensity**	**Aftertaste Persistence**
CNT	6.0 ± 0.3^{b}	1.2 ± 0.4^{a}	1.0 ± 0.0 a,b	4.6 ± 0.4 b	n.d.	n.d.	6.0 ± 0.0^{b}	6.0 ± 0.0^{c}
Br-SC	7.0 ± 0.0^{c}	n.d.	1.4 ± 0.4^{b}	5.1 ± 0.2 b	n.d.	1.2 ± 0.4^{a}	7.0 ± 0.2^{c}	6.7 ± 0.4^{d}
CB-SC	5.6 ± 0.3^{a}	2.0 ± 0.0^{b}	0.7 ± 0.3^{a}	4.0 ± 0.2 a	n.d.	2.0 ± 0.0^{b}	5.6 ± 0.3^{b}	5.4 ± 0.2^{b}
Art-SC	6.9 ± 0.2^{c}	n.d.	1.6 ± 0.4^{b}	4.9 ± 0.4 b	6.0 ± 0.0	0.8 ± 0.4^{a}	6.6 ± 0.4^{c}	6.2 ± 0.3^{c}
TP-SC	5.5 ± 0.3^{a}	n.d.	0.5 ± 0.5^{a}	6.0 ± 0.0^{c}	n.d.	0.9 ± 0.4^{a}	5.0 ± 0.3^{a}	4.1 ± 0.2^{a}
RGP-SC	7.0 ± 0.0^{c}	n.d.	n.d.	7.0 ± 0.0 d	n.d.	3.0 ± 0.0^{c}	7.0 ± 0.0^{d}	7.0 ± 0.0^{d}
WGP-SC	6.9 ± 0.2^{c}	n.d.	n.d.	6.9 ± 0.2 d	n.d.	3.0 ± 0.3^{c}	7.0 ± 0.2^{d}	6.2 ± 0.3^{c}

a–d: Data in each column with different superscripts are significantly different ($p < 0.05$). Results are expressed as means ± Standard Deviation. n.d.: not detected; CNT: control spreadable cheese; Br-SC: broccoli spreadable cheese; CB-SC: corn bran spreadable cheese; Art-SC: artichoke spreadable cheese; TP-SC: tomato peel spreadable cheese; RGP-SC: red grape pomace spreadable cheese; WGP-SC: white grape pomace spreadable cheese.

Fruit and Vegetable By-Products to Fortify Spreadable Cheese

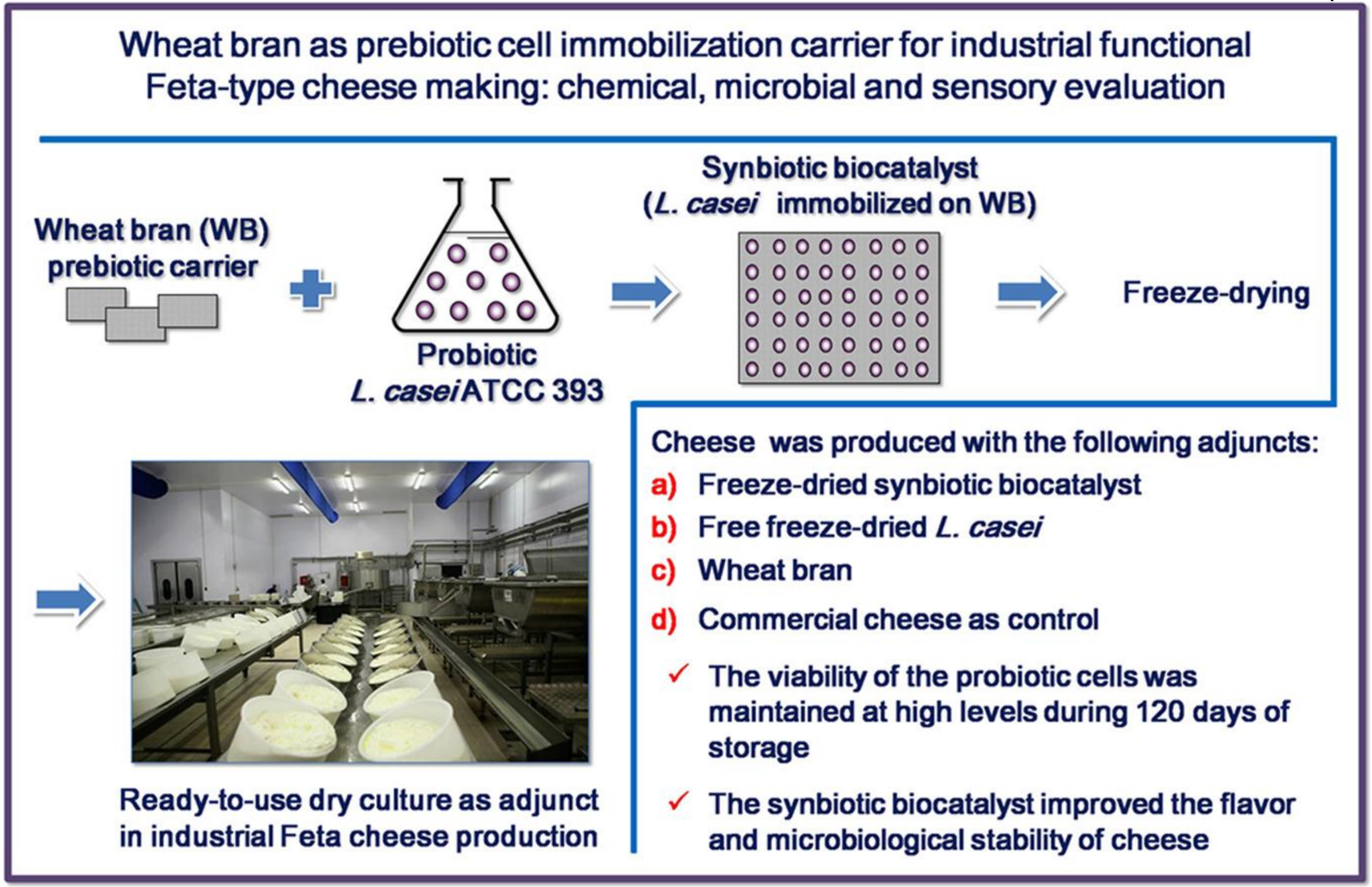
Table 4. Rating for textural attributes of spreadable cheeses investigated.

	Textural Attributes (0–7)					
Samples	**Spreadability**	**Fibrous**	**Adhesiveness**	**Graininess**	**Solubility**	**Juiciness**
CNT	7.0 ± 0.0 d	n.d.	4.0 ± 0.0 a	n.d.	6.0 ± 0.3 d	6.0 ± 0.0 c
Br-SC	4.5 ± 0.4 a	6.0 ± 0.0 b	5.5 ± 0.3 d	5.1 ± 0.2 b	3.0 ± 0.3 a	3.9 ± 0.2 a
CB-SC	6.3 ± 0.2 c	4.5 ± 0.4 a	4.5 ± 0.4 b	3.9 ± 0.2 a	5.0 ± 0.3 c	4.5 ± 0.4 b
Art-SC	5.5 ± 0.3 b	6.3 ± 0.2 c	5.5 ± 0.0 d	5.5 ± 0.0 c	3.9 ± 0.2 b	4.0 ± 0.0 a
TP-SC	6.0 ± 0.0 c	6.5 ± 0.0 c	5.1 ± 0.2 c	5.1 ± 0.2 b	4.0 ± 0.0 b	4.0 ± 0.3 a
RGP-SC	5.3 ± 0.2 b	7.0 ± 0.2 d	5.0 ± 0.0 c	6.0 ± 0.0 d	4.5 ± 0.4 c	4.0 ± 0.3 a
WGP-SC	5.1 ± 0.2 b	7.0 ± 0.0 d	5.1 ± 0.2 c	6.0 ± 0.3 d	4.6 ± 0.4 c	4.0 ± 0.3 a

a–d: Data in each column with different superscripts are significantly different ($p < 0.05$). Results are expressed as means ± Standard Deviation. n.d.: not detected; CNT: control spreadable cheese; Br-SC: broccoli spreadable cheese; CB-SC: corn bran spreadable cheese; Art-SC: artichoke spreadable cheese; TP-SC: tomato peel spreadable cheese; RGP-SC: red grape pomace spreadable cheese; WGP-SC: white grape pomace spreadable cheese.

Wheat bran as prebiotic cell immobilisation carrier for industrial functional Feta-type cheese making: Chemical, microbial and sensory evaluation

Terpou et al., 2019



Wheat bran as prebiotic cell immobilisation carrier for industrial functional Feta-type cheese making: Chemical, microbial and sensory evaluation

Pasteurized and standardized sheep's milk (70%) and goat's milk (30%)

+

rennin and the Chelmos Feta starter

a) freeze-dried synbiotic immobilised biocatalyst as adjunct (FIL)

b) cheese made with free freeze-dried L. casei cells (in equal cell counts as in FIL), as adjunct (FFL)

c) cheese made with 10 g of wheat bran as prebiotic adjunct (WB)

d) commercial Feta cheese (Chelmos starter only) (CS)

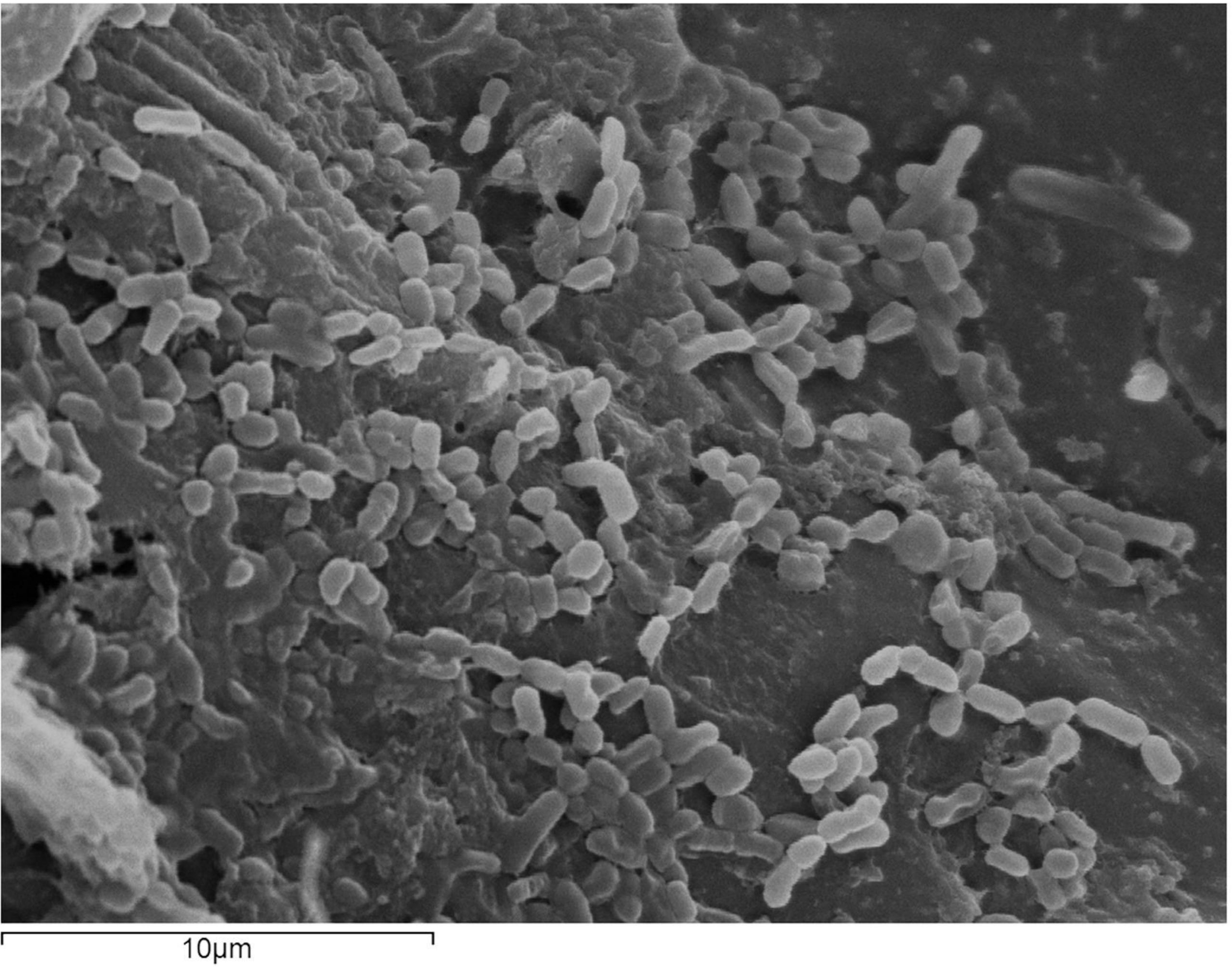
The Chelmos Feta starter culture was added in the milk, mixed well and left undisturbed for 2 h for curd formation.

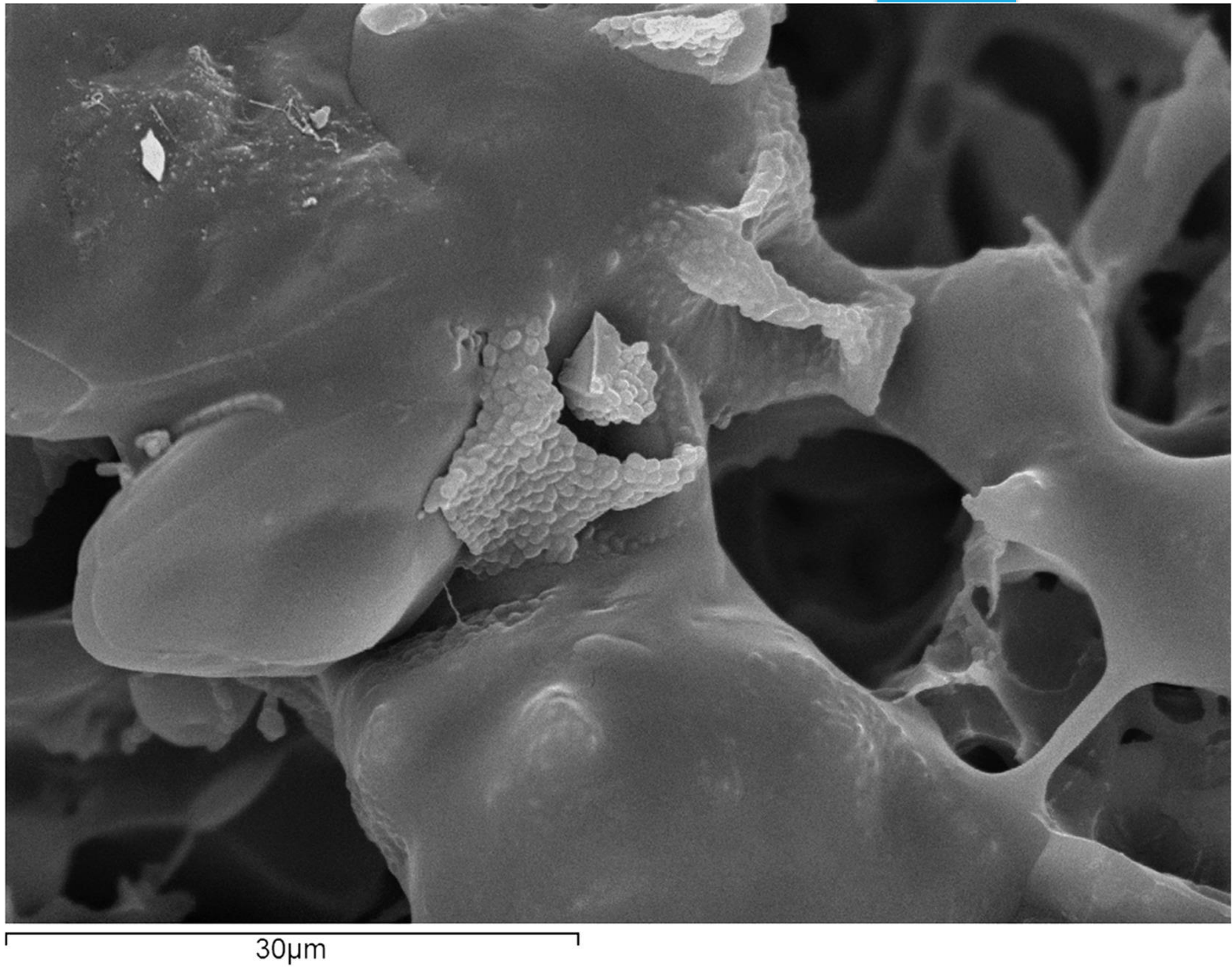
The adjuncts in each case were then added and mixed well for 5 min. All cheese samples were placed into cubic cheese molds and were left at room temperature (17–23 °C) overnight for whey to drain.

The cheeses were then were placed in brine (12% salt) and were kept at 15–18 °C for approximately 15–20 days (until pH dropped to 4.6), and then at 4 °C for 40–45 days in 6% brine to mature.

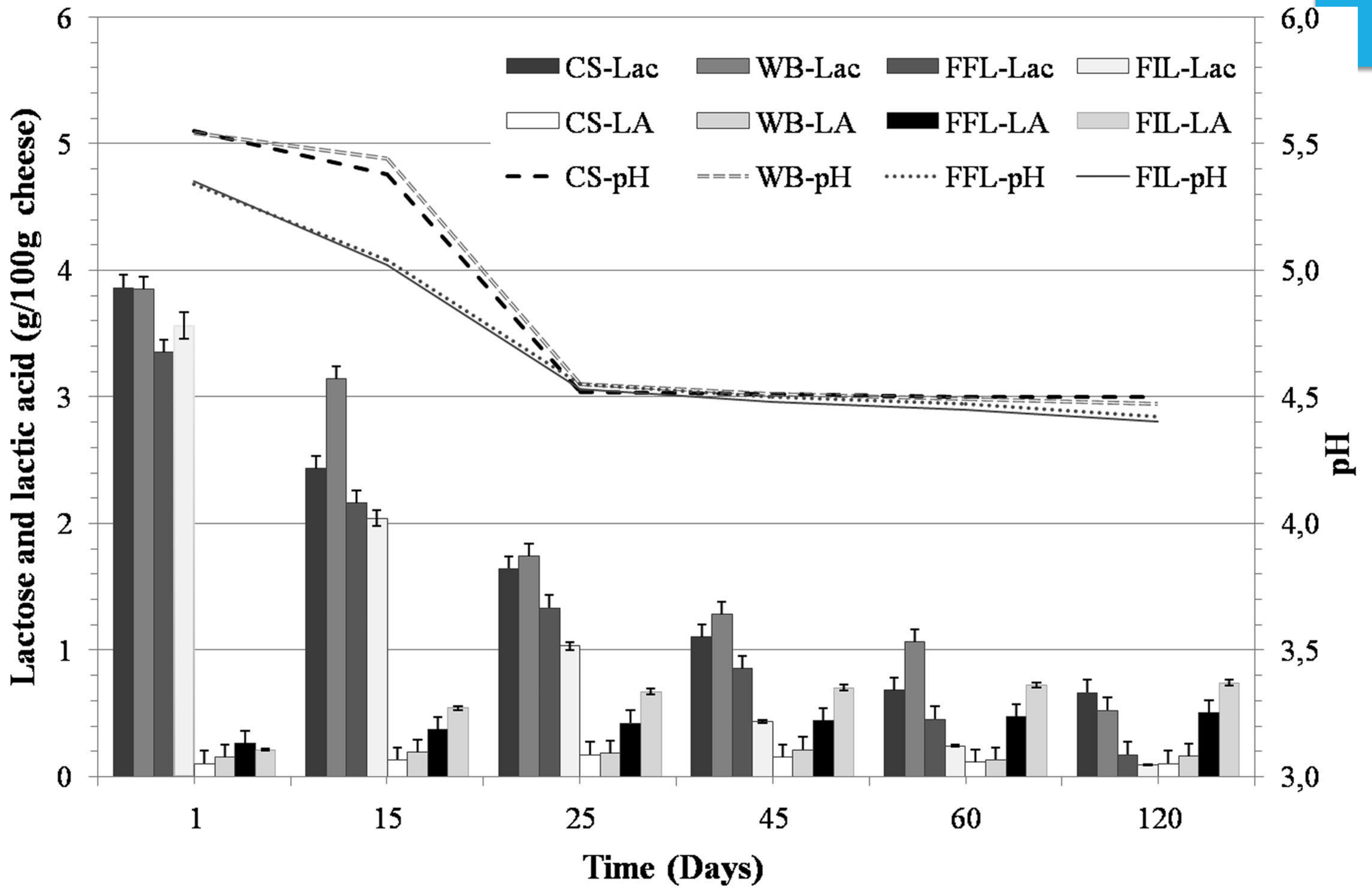
After a total of 60 days of maturation, the cheese samples were stored at 4 °C in the 6% brine for other 60 days.

SEM photographs of freeze-dried synbiotic biocatalyst (L. casei ATCC 393 immobilised on wheat bran) at different magnifications and optical views.





Physico-chemical characteristics of cheese



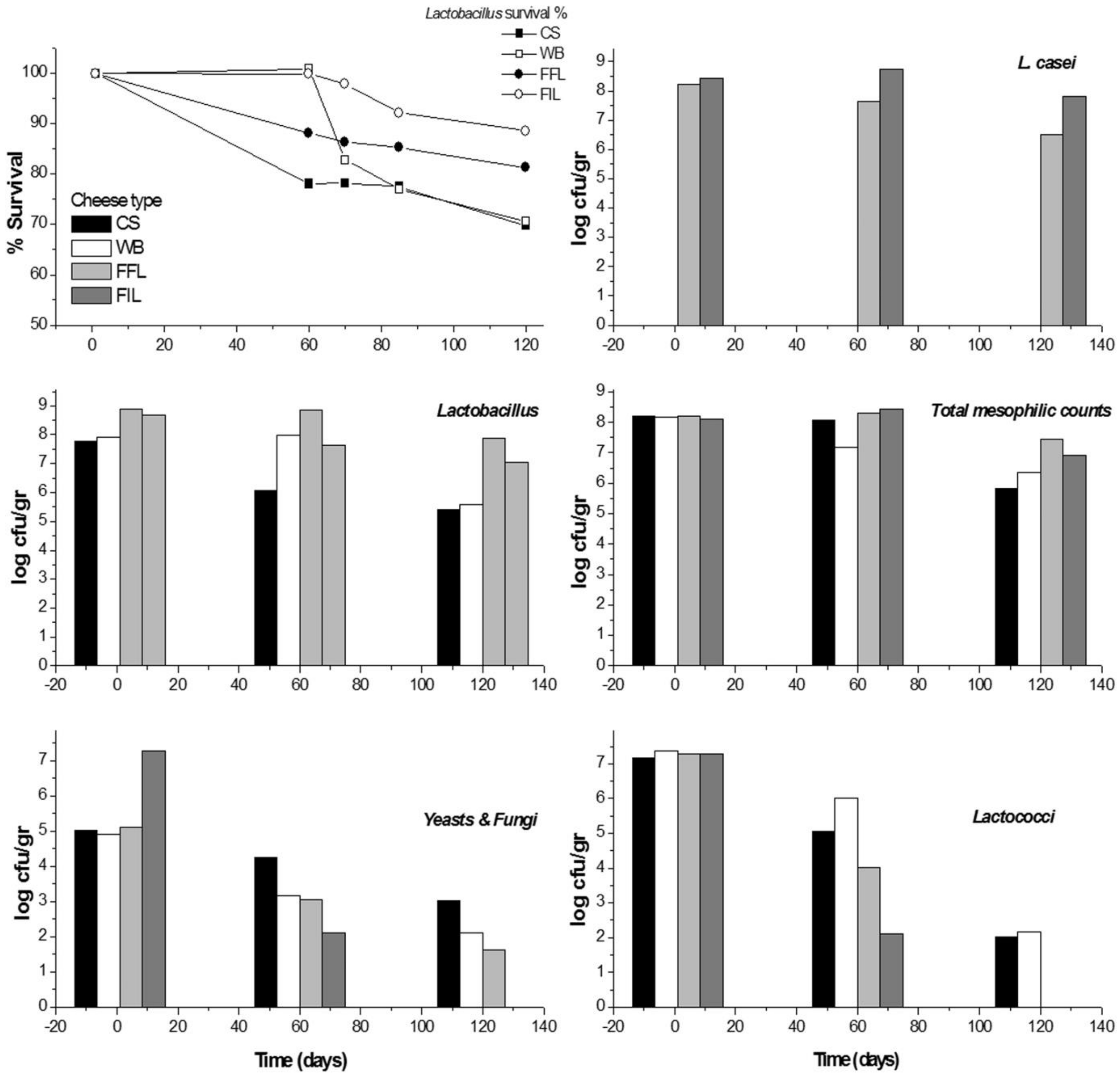
Cell survival in simulated gastric juice

Table 2. Effect of the exposure to simulated gastric juice (pH 3) on the survival (log cfu/g) of *L. casei* ATCC393 in the freeze-dried (free and immobilised), cultures and in the produced cheeses.

Time (min)	**Free freeze-dried *L. casei* (FFL)**	**Freeze-dried immobilised *L. casei* (FIL)**	**Cheese with FFL (day 1)**	**Cheese with FIL (day 1)**
0	9.00 ± 0.12	8.13 ± 0.10	8.24 ± 0.10	8.43 ± 0.10
10	8.52 ± 0.10	8.00 ± 0.13	8.02 ± 0.10	8.39 ± 0.11
30	8.45 ± 0.14	7.96 ± 0.13	7.94 ± 0.11	8.32 ± 0.12
60	8.41 ± 0.16	7.84 ± 0.11	7.89 ± 0.08	8.26 ± 0.13
90	8.51 ± 0.11	7.81 ± 0.09	7.82 ± 0.10	8.19 ± 0.10

5.5% 4% 5.3% 3%

Microbiological analysis of cheese during maturation and storage



Sensory evaluation

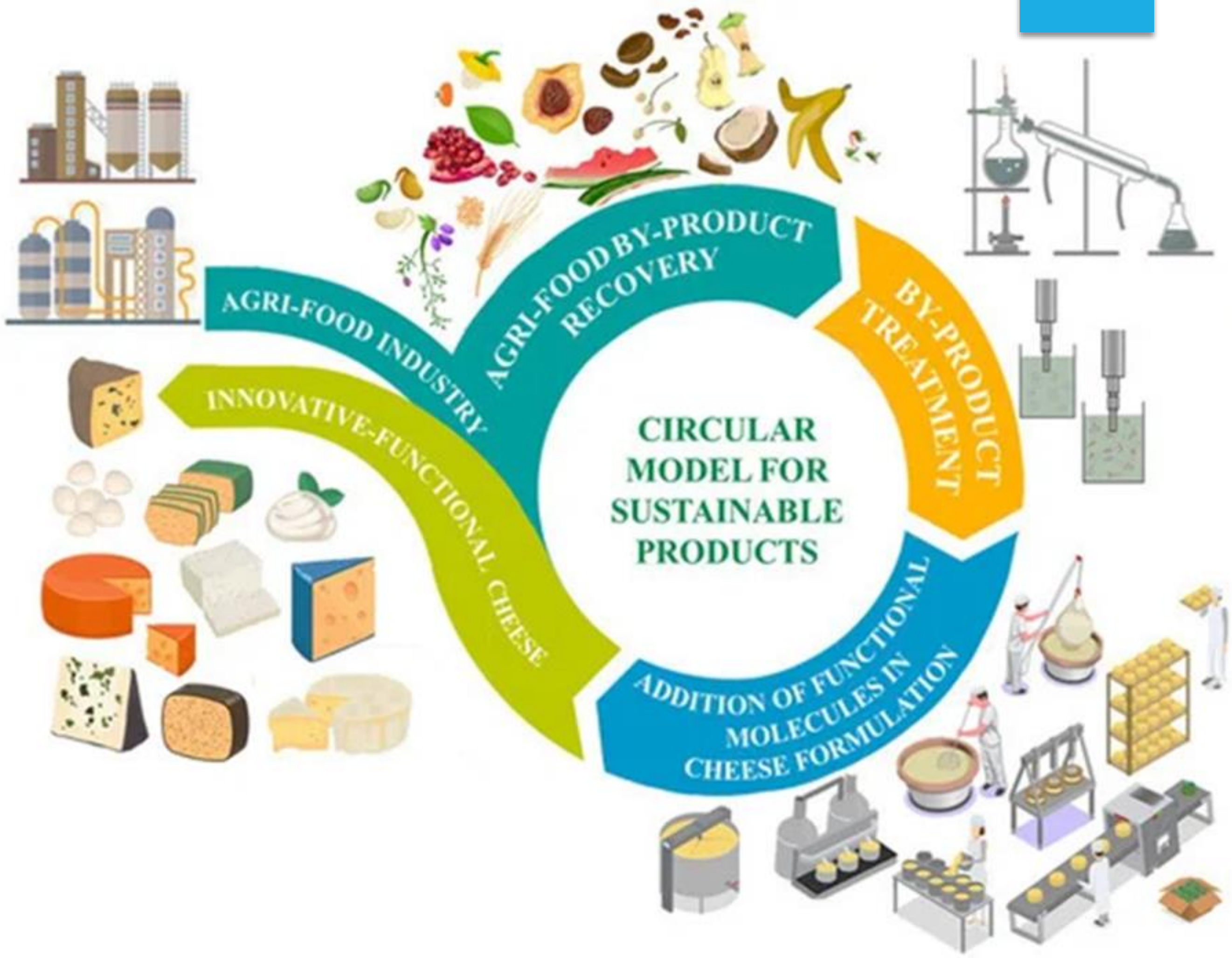
Table 5. Preliminary sensory assessment of Feta-type cheeses with added wheat bran (WB), free freeze-dried *L. casei* cells (FFL) and the freeze-dried synbiotic biocatalyst (FIL) after 60 and 120 days of storage (at 4 °C) compared with commercial Feta cheese (CS).

Day of maturation/storage	Quality Characteristic	CS*	WB*	FFL*	FIL*
60	Appearance	4.95	4.60	4.75	4.75
	Taste	4.95	4.60	4.95	4.75
	Aroma	4.80	4.35	4.65	4.55
	Consistency	4.80	4.35	4.85	4.75
120	Appearance	4.75	4.15	4.80	4.45
	Taste	4.80	4.20	4.80	4.80
	Aroma	3.90	3.40	4.65	4.60
	Consistency	4.00	3.20	4.50	4.50
	Overall acceptance	4.61	4.10	4.74	4.64

*Sensory attributes were scored based on a preference 0–5 scale. Data are the means of scores of three evaluations (standard deviation ≤ 0.2).

TAKE HOME MESSAGE

- The potential of numerous agri-food by-products for application in the production of functional cheeses, from both a health and a functional point of view has been found.
- Contrasting results have been obtained regarding physicochemical and sensory properties of enriched cheeses depending on the selected by-products and on the technology adopted for the extract preparation.
- Numerous variables modify the power of the extracts added to cheese formulations, based on the method of application.
- The reuse of agri-food by-products in cheesemaking, although challenging, deserves to be explored.



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