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Formulation and Evaluation of Sweet Lime (*Citrus limetta*) Peel Incorporated Chocolate Spread

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ABSTRACT

The present study focused on the utilization of sweet lime (*Citrus limetta*) peel, an underused citrus by-product rich in dietary fibre, vitamin C, β-carotene, minerals and polyphenols, for the development of a value-added chocolate spread. Sweet lime peel powder (SLPP) was prepared by KMS pre-treatment followed by dehydration and incorporated into chocolate spread at 2, 4, 6 and 8 per cent levels, with control containing only almonds and without SLPP. Sensory evaluation by a semi-trained panel of 21 members revealed that the 4 per cent incorporated sweet lime peel chocolate spread (SCS2) achieved the highest acceptability, recording scores of 8.00 for flavour, 7.28 for taste and 7.64 for overall acceptability, while higher incorporation (8%) reduced acceptability due to bitterness. Nutrient analysis revealed that SCS2 had lower moisture (4.76%) and fat (34.94 g/100 g) than the control (5.42% and 37.75 g/100 g), while exhibiting higher ash (11.20 g), crude fibre (2.42 g/100g), dietary fibre (12.80 g/100g), vitamin C (33.00 mg/100g) and β-carotene (4.01 µg/100g). SCS2 contained calcium (177 mg/100g), iron (3.7 mg/100g), magnesium (203 mg/100g) and manganese (1.7 mg/100g). Phytonutrient analysis further confirmed enhanced functional quality, with SCS2 showing higher polyphenols (370.61 mg GAE/100 g), tannins (16.20%) and antioxidant activity (342.34 mg AAE/100 g). Storage study showed gradual decrease in sensory scores, increase in pH, moisture, peroxide and free fatty acids with increased storage days which indicated that it is safe for 15 days when stored at room temperature in air-tight screw cap glass jars. Overall, incorporation of 4 per cent sweet lime peel powder enhanced the nutritional, functional and storage characteristics of chocolate spread while supporting sustainable citrus waste utilization.

Keywords : Sweet lime peel powder, Chocolate spread, Sensory, Nutrient composition, Storage study

CITRUS fruits and juices are important sources of bioactive compounds including antioxidants such as ascorbic acid, flavonoids, phenolic compounds and pectin which are important for human nutrition. Citrus fruits are one of the largest family of fruits grown in the world. China, Brazil and India are the top citrus fruit-producing nations, accounting for 49.22 per cent of the total global production (FAOSTAT, 2020). Citrus fruits contain a good repository of nutrients, phytochemicals and bioactive polyphenols that contributes towards their high antioxidant potential leading to a protective effect on human health (Suri *et al.,* 2021). Sweet lime (*Citrus limetta*) also known as 'Mosambi' is one of the popular citrus fruit. Sweet lime is a highly valued fruit due to its unique appealing taste, flavor and aroma. It is often consumed fresh or processed in the form of juice (Buyukkurt *et al.,* 2019). In addition to the edible portions, the non-edible parts such as peels (50-55% of total fruit weight) are an important source of

valuable biologically active components for example; phenols, flavonoids, essential oil, carotenoids, organic acids, ascorbic acid and vitamins (Jeong *et al.,* 2021). Sweet lime peels are an excellent storehouse of antioxidant compounds, pectin and dietary fibre that help in lowering blood glucose and cholesterol levels (Kumari *et al.,* 2020). Also, the ratio of soluble to insoluble dietary fibre in peels is higher than in cereals. In addition, bioactive compounds found in sweet lime peels provide a number of therapeutic benefits, namely; anti-bacterial, anti-viral, anti-inflammatory, anti-cancer and free radical scavenging properties (Javed *et al*., 2013). Owing to the health benefits, sweet lime peels could have suitable applications as an ingredient in the preparation of jam, jelly, beverages, dairy and bakery products, candy and chocolate if appropriate processing techniques for retaining their nutrient bio-availability be explored (Zhang *et al.,* 2019). However, the high moisture content of peels is the only obstacle to its effective utilization.

Chocolate spreads are semi-solid emulsions primarily composed of cocoa powder, sugar, fat and nut ingredients, widely appreciated for their smooth texture, rich flavour and versatility as a bread spread or dessert topping. With the growing demand for healthier alternatives to conventional high-fat spreads, the incorporation of functional ingredients derived from fruit by-products has gained increasing attention. Such fortification not only enhances the nutritional quality but also contributes to sustainability by minimizing food waste. Sweet lime peel, an abundant agro-waste, is a rich source of dietary fibre, flavonoids, vitamin C and essential minerals that can contribute both to the nutritional and functional properties of food products. Fibre-rich foods generally have a low-glycemic index. High-fibre diets with low-glycemic index have been shown to deliver several beneficial effects including lowering postprandial glucose and insulin responses. Therefore, an attempt was made to develop a chocolate spread incorporating sweet lime peel powder.

Material and Methods

Procurement of Raw Materials

Sweet lime peels were procured from a local fruit juice shop in Bangalore. Other ingredients *viz.,* dark chocolate, butter, cocoa powder, sugar were procured from the local market in Bengaluru. The peel was free of decay, mold growth and was of good commercial quality. Chemicals used in the study were of laboratory grade.

Processing of Sweet Lime Peel

The sweet lime peels were washed under running water to remove dirt and soil. The peels were then pretreated by soaking in 1 per cent KMS solution for 2 hours to remove bitterness and they were dried in hot air oven at 50°C for 4 hours. The dried peels were ground into fine powder using laboratory mixer and sieved through a 60-mesh sieve. The dried powder was packed in Multi layered polypropylene (MPP) covers and stored in refrigerator.

Development of Sweet Lime Peel Incorporated Chocolate Spread

Chocolate bread spread is a smooth, sweet and creamy paste made primarily from cocoa, sugar and fats, often enriched with milk or nuts. It is commonly used as a topping for bread, pancakes or desserts, offering a rich chocolate flavour and appealing texture. Sweet lime peel powder chocolate spread was standardized by incorporating sweet lime peel powder with almonds at 2% (SCS1), 4% (SCS2), 6% (SCS3) and 8% (SCS4) and control was 100 per cent almonds without sweet lime peel powder (CCS). All the other ingredients for preparation of chocolate spread were kept constant. The preparation of sweet lime peel chocolate spread is presented in Fig. 1.

Sensory Evaluation of Developed Sweet Lime Peel Incorporated Chocolate Spread

Developed sweet lime peel incorporated chocolate spread with different variations were evaluated by a panel of 21 semi-trained members. The product was evaluated for sensory attributes such as appearance, colour, texture, flavour, taste and overall acceptability.

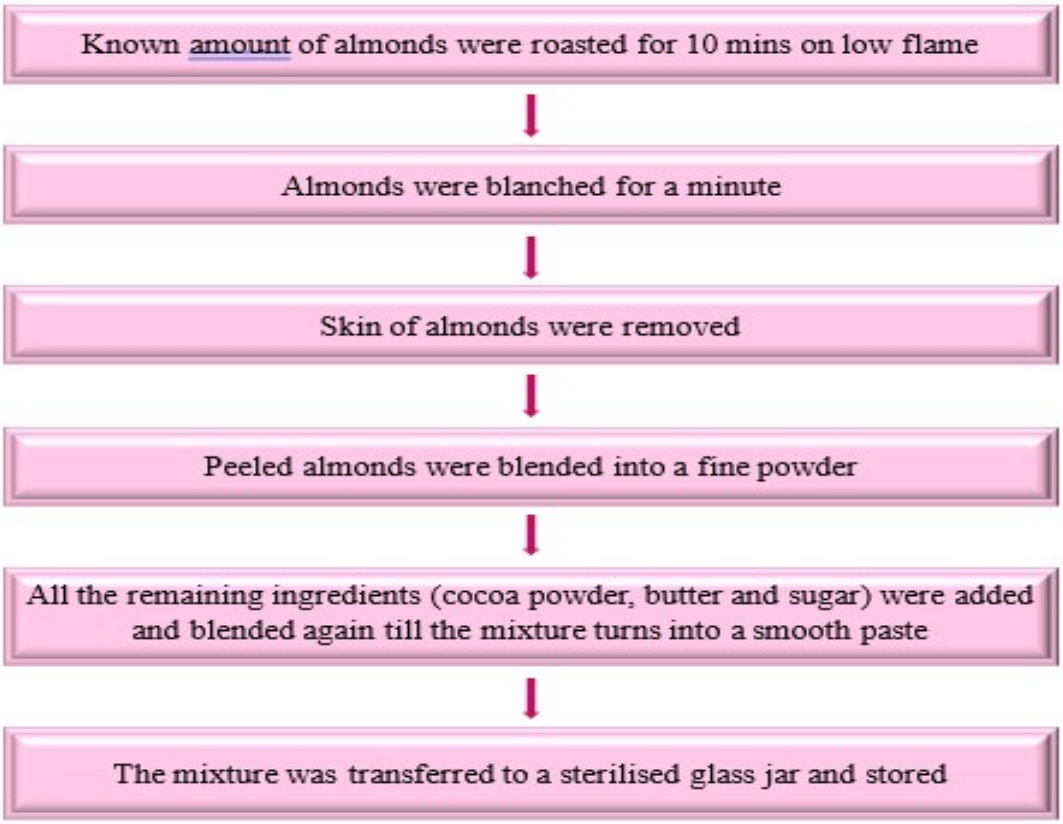


Fig. 1 : Flowchart for the preparation of sweet lime peel incorporated chocolate spread

Nutrient Composition, Phytonutrient and Total Antioxidant Activity of Sweet Lime Peel Incorporated Chocolate Spread

All the analyses were done by following AOAC (2005) methods. Moisture was determined from sample weight loss after drying in the oven at 105 °C for 2-3 hours. Protein (g) content was determined by kjeldahl method. The Soxhlet method was used for total fat (g) determination. Crude fibre was estimated by using moisture and fat- free samples by treatment of sample first with acid and subsequently with alkali. Minerals such as Iron, Zinc and Copper were analyzed using Atomic Absorption Spectrophotometer, calcium and magnesium by titration method and Phosphorus, Potassium and Manganese was assessed by standard procedure (AOAC, 2005).

Best accepted sweet lime peel chocolate spread was analyzed for total polyphenols using Folin Ciocalteu reagent (FCR), according to the method described by Ranganna (2005). Tannins were determined using calorimetrically based on the measurement of blue colour formed by the reduction of phosphotungstomoylybdic acid in alkali solution. Total antioxidant activity was assessed by using DPPH (2,2-diphenyl-1-picrylhydrazyl) method.

Statistical Analysis

All the analyses were performed in triplicate and data was analysed using EXCEL and OPStat software. Analysis of variance (ANOVA), Critical difference and F-test were used to analyze data. Data was analysed using one-way ANOVA and in CRD to determine LOS. One-way analysis of the variance was applied for sensory scores, microbial population and physico chemical parameters.

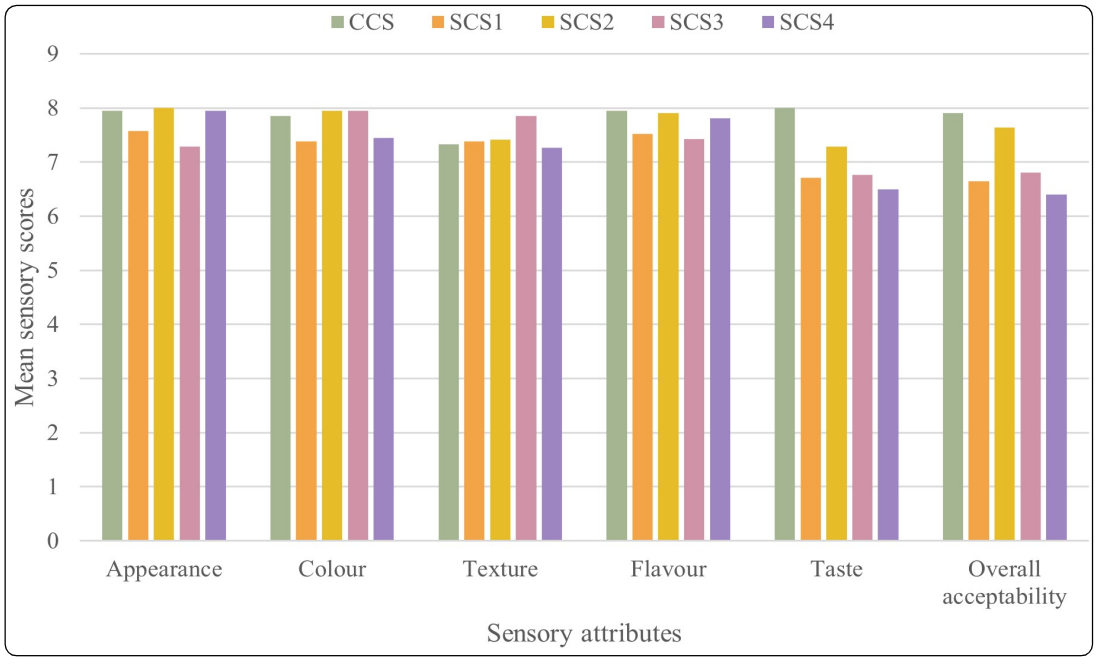
Results and Discussion

Sensory Evaluation of Sweet Lime Peel Incorporated Chocolate Spread

The sensory scores of sweet lime peel powder-incorporated chocolate spreads are presented in Fig. 2. Among the variations, the highest scores for appearance, colour, flavour, taste and overall acceptability were recorded for SCS2 (4% sweet lime peel incorporated chocolate spread) with scores of 8.00, 7.95, 7.90, 7.28 and 7.64, respectively. The incorporation of sweet lime peel at 4 per cent improved the flavour profile by introducing a mild citrus note that complemented the cocoa taste without over powering it, resulting in better acceptability among panelists.

The control sample (CCS) also received high scores for most of the sensory attributes, particularly for taste (8.00) and overall acceptability (7.90). However, the slight enhancement of the sensory scores observed in SCS2 suggests that moderate addition of sweet lime peel powder can positively influence product palatability. In contrast, the highest level of incorporation (SCS4, 8% sweet lime peel chocolate spread) recorded the lowest scores for texture (7.26), taste (6.50) and overall acceptability (6.40). The reduction in acceptability at higher levels could be attributed to increased bitterness and an overly strong citrus aroma derived from excessive peel content, which may have masked the desirable chocolate flavour.

The sensory scores for SCS1 (2% sweet lime peel chocolate spread) and SCS3 (6% sweet lime peel chocolate spread) were moderate, showing neither significant improvement nor major decline in sensory attributes compared to the control. This indicates that lower and medium levels of incorporation did not adversely affect the sensory



CCS - Control chocolate spread (with almonds)
SCS1 - Sweet lime peel chocolate spread (2%)
SCS2 - Sweet lime peel chocolate spread (4%)
SCS3 - Sweet lime peel chocolate spread (6%)
SCS4 - Sweet lime peel chocolate spread (8%)

Fig. 2 : Mean sensory scores of sweet lime peel incorporated chocolate spread

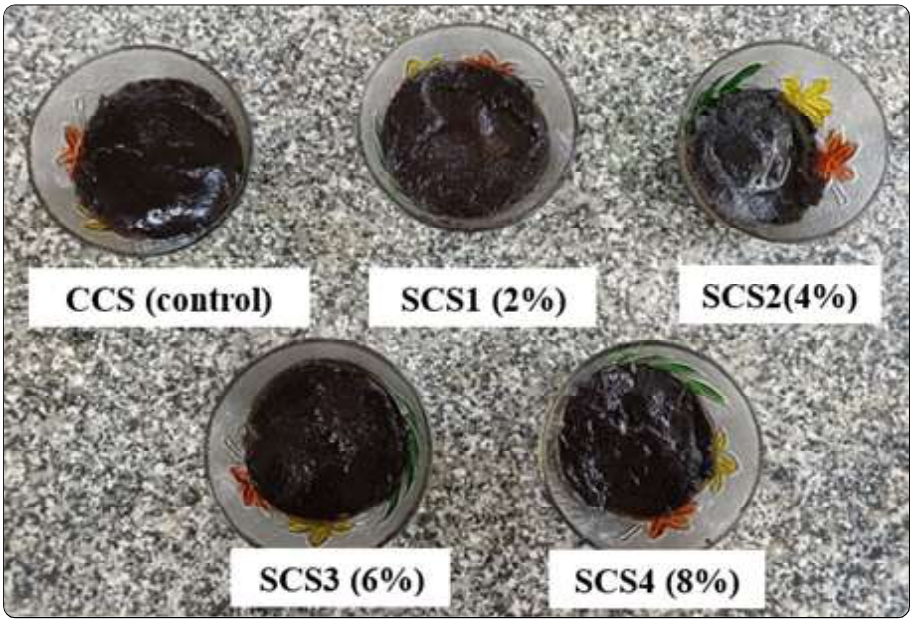


Plate 1 : Sweet lime peel incorporated chocolate spread variations

quality, though they did not achieve the same balanced flavour contribution seen in SCS2. The differences in sensory parameters among the variations were observed to be statistically significant ($p<0.05$).

Nutritional Composition, Phytonutrient and Total Antioxidant Activity of Sweet Lime Peel Chocolate Spread

The nutrient composition of the control and best accepted sweet lime peel incorporated chocolate spread is given in Table 1.

In sweet lime peel powder chocolate spread (SCS2), the moisture content was 4.76 per cent whereas control had 5.42 per cent. Lower amount of protein and fat (8.53g and 34.94g/100g) was found compared to control (10.58g and 37.75g/1000g). Higher amount of ash, crude fibre and dietary fibre (11.20, 2.42 and 12.80g/100g) was observed in SCS2 compared to control (9.87g, 2.21g and 10.60g/100g). Increase in dietary fibre indicates the fibre-fortifying potential of sweet lime peel powder. The vitamin C and β-carotene content was high in SCS2 (33.00 mg and 4.01 µg /100g) compared to control (30.56 mg and 1.44 µg/100g).

Yeo and Thed (2022) developed passion fruit and orange peel powder-enriched dark chocolate, showing increased dietary fibre content (3.06±0.02%) with fat content (51.15%) while lower in moisture content (9.55%), protein content (8.04%) and ash content (3.56%). Albak and Tekin (2014) formulated functional dark chocolate, showing moisture 0.54 per cent, fat 33.45 per cent, protein 9.16 per cent, ash 1.92 per cent and carbohydrates 54.93 per cent.

Overall, incorporation of sweet lime peel powder in the developed products improved their nutritional composition by increasing dietary fibre, vitamin C and β-carotene content, while reducing fat and moisture levels, thereby enhancing their nutritional and functional quality.

The mineral composition of control chocolate spread and sweet lime peel incorporated chocolate spread is given in Table 2.

The control chocolate spread (CCS) showed 168 mg calcium, 376 mg phosphorous, 525 mg potassium, 198 mg magnesium, 3.1 mg iron, 2.4 mg zinc, 0.72 mg copper, and 1.6 mg manganese per 100 g, whereas the sweet lime peel chocolate spread (SCS2) contained 177 mg calcium, 368 mg phosphorous, 509.6 mg potassium, 203.2 mg magnesium, 3.7 mg

Table 1

Nutrient composition of sweet lime peel incorporated chocolate spread

Nutrients (per 100g)	Chocolate spread		
	CCS	SCS2	t-value
Moisture (%)	5.42 ± 0.22	4.76 ± 0.24	3.51 #
Protein (g)	10.58 ± 0.44	8.53 ± 0.02	8.06 #
Fat (g)	37.75 ± 0.14	34.94 ± 0.12	26.40 #
Ash (g)	9.87 ± 0.25	11.20 ± 0.26	-6.39 #
Crude fibre (g)	2.21 ± 0.41	2.42 ± 0.61	-0.49 NS
Carbohydrates* (g)	34.17 ± 0.70	38.15 ± 0.87	-6.17 #
Energy** (kcal)	519 ± 0.60	501 ± 0.30	46.48 #
Total dietary fibre (g)	10.60 ± 0.11	12.80 ± 0.06	-30.41 #
Vitamin C (mg)	30.56 ± 0.04	33.00 ± 0.01	-102.50 #
β- carotene (µg)	1.44 ± 0.02	4.01 ± 0.06	-70.38 #

Note : Values are mean ± standard deviation; CCS – Control chocolate spread

SCS2 - sweet lime peel incorporated chocolate spread (4%); * - difference method; **- computation method; # - Significant at ($p \leq 0.05$), NS – non significant

Table 2

Mineral composition of best accepted sweet lime peel chocolate spread

Minerals (mg/100g)	Chocolate spread		
	CCS	SCS2	t-value
Calcium	168 ± 0.21	177 ± 0.61	-24.16 *
Phosphorus	376 ± 0.29	368 ± 0.94	14.09 *
Potassium	525 ± 0.45	509 ± 0.64	35.42 *
Magnesium	198 ± 0.33	203 ± 0.20	-22.44 *
Iron	3.10 ± 0.32	3.70 ± 0.36	-2.16 NS
Zinc	2.40 ± 0.30	2.40 ± 0.74	0.00 NS
Copper	0.72 ± 0.60	0.77 ± 0.25	-0.13 NS
Manganese	1.6 ± 0.11	1.7 ± 0.30	-0.54 NS

Note : Values are mean ± standard deviation; CCS – Control chocolate spread

SCS2 - sweet lime peel incorporated chocolate spread (4%); * - difference method; **- computation method; # - Significant at ($p \leq 0.05$), NS – non significant

iron, 2.4 mg zinc, 0.77 mg copper and 1.7 mg manganese per 100 g. These high mineral values further confirm their potential as nutrient-dense confectionery products.

The phytonutrient composition and total antioxidant activity of sweet lime peel incorporated chocolate spread is given in Table 3.

Among the products, the sweet lime peel chocolate spread (SCS2) exhibited the highest polyphenol content (370.61 mg GAE/100 g), tannin content (161.15mg TAE/100g) and total antioxidant activity (342.34 mg AAE/100 g). The higher polyphenol and tannin contents observed in the chocolate spread may be due to the synergistic interaction between

TABLE 3

Phytonutrient composition and total antioxidant activity of sweet lime peel incorporated chocolate spread

Parameters		Chocolate spread			
		CCS	SCS2	t-value	
Polyphenols (mg GAE/100g)		312.14	370.61	-33.18	*
Tannins	(%)	15.00	16.20	-	
	mg TAE/100g	150.65	161.15	-6.65	*
Total anti-	(%)	25.80	28.77	-10.39	*
oxidant activity	mg AAE/100g	323.54	342.34	-8.17	*

Note : CCS – Control chocolate spread; SCS2 - sweet lime peel incorporated chocolate spread (4%); * - Significant at ($p \leq 0.05$), NS – non significant

cocoa constituents and the phenolic compounds present in sweet lime peel powder.

Yeo and Thed (2022) developed dark chocolate enriched with passion fruit and citrus peel powder, showing high antioxidant activity (DPPH scavenging 86.10±0.13%). Polyphenols in sweet lime peel powder are major contributors to antioxidant activity. The main flavonoids in cocoa and chocolate are the flavan-3-ols catechin and epicatechin (monomeric units) and proanthocyanidins, which are polymeric compounds comprising catechin and epicatechin subunits (Steinberg *et al.,* 2003). The citrus flavonoids include a class of glycosides, namely, hesperidin and naringin, and another class of O-methylated aglycones of flavones such as nobiletin and tangeretin (Rafiq *et al.,* 2018).

Colour Analysis of Chocolate Spread

The colour attributes (L^*, a^* and b^* values) of the best accepted sweet lime peel-based products are presented in Table 4. The L^* value represents lightness, a^* value indicates redness or greenness and b^* value corresponds to yellowness or blueness of the products.

For chocolate spread (SCS2), the L^* value of control was 18.6 and of SCS2 was 17.8 which indicates a darker appearance upon addition of sweet lime peel powder. The a^* value increased from 9.8 to 10.4, reflecting a deeper reddish-brown tone, while the b^* value remained nearly constant (7.2 to 7.1). The incorporation of sweet lime peel powder might have enhanced colour depth due to pigment interactions with cocoa and sugar components during blending. The darker tone was, however, consistent with the typical visual appeal of chocolate-based products.

TABLE 4

Colour analysis of chocolate spread

Colour parameters	Chocolate spread		
	CCS	SCS2	t-value
L^*	18.6 ± 0.10	17.8 ± 0.30	4.38 *
a^*	9.8 ± 0.40	10.4 ± 0.25	2.20 NS
b^*	7.2 ± 0.22	7.1 ± 0.20	0.58 NS

Note : CCS – Control chocolate spread; SCS2 - sweet lime peel incorporated chocolate spread (4%); * - Significant at ($p \leq 0.05$), NS – non significant

Yeo and Thed (2022) demonstrated that enrichment with citrus peel powder in dark chocolate marginally lowered L^* values (darker color) while increasing a* (redness), supporting findings where sweet lime peel chocolate spread had L^* of 17.8, a^* of 10.4 and b^* of 7.1. Such consistency suggests that citrus peel addition imparts expected colour shifts aligning with previously documented parameters.

Mean Sensory Scores of Sweet Lime Peel chocolate Spread on Storage

Sweet lime peel chocolate spread (SCS2) and control chocolate spread were packed in screw cap glass jars and kept for storage study under room temperature (33 ± 2°C). The samples were observed daily for visual changes and subjected to sensory evaluation along with microbial quality for a period of 15 days.

Effect of storage on sensory attributes of best accepted chocolate spread is presented in Table 5. During storage period, significant decrease in all the sensory attributes in both control (CCS) and 4 per cent sweet lime peel incorporated chocolate spread (SCS2) was observed. In the control sample, the appearance score decreased from 7.95 at 0th to 6.23 by 15th day, while the colour score reduced from 7.85 to 6.14 over the same period. Texture and flavour also declined from 8.23 to 5.57 and from 7.95 to 5.90 respectively. Taste followed a similar decreasing trend from 7.90 to 5.57, leading to a reduction in overall acceptability from 8.16 at the initial day to 5.61 on the 15th day of storage.

A similar pattern was observed in SCS2 (4% sweet lime peel incorporated chocolate spread), where appearance decreased from 8.31 initially to 5.90 on the 15th day, while colour dropped from 8.09 to 5.76. Texture and flavour reduced from 8.07 to 5.33 and from 8.00 to 5.76 respectively. Taste and overall acceptability also declined from 7.95 to 5.57 and from 8.21 to 5.57 respectively. The F-values indicated that these decreases were statistically significant at the 5 per cent level for both treatments.

Effect of Storage on pH, TSS, Moisture, Peroxide and Free Fatty Acids Parameters of Best Accepted Sweet Lime Peel Incorporated Chocolate Spread

Table 6 depicts the effect of storage on pH, TSS, moisture, peroxide and free fatty acids parameters of best accepted sweet lime peel chocolate spread. The pH of the control chocolate spread increased slightly during storage, rising from 5.50 at the initial day to 5.90 by the 15th day, whereas the SCS2 (4% sweet lime peel incorporated chocolate spread) showed a similar increasing trend from 5.10 to 5.70

Table 5

Effect of storage on sensory attributes of best accepted sweet lime peel incorporated chocolate spread

Products	Duration (days)	Appearance	Colour	Texture	Flavour	Taste	Overall acceptability
CCS	Initial	7.95 ± 0.04	7.85 ± 0.07	8.23 ±0.11	7.95 ± 0.08	7.90 ± 0.06	8.16 ± 0.12
	7	7.52 ± 0.11	7.19 ± 0.14	6.88 ±0.15	7.11 ± 0.09	7.21 ± 0.13	6.73 ± 0.16
	15	6.23 ± 0.09	6.14 ± 0.12	5.57 ±0.11	5.90 ± 0.13	5.57 ± 0.16	5.61 ± 0.14
	F-value	*	*	*	*	*	*
	SEm±	0.08	0.12	0.12	0.10	0.13	0.14
	CD at 5%	0.25	0.34	0.35	0.30	0.37	0.41
SCS2	Initial	8.31 ± 0.12	8.09 ± 0.11	8.07 ±0.42	8.00 ± 0.09	7.95 ± 0.10	8.21 ± 0.10
	7	7.33 ± 0.12	7.09 ± 0.14	6.78 ±0.16	6.95 ± 0.15	7.00 ± 0.12	6.69 ± 0.16
	15	6.90 ± 0.15	6.76 ± 0.15	6.33 ±0.15	6.76 ± 0.18	6.57 ± 0.16	6.57 ± 0.14
	F-value	*	*	*	*	*	*
	SEm±	0.13	0.13	0.27	0.14	0.13	0.14
	CD at 5%	0.37	0.39	0.78	0.41	0.38	0.40

Note :Values are mean±standard deviation; *Significant at 5%; CCS – chocolate spread with almonds; SCS2 - sweet lime peel incorporated chocolate spread (4%)

TABLE 6

Effect of storage on pH, moisture, peroxide value and free fatty acids parameters of best accepted sweet lime peel incorporated chocolate spread

Chocolate spread	Parameters	Duration (days)			F-value	SEm±	CD at 5%
		Initial	7	15			
CCS	pH	5.50	5.60	5.90	*	0.056	0.26
	TSS	29.60	29.40	29.20	*	0.02	0.21
	Moisture (%)	8.06	9.40	10.16	*	0.092	0.32
	Peroxide value (meq O_2/kg of fat)	6.11	6.89	8.11	*	0.008	0.029
	Free fatty acid (mg KOH/kg)	0.26	0.35	0.50	*	0.01	0.03
SCS2	pH	5.10	5.40	5.70	*	0.086	0.31
	TSS	29.50	29.40	29.10	*	0.011	0.32
	Moisture (%)	7.20	8.33	9.54	*	0.16	0.57
	Peroxide value (meq O_2/kg of fat)	5.92	6.62	7.84	*	0.01	0.05
	Free fatty acid (mg KOH/kg)	0.24	0.33	0.46	*	0.01	0.03

Note : *Significant at 5%; CCS - chocolate spread with almonds; SCS2 - sweet lime peel incorporated chocolate spread (4%)

over the same storage period. Total soluble solids (TSS) decreased marginally in both treatments, with the control decreasing from 29.6 to 29.2 °Brix and the SCS2 sample decreasing from 29.5 to 29.1 °Brix by the 15th day. Similarly decrease in TSS was reported by Vaibhavi *et al.* (2019) in mango ginger murabba, total soluble solids in control decreased from 73.00 to 72.5 per cent and in mango ginger murabba (25%) and decreased from 77.00 to 76.50 in mango ginger murabba (37.5%).

Moisture content showed a gradual increase in both samples; In control, it increased from 8.06 per cent to 10.16 per cent and in SCS2 sample, it increased from 7.20 per cent to 9.54 per centduring storage period. Peroxide value increased from 6.11 to 8.11 meq O, /kg in the control and from 5.92 to 7.84 meq O, /kg in the SCS2 sample, while free fatty acid levels rose from 0.26 to 0.50 mg KOH/kg in control and from 0.24 to 0.46 mg KOH/kg in the SCS2 by 15th day. The F-values indicated that all parameters differed significantly at the 5 per cent level.

The gradual increase in pH during storage may be attributed to proteolytic and biochemical changes that occur in chocolate-based spreads over time. The slight decrease in TSS could be related to moisture absorption and subsequent dilution of soluble solids. Increase in peroxide value and free fatty acid levels are indicative of oxidative rancidity and hydrolysis of fats, which are common reactions in lipid-rich food products during storage. However, the SCS2 (4%) chocolate spread recorded comparatively lower peroxide and free fatty acid values than the control, suggesting a slower rate of lipid degradation. This protective effect may be linked to the antioxidant compounds naturally present in sweet lime peel, such as flavonoids and limonoids, which are known to delay oxidative reactions. These changes are consistent with oxidative rancidity and hydrolysis commonly seen in lipid-rich spreads during storage.

Microbial Population of Sweet Lime Peel Incorporated Chocolate Spread on Storage

Effect of storage on microbial population of sweet lime peel chocolate spread is depicted in Table 7. In the control chocolate spread, total bacterial count increased from no detectable colonies on the initial day to 0.36×10^2 cfu/g on the 7th day and 1.08×10^2 cfu/

TABLE 7

Effect of storage on microbial population of sweet lime peel incorporated chocolate spread

Chocolate spread	Population of microorganisms (cfu/g)	Duration (days)		
		Initial	7	15
CCS	TBC ($x10^2$)	ND	0.36	1.08
	Fungi ($x10^2$)	ND	0.44	0.92
	Coliforms	ND	ND	ND
SCS2	TBC ($x10^2$)	ND	0.29	0.95
	Fungi ($x10^2$)	ND	ND	0.63
	Coliforms	ND	ND	ND

Note : TBC - Total bacterial count; ND - Not detected; CCS - chocolate spread with almonds; SCS2 - sweet lime peel incorporated chocolate spread (4%)

g on the 15th day. Fungal count also increased from 0.44×10^2 cfu/g on the 7th day to 0.92×10^2 cfu/g on the 15th day, while coliforms remained absent. In the SCS2 (4%) variation, TBC not detected on initial day and it appeared on 7th day (0.29×10^2 cfu/g) and increased by 15th day (0.95×10^2 cfu/g). Coliforms continued to be absent in this treatment.

The increase in microbial population during storage may be due to the higher moisture and nutrient content in chocolate spread, which provides a favourable environment for microbial growth. However, the SCS2 (4% sweet lime peel incorporated chocolate spread) showed lower levels of bacterial and fungal colonies as compared to the control. This reduction can be attributed to the antimicrobial activity of sweet lime peel powder, which contains natural phenolics and essential oils known to inhibit microbial growth. Storage studies were terminated after 15 days because the microbial population in the samples exceeded the safe microbial limits.

A similar study conducted by Prabha *et al.* (2016) on *Phyllanthus amarus* based Fruit Spread also reported the absence of coliforms for 30, 60 and 90 days. However, all these microbial counts were within the safe limits as recommended by FSSAI (Total bacterial Count not more than 50,000 per g, while fungi and coliforms should be absent). Thus, the products can be stored upto 15 days.

Sweet lime peel, a nutrient-dense by-product of citrus processing, was effectively utilized in the present study to develop value-added products with enhanced nutritional and functional properties. The study revealed that the peel is a rich source of dietary fibre, vitamin C, β-carotene, minerals and bioactive compounds such as polyphenols and flavonoids, which contribute to its strong antioxidant potential. Incorporation of the peel powder into chocolate spread significantly improved their fibre and total antioxidant activity without compromising sensory acceptability. Thus, sweet lime peel powder can be effectively employed as a functional ingredient in food formulations to enhance nutritional value and promote health. Moreover, its utilization provides a sustainable approach to fruit-waste management and can be encouraged to promote the development of healthy, nutritious and functional foods.

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