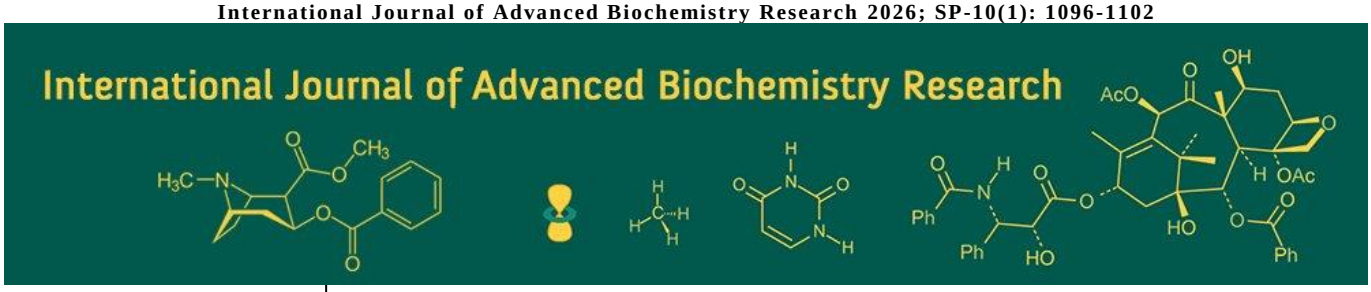

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Optimization of fennel seed powder incorporation in Burfi: Effects on antioxidant activity, colour, sensory quality and proximate composition

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Abstract
The growing demand for formulations based on naturally sourced functional ingredients has driven the replacement of synthetic antioxidants with plant-based alternatives in dairy confectionery, without compromising sensory attributes. This paper focuses on the optimization of fennel (*Foeniculum vulgare*) seed powder usage in burfi (a traditional heat-desiccated dairy sweet) and further evaluates the impact of the addition on antioxidant activity, colour properties, sensory attributes and proximate composition. First, 0.5% w/v milk of fennel seed powder was added either during milk heating or at the pat formation stage along with a control, to find the most suitable time of addition. Secondly, after the selection of the stage of addition, 0.25-1.0% w/v milk of fennel seed powder was added. Addition at the pat formation stage helped to keep antioxidants (0.31 mM Trolox equivalents g^{-1}) at a significantly higher level as compared to both early-stage addition (0.28 mM Trolox equivalents g^{-1}) and control (0.15 mM Trolox equivalents g^{-1}) ($p<0.05$), along with colour and sensory qualities within an acceptable range. A higher level of fennel seed powder caused a greater increase in antioxidant activity in a dose-dependent manner-even up to 0.46 mM Trolox equivalents g^{-1} at 1.0% addition; although sensory liking did not match the increase at the higher inclusion levels. The optimal level of incorporation was 0.5% (w/v of milk) consisted of 0.5% (w/v of milk) fennel seed powder incorporation at the pat formation stage that acceptable a nice balance between the enhancement in antioxidant potential and overall sensory acceptability. Besides a slight raise in moisture content, the proximate composition of burfi was practically unchanged. The current results offer a process-level optimization approach for the efficient use of fennel seed powder in burfi, thereby enabling the preparation of functional, value-added, and clean-label dairy confectionery products.

Keywords: Burfi, fennel seed powder (*Foeniculum vulgare*), natural antioxidants, Trolox equivalents

Introduction
The Indian packaged sweets market, valued at INR 7,268.0 Crore in 2024, is projected to reach INR 27,647.5 Crore by 2033, growing at a compound annual growth rate (CAGR) of 16% during 2025-2033. Within the organized sweet sector, which constitutes only 5-7% of the total market, milk-based sweets account for approximately 36% of the share. This rapid expansion reflects evolving consumer preferences toward value-added traditional dairy sweets enriched with natural ingredients that deliver essential nutrients, antioxidants, desirable color, and flavor profiles.

Burfi, a popular khoa-based confection from the Indian subcontinent, is traditionally prepared by heat-desiccating whole milk to form khoa or milk, which is then combined with sugar, heated to a homogeneous consistency, cooled, and shaped. Renowned for its rich nutritional value, unique texture, and sensory appeal, burfi holds significant commercial potential in both organized and unorganized sectors. While synthetic additives such as butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), and tocopherols have been employed to enhance shelf life, color, and oxidative stability in khoa-based sweets, their prolonged use raises health concerns, including adverse effects observed in animal models. In response, the food industry is shifting toward natural alternatives, particularly herbs and spices rich in phenolic compounds, which exhibit potent antioxidant activity to mitigate lipid oxidation during storage (Aneja *et al.*, 2002; Pal and Raju, 2010; Prasad *et al.*, 2017; Badola

et al., 2023) [1, 15, 17, 2]. Thermal processing of dairy systems significantly influences the stability, accessibility, and redox behaviour of plant-derived phenolic compounds, primarily through oxidation, polymerization, and interactions with milk proteins, yet limited studies have systematically optimized processing stage to minimize such biochemical losses in traditional dairy matrices (Jakobek, 2014, Gote *et al.*, 2020) [11, 8].

Fennel seeds (*Foeniculum vulgare*), valued for its inherent antioxidant properties, vibrant color, and aromatic flavor, represent an underexplored natural additive for dairy sweets. Although prior studies have investigated spice incorporation in select dairy products, limited research addresses the optimization of fennel seed powder in burfi, particularly regarding the stage of addition and dosage for optimized sensory quality, antioxidant capacity, and color retention. This gap is significant, as suboptimal addition timing or levels could compromise product stability, flavor balance, or consumer acceptance in functional products. Phenolic compounds present in fennel seeds, including flavonoids and phenylpropanoids, exhibit strong radical-scavenging and ferric-reducing properties; however, their functional expression in food systems is governed by processing-induced structural transformations and protein-polyphenol interactions (Rather *et al.*, 2016) [18].

The present study addresses this research gap by systematically optimizing the stage of addition and rate of fennel seed powder incorporation in burfi. In the first phase, fennel seed powder (0.5% w/v of milk) was added either during milk heating (S_1) or at the pat formation stage (S_2), with untreated burfi serving as control (S_0). The optimal stage, selected based on superior sensory scores, DPPH radical scavenging activity, and colour attributes, informed the second phase. Here, varying levels (0.25%, 0.5%, 0.75%, and 1.0% w/v of milk) were evaluated using identical criteria to determine the ideal dosage. This novel approach not only enhances burfi's functional properties—aligning with clean-label trends—but also provides actionable insights for industrial scale-up, potentially elevating the nutritional and market viability of traditional Indian dairy sweets. Therefore, the present study aimed to optimize the stage and rate of fennel seed powder incorporation in burfi and evaluate its effect on sensory quality, antioxidant activity, colour characteristics and proximate composition.

Materials

Full cream milk (6.0% fat, 9.0% solids-not-fat) of the Amul brand was procured from the local market of Anand, Gujarat, and used for the preparation of burfi. Fennel seeds were obtained from an FSSAI-licensed commercial brand available locally. The fennel seeds were ground using an electric grinder, passed through a 35-mesh sieve, and stored in airtight containers under refrigerated conditions until use. Sugar (Madhur brand) was procured locally and ground prior to incorporation.

Preparation of burfi

Burfi was prepared from full cream milk following the traditional method described by Aneja *et al.* (2002) [1].

Experimental Design

Selection of Stage of Addition of Fennel Seed Powder

To determine the appropriate stage for incorporation of fennel seed powder, it was added at a concentration of 0.5 % (w/v of milk) at two different stages of burfi manufacture: (i) initial addition to milk, and (ii) addition at the pat formation stage. A control sample without fennel seed powder was prepared for comparison. All samples were evaluated for sensory acceptability using a 9-point hedonic scale. Antioxidant activity was determined using the DPPH radical scavenging assay, and colour values were recorded. The stage of addition yielding the highest sensory score and/or antioxidant activity was selected for further experimentation.

Optimization of Level of Fennel Seed Powder Addition

Following selection of the appropriate stage of addition, fennel seed powder was incorporated at 0 (control), 0.25, 0.5, 0.75, and 1.0% (w/v of milk). The resulting burfi samples were evaluated for sensory acceptability using a 9-point hedonic scale. Antioxidant activity (DPPH assay) and colour values were simultaneously assessed. The level of fennel seed powder producing the highest sensory acceptability and/or antioxidant activity was selected for further study.

Sensory Evaluation

Sensory evaluation of burfi samples was carried out by a trained panel consisting of eight judges using a 9-point hedonic scale to assess overall acceptability.

DPPH Radical Scavenging Activity

Antioxidant activity of burfi was determined using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay following the method of Gote *et al.* (2020) [8], with minor modifications. Burfi samples (2.5 g) were extracted with 50 mL of methanol-water (8:2, v/v) and incubated at 37 °C for 24 h in a water bath. The extract was subsequently filtered through Whatman No. 42 filter paper to remove solid residues. An aliquot (1 mL) of the methanolic extract was mixed with 3 mL of 0.15 mM DPPH solution. The reaction mixture was incubated in the dark at 37 °C for 30 min, after which absorbance was measured at 517 nm using a spectrophotometer. Methanol served as the blank. Radical scavenging activity was calculated as percentage inhibition using the following equation:

$$\text{Radical scavenging activity (\% inhibition)} = \frac{(A_c - A_s)}{A_c} \times 100$$

where A_c is the absorbance of the control and A_s is the absorbance of the sample.

Antioxidant activity was quantified using a Trolox standard curve and expressed as mM Trolox equivalents per gram of sample.

Ferric reducing antioxidant power (FRAP) assay

The ferric reducing antioxidant power (FRAP) of burfi samples was determined according to the method described by Benzie and Strain (1999) [3]. An aliquot of 90 µL of the methanolic extract was mixed with 2.7 mL of freshly prepared FRAP reagent in a 10 mL test tube. The reaction mixture was allowed to develop, and the absorbance was measured at 595 nm using a spectrophotometer. Antioxidant capacity was calculated from the calibration curve obtained using ferrous sulphate standards and expressed as mM Fe^{2+} equivalents per gram of sample.

Determination of colour value of burfi

Changes in the colour of burfi samples during storage were measured using a chroma meter (Konica Minolta CR-400, Japan). Colour measurements were recorded in terms of CIE *L**, *a**, and *b** colour coordinates. All measurements were carried out under controlled conditions at the sample surface, ensuring minimal interference from external light sources.

Analysis of burfi for proximate chemical composition

The moisture content of burfi samples was determined using the gravimetric method as prescribed by the Bureau of Indian Standards (BIS, 1981). Fat content was estimated by the acid digestion method following BIS (1981). Protein content was determined using the Kjeldahl method according to AOAC (1980) with a block digester and automatic distillation unit, applying a conversion factor of 6.38 for calculation of crude protein. Ash content was determined as per the method described by AOAC (1995). Lactose and sucrose contents were estimated using standard procedures outlined by the Bureau of Indian Standards (BIS, 1981).

Statistical analysis

The obtained results were subjected to statistical analysis using Analysis of Variance (ANOVA) at a significance level of 5 per cent. For analyzing the data of each attribute under study, a statistical analysis was performed using the completely randomized design as described by Steel and Torrie, 1980 [21].

Results and Discussion

The experimental results generated from the two-stage optimization strategy are critically examined to elucidate the influence of processing stage and incorporation level of fennel (*Foeniculum vulgare*) seed powder on the sensory attributes, antioxidant capacity, colour characteristics, and proximate composition of burfi. The outcomes are discussed with reference to thermal stability of bioactive compounds, and dose-dependent responses, and are compared with relevant published literature to substantiate the observed trends and technological implications.

Selection for stage of addition of fennel seed powder in burfi

In this study, the stage of fennel seed powder addition in burfi was evaluated. Fennel seed powder was added at two different stages: (i) addition in milk at the rate of 0.5 per cent w/v of milk (S_1), and (ii) addition in pat formation stage at the rate of 0.5 per cent w/v (S_2) of milk.

The sample without addition of fennel seed powder was treated as control (S_0). The freshly prepared burfi samples were subjected to sensory evaluation by a panel of eight judges using 9-point hedonic scale. The samples were also monitored for their antioxidant activity (DPPH radical scavenging activity) and colour value. The results obtained for sensory evaluation, antioxidant activity and colour value are presented below.

Effect of stage of addition of fennel seed powder on sensory characteristics of burfi

Sensory attributes are key determinants of consumer acceptance of traditional dairy confections. The influence of the stage of fennel seed powder addition on the sensory quality of burfi was evaluated and presented in Table 1.

Table 1: Effect of stage of addition of fennel seed powder on sensory characteristics of burfi

Burfi Samples	Sensory Score (9-point hedonic scale)			
	Flavour	Colour and appearance	Body and texture	Overall acceptability
S_0	8.44[a]	8.45[a]	8.30[a]	8.39[a]
S_1	7.75[c]	7.55[c]	7.75[b]	7.59[c]
S_2	8.13[b]	8.11[b]	7.86[b]	8.01[b]
SEm ±	0.083	0.094	0.102	0.106
CD (0.05)	0.26	0.289	0.315	0.327
CV%	2.31	2.610	2.865	2.966

S_0: burfi without fennel seed powder
S_1: added initially in milk at the rate of 0.5 % w/v of milk
S_2: added at pat formation stage at the rate of 0.5 % w/v of milk
n = 5, the values a within a column with same superscript did not differ significantly (p>0.05) from each other

The results demonstrated significant differences (p<0.05) among the samples across the different stages of fennel seed powder addition. The highest flavour score was recorded for the control sample, followed by S_2, while S_1 exhibited the lowest score (7.75). These variations may be attributed to differences in the release and retention of volatile flavour compounds of fennel seed powder at different processing stages.

Colour and appearance, a critical determinant of consumer acceptability, were significantly (p<0.05) affected by the stage of fennel seed powder addition. The highest colour and appearance score was observed in S_0 (8.45), followed by S_1 (8.11) and S2 (7.55). The comparatively lower score in S_2 could be due to prolonged heat exposure at later stages, leading to pigment degradation or uneven dispersion of the powder.

No significant difference (p>0.05) was observed in the body and texture scores of burfi prepared with fennel seed powder at different stages. Nevertheless, the highest score was obtained for S_0 (8.30), followed by S_2 (7.86) and S1 (7.75). This indicates that fennel seed powder addition did not markedly interfere with the structural matrix of burfi, irrespective of the stage of incorporation.

The overall acceptability score was highest for S_0 (8.39), followed by S_2 (8.01) and S_1 (7.59), with a significant difference (p<0.05) observed among the samples. The superior acceptability of S_2 compared to S_1 may be attributed to better flavour integration and reduced thermal degradation of bioactive compounds when the fennel seed powder was added at the pat formation stage (short time heating exposer) rather than during the initial milk stage (long time heating exposer).

The comparatively inferior sensory performance observed when fennel seed powder was added at the initial milk stage can be attributed to prolonged thermal exposure, which likely accelerated the volatilization and degradation of characteristic fennel aroma compounds such as anethole, fenchone, and estragole. These compounds are thermolabile and are known to undergo oxidative and evaporative losses during extended heating (Rather *et al.*, 2016) [18].

In contrast, incorporation at the pat formation stage minimized thermal stress, facilitating better retention and integration of fennel-derived volatiles within the fat-protein matrix of khoa. Dairy matrices rich in milk fat are known to act as effective carriers for lipophilic aroma compounds, enhancing flavour perception when thermal degradation is limited (Gierczynski *et al.*, 2011) [7].

Limited literature is available on the sensory evaluation of burfi enriched with fennel seed powder. However, comparable findings were reported by Gote *et al.* (2020) [8], who studied burfi fortified with curcumin in different forms and at various stages of processing. They reported higher overall acceptability (7.49) when curcumin encapsulate was added at the pat formation stage. A similar trend was observed in the present study, suggesting that the stage of addition plays a vital role in preserving sensory attributes. Thus, incorporation of fennel seed powder during pat formation is recommended to achieve improved sensory quality in burfi

Effect of stage of addition of fennel seed powder on antioxidant activity of burfi

The antioxidant activity of burfi samples prepared by incorporating fennel (*Foeniculum vulgare*) seed powder at different processing stages was evaluated and results, expressed as DPPH radical scavenging activity (mM Trolox equivalents g^{-1}), are presented in Table 2.

Table 2: Effect of stage of addition of fennel seed powder on antioxidant activity of burfi

Burfi samples	mM Trolox equivalent/g
S_0	0.15^c
S_1	0.28^b
S_2	0.31^a
SEm ±	0.005
CD (0.05)	0.017
CV%	4.94

S_0: burfi without fennel seed powder
S_1: added initially in milk at the rate of 0.5 % w/v of milk
S_2: added at pat formation stage at the rate of 0.5 % w/v of milk
n = 5, the values within a column with same superscript did not differ significantly (p>0.05) from each other.

The antioxidant activity of burfi samples prepared with fennel seed powder added at different stages (S_1 and S_2) was evaluated using the DPPH radical scavenging assay and expressed as mM Trolox equivalent (TE)/g of burfi (Table 4.6). The highest antioxidant activity was observed in S_2 (0.31 mM TE/g), followed by S_1 (0.28 mM TE/g), while the control sample (S_0) showed the lowest activity (0.15 mM TE/g). A significant difference (p<0.05) was observed between samples when fennel seed powder was incorporated at different processing stages.

The higher antioxidant activity in S_2 may be attributed to reduced thermal degradation of heat-sensitive phenolic compounds and improved retention of bioactive constituents when fennel seed powder was added at the pat formation stage, compared to earlier addition during milk heating.

Similar observations were reported by Gote *et al.* (2020) [8], who evaluated the effect of stage and form of curcumin addition on antioxidant activity in burfi. They reported significantly higher antioxidant potential when curcumin encapsulate was incorporated at the patting stage compared to earlier stages, highlighting the importance of processing conditions in preserving antioxidant compounds. Similar stage-dependent improvements in antioxidant activity have been reported in burfi fortified with plant-derived antioxidants (Gote *et al.*, 2020; Prasad *et al.*, 2017) [8, 17].

This trend can be explained by the thermal sensitivity of phenolic compounds and flavonoids present in fennel seeds, which are primarily responsible for their antioxidant activity. Prolonged heating during milk concentration likely induced oxidative degradation and polymerization of phenolics, thereby reducing radical scavenging efficiency when fennel seed powder was added during the initial heating phase (Huang *et al.*, 2012) [10]. Conversely, late-stage incorporation limited heat-induced losses and allowed better preservation of bioactive constituents. In addition, interactions between fennel phenolics and milk proteins may have contributed to antioxidant stabilization. Protein-polyphenol complexes formed during processing have been reported to enhance antioxidant persistence by protecting phenolics from oxidation and thermal degradation. Additionally, the formation of non-covalent complexes between fennel phenolics and milk proteins may have contributed to enhanced antioxidant persistence by protecting bioactive compounds from thermal and oxidative degradation (Jakobek, 2014, Gierczynski *et al.*, 2011) [11, 7].

Based on the combined results of sensory evaluation and antioxidant activity, it can be concluded that burfi prepared with fennel seed powder added at the pat formation stage (S_2) exhibited superior sensory attributes along with enhanced antioxidant activity, making it the most suitable stage for incorporation.

Effect of stage of addition of fennel seed powder on colour value of burfi

Colour of burfi samples was measured using a chroma meter and expressed in terms of L*, a* and b* values that are presented in Table 3.

Table 3: Effect of stage of addition of fennel seed powder on colour value of burfi

Burfi Samples	L*	a*	b*
S_0	72.40^a	-1.77^c	26.19^a
S_1	64.64^b	-3.45^b	24.50^b
S_2	65.57^b	-3.85^a	25.39^{ab}
SEm ±	0.37	0.04	0.33
CD (0.05)	1.15	0.13	1.04
CV%	1.23	3.06	2.99

S_0: burfi without fennel seed powder
S_1: added initially in milk at the rate of 0.5 % w/v of milk
S_2: added at pat formation stage @ of 0.5 % w/v of milk
n = 5, the values within a column with the same superscript did not differ significantly (p>0.05) from each other.

Colour characteristics of burfi samples were evaluated using a chroma meter and expressed as L*, a*, and b* values (Table 4.7), where L* indicates lightness (0 = black, 100 = white), a* represents the red-green axis (positive = red, negative = green), and b* represents the yellow-blue axis (positive = yellow, negative = blue).

No significant difference (p>0.05) was observed in the L* values of burfi samples when fennel seed powder was added at two different stages (S_1 and S_2); however, both differed significantly from the control. The highest L* value was recorded for S_0 (72.40), followed by S_2 (65.57) and S_1 (64.64), indicating a reduction in lightness due to fennel seed powder incorporation.

The a* values of-1.77,-3.45, and-3.85 were observed for S_0, S_1, and S_2, respectively. A significant difference (p<0.05) was noted between S1 and S2, suggesting enhanced retention of green colour when fennel seed powder was added at the pat formation stage. This may be attributed to reduced thermal degradation of chlorophyll and other green pigments due to shorter heat exposure.

The b* values were highest in S_0 (26.19), followed by S_2 (25.39) and S_1 (24.50). A significant difference ($p<0.05$) was observed between S_0 and S_1, whereas S_2 did not differ significantly ($p>0.05$) from either S_0 or S_1, indicating that the stage of fennel seed powder addition had no marked effect on yellowness.

This effect is likely attributable to reduced thermal degradation of chlorophyll and related pigments, which are highly susceptible to heat-induced pheophytinization (Hirasa & Takemasa, 1998) [9]. Early-stage addition, by contrast, subjected pigments to extended heating, resulting in greater colour dulling and pigment breakdown. The results indicate improved retention of green colour when fennel seed powder was incorporated at the pat formation stage compared to its addition during milk heating. This observation aligns with the findings of Hirasa and Takemasa (1998) [9], who reported that reduced cooking time and late-stage addition of herbs help preserve green pigments. Therefore, incorporation of fennel seed powder at the pat formation stage resulted in better colour retention, higher antioxidant activity, and acceptable sensory attributes. Consequently, this stage of addition was selected for subsequent studies.

Optimization for rate of addition of fennel seed powder in burfi

To optimize the rate of fennel seed powder addition in burfi, the powder was incorporated at the pat formation stage at levels of 0.25, 0.50, 0.75, and 1.00% (w/v of milk). Burfi prepared without fennel seed powder served as the control. Freshly prepared burfi samples were evaluated for sensory attributes by a trained panel of eight judges using a 9-point hedonic scale. In addition, antioxidant activity was determined using the DPPH radical scavenging assay, and colour parameters (L*, a*, b*) were measured using a chroma meter.

Effect of rate of addition of fennel seed powder on sensory characteristics of burfi

The effect of different rate of addition of fennel seed powder on sensory characteristics of burfi is presented in Table 4.

Table 4: Effect of rate of addition of fennel seed powder on sensory characteristics of burfi

Rate of addition (%, w/v)	Sensory score (9-point hedonic scale)			
	Flavour	Colour and appearance	Body and texture	Overall acceptability
R_0	8.57^a	8.38^a	8.31^a	8.43^a
R_1	7.85^c	7.71^c	7.91^b	7.88^b
R_2	8.20^b	8.05^b	7.99^b	8.07^b
R_3	7.36^d	7.46^d	7.42^c	7.43^c
R_4	6.94^e	6.86^e	6.86^d	6.93^d
SEm ±	0.112	0.083	0.103	0.112
CD (0.05)	0.34	0.25	0.31	0.34
CV%	2.87	2.16	2.67	2.89

R_0: burfi without fennel seed powder (control)
R_1, R_2, R_3 and R_4 burfi samples were added with 0.25, 0.5, 0.75 and 1 % w/v of fennel seed powder, respectively
n = 4, the values within a column with same superscript did not differ significantly ($p>0.05$) from each other

Sensory evaluation showed that the rate of fennel seed powder incorporation significantly affected ($p<0.05$) flavour, colour and appearance, body and texture, and overall acceptability of burfi samples. The control sample (R_0) consistently received the highest scores, reflecting consumer preference for the traditional product. However, among the fennel seed powder incorporated samples, moderate inclusion levels resulted in improved sensory responses.

Flavour scores increased with fennel seed powder addition up to 0.5 per cent, with R_2 recording the highest flavour score among the treated samples. The aromatic and mildly sweet characteristics of fennel likely complemented the milk solids and sugar matrix at this level. Higher concentrations led to a decline in flavour acceptability, with R_4 receiving the lowest score, possibly due to excessive herbal intensity.

Colour and appearance scores followed a similar trend. While R_0 maintained the highest score, R_2 showed the best visual appeal among the experimental samples. Increased addition levels (R_3 and R_4) resulted in dull and brownish coloration, likely due to the natural pigment of fennel seed powder and intensified thermal browning during processing.

Body and texture were also significantly influenced by fennel seed powder incorporation. R_0 exhibited superior texture owing to a uniform milk matrix. Among the treated samples, R_2 achieved the highest body and texture score, whereas higher levels resulted in graininess and a loose body due to the presence of fennel seed particles.

Overall acceptability reflected the combined effect of all sensory attributes. Although R_0 remained the most preferred, R_2 showed the highest acceptability among the fennel seed powder incorporated samples. Acceptability declined at higher inclusion levels (R_3 and R_4), indicating sensory limitations at excessive concentrations. Incorporation of fennel seed powder at 0.5 per cent (w/v of milk) at the pat formation stage was optimal for enhancing sensory quality while maintaining consumer acceptability, supporting its suitability for value-added functional burfi development. The dose-dependent increase in antioxidant activity reflects the proportional enrichment of phenolic and flavonoid constituents; however, excessive concentrations likely intensified matrix-phenolic interactions and sensory masking effects, thereby limiting overall product acceptability.

Effect of rate of addition of fennel seed powder on antioxidant activity of burfi

The antioxidant activity (DPPH radical scavenging activity) of burfi added with different rate of fennel seed powder are presented in Table 5.

Table 5: Effect of rate of addition of fennel seed powder on antioxidant activity of burfi

Rate of addition of fennel seed powder (% w/v)	mM Trolox equivalent/g
R_0	0.15^e
R_1	0.23^d
R_2	0.31^c
R_3	0.37^b
R_4	0.46^a
SEm ±	0.006
CD (0.05)	0.019
CV%	4.08

R_0: burfi without fennel seed powder (control)
R_1, R_2, R_3 and R_4 burfi samples were added with 0.25, 0.5, 0.75 and 1 % w/v of fennel seed powder, respectively
n = 4, the values within a column with same superscript did not differ significantly ($p>0.05$) from each other

Antioxidant activity differed significantly ($p<0.05$) with varying rates of fennel seed powder addition. A progressive increase in antioxidant activity was observed with increasing levels of fennel seed powder, indicating a dose-dependent effect. The antioxidant potential of burfi samples R_4, R_3, R_2, R_1, and R_0 was 0.46, 0.37, 0.31, 0.23, and 0.15-mM TE/g, respectively.

The enhanced antioxidant activity at higher inclusion levels may be attributed to the increased concentration of phenolic compounds and other bioactive constituents present in fennel seed powder. However, despite exhibiting the highest antioxidant activity, sample R_4 recorded lower sensory scores, likely due to excessive flavour intensity, darker colour, and textural defects.

Among the fortified samples, R_2 demonstrated a desirable balance between antioxidant activity and sensory acceptability, with a considerably higher overall acceptability score compared to higher inclusion levels. Since consumer preference is primarily governed by sensory quality, incorporation of fennel seed powder at 0.5% (w/v of milk) was selected as the optimum level for burfi preparation and was therefore carried forward for further study.

Effect of rate of addition of fennel seed powder on colour of burfi

Colour of burfi samples was measured using a chroma meter and expressed in terms of L*, a* and b* values are presented in Table 6.

Table 6: Effect of rate of addition of fennel seed powder on colour value of burfi

Burfi Samples	L*	a*	b*
R_0	71.29^a	-1.72^e	27.02^a
R_1	67.20^b	-2.48^d	26.15^{ab}
R_2	65.13^c	-3.80^c	26.06^{ab}
R_3	63.32^d	-4.43^b	25.60^{ab}
R_4	61.45^e	-5.62^a	24.71^b
SEm ±	0.40	0.08	0.62
CD (0.05)	1.21	0.25	1.87
CV%	1.22	4.51	4.78

R_0: burfi without fennel seed powder (control)
R_1, R_2, R_3 and R_4 burfi samples were added with 0.25, 0.5, 0.75 and 1 % w/v of fennel seed powder, respectively
n = 4, the values within a column with same superscript did not differ significantly ($p>0.05$) from each other

Significant differences ($p<0.05$) were observed in the L* values of burfi samples prepared with varying levels of fennel seed powder. The highest lightness (L*) was recorded for the control sample (R_0), and a progressive decline was noted with increasing levels of fennel seed powder, with L* values of 67.20, 65.13, 63.32, and 61.45 for R_1, R_2, R_3, and R_4, respectively. This reduction in lightness may be attributed to the presence of natural pigments in fennel seed powder and increased solid content, resulting in a darker appearance.

The a* values differed significantly ($p<0.05$) among the samples. All burfi samples exhibited negative a* values, indicating green colour tones. The a* value decreased from −1.72 in R_0 to −5.62 in R_4, reflecting increased green colour intensity with higher fennel seed powder incorporation. This trend is likely due to the higher concentration of chlorophyll and associated pigments contributed by fennel seed powder. Notably, incorporation at the pat formation stage resulted in more pronounced negative a* values, indicating enhanced retention of green colour tones.

The b* values were highest in R_0 (27.02) and decreased gradually with increasing fennel seed powder addition, reaching the lowest value in R_4 (24.71). A significant difference ($p<0.05$) was observed between R_0 and R_4, whereas intermediate samples (R_1-R_3) did not differ significantly. The decline in b* values may be attributed to masking of the inherent yellow colour of burfi by the green pigments of fennel seed powder. The relatively stable b* values across treatments suggest that fennel seed powder had a limited influence on the yellowness of burfi, which is predominantly governed by milk fat content and Maillard reaction products formed during desiccation. The dose-dependent increase in antioxidant activity reflects the proportional enrichment of phenolic and flavonoid constituents; however, excessive concentrations likely intensified matrix-phenolic interactions and sensory masking effects, thereby limiting overall product acceptability (Chaudhary *et al.*, 2019) [5].

Similar findings were reported by Chaudhary *et al.* (2019) [5], who observed a decrease in L* and b* values and an increase in green intensity (more negative a* values) with increasing levels of aloe vera juice in burfi. They attributed these changes to the natural green pigments present in aloe vera, supporting the trends observed in the present study. Overall, burfi sample R_2 exhibited the highest sensory acceptability, while samples R_3 and R_4 showed greater antioxidant activity and more pronounced green colour but lower sensory scores. These findings indicate that moderate incorporation of fennel seed powder provides an optimal balance between visual appeal, sensory quality, and functional properties.

Chemical composition of burfi

The burfi samples were analyzed for moisture, fat, protein, lactose, sucrose and ash content. The results obtained are presented in Table 7.

Table 7: Proximate composition of burfi

Burfi Samples	Constituents (%)					
	Moisture	Fat	Protein	Lactose	Sucrose	Ash
T_0	17.94	23.30	13.88	18.38	23.62	2.84
T_1	19.00	23.14	13.31	18.07	23.20	2.94

T_0: burfi without fennel seed powder (control burfi)
T_1: burfi made with 0.5 % w/v of fennel seed powder

The proximate composition of burfi samples showed moisture, fat, protein, lactose, sucrose, and ash contents within a narrow range. Statistical analysis indicated no significant differences ($p>0.05$) between T_0 and T_1 samples for fat, protein, lactose, sucrose, and ash contents, whereas moisture content differed significantly ($p<0.05$). The higher moisture content in T_1 may be attributed to the hygroscopic nature of fennel seed powder and its water-binding capacity during processing. Overall, incorporation of fennel seed powder at 0.5% (w/v of milk) did not markedly alter the proximate chemical composition of burfi, except for moisture content.

Considerable variation in the chemical composition of burfi has been reported in earlier studies, with moisture ranging from 12.25 to 23.65%, fat from 15.35 to 28.32%, protein from 9.47 to 23.68%, lactose from 10.43 to 33.88%, and ash

content from 1.56 to 4.06% (Bhutkar *et al.*, 2015; Patil *et al.*, 2015; Mete *et al.*, 2017; Prasad *et al.*, 2017; Dua *et al.*, 2018; Narwade, 2017; Shrivas *et al.*, 2018; Yadav *et al.*, 2019) [4, 16, 13, 17, 6, 14, 19, 20]. The values obtained in the present study fall well within these reported ranges, confirming the consistency of the results with existing literature.

Conclusion

This study successfully identified not only the optimized stage of addition but also the optimal level of inclusion for fennel (*Foeniculum vulgare*) seed powder in a burfi recipe. It was shown that process-stage optimization is essential for raising functional quality without losing sensory acceptance. Adding the ingredient at the pat formation phase was better than early-stage addition as it resulted in improved antioxidant retention, colour stability, and flavour integration while allowing for the desired body and texture to be maintained. These findings emphasize the significance of reducing thermal exposure when it comes to preserving heat-sensitive bioactive compounds in heat-desiccated dairy products. It was found that a moderate inclusion level offered the most agreeable combination of elevated antioxidant activity and consumer acceptability among the different concentrations tested, while higher levels, although functionally more beneficial, caused a decline in sensory quality. Moreover, the lack of significant variation in proximate composition indicates that fennel seed powder is technologically compatible with the traditional burfi matrix. The major enablement of this study is describing a process-level intervention, not just a formulation enhancement, for boosting the functional properties of a traditional dairy confection. On the industrial side, the refined recipe is a clean-label, scalable alternative to synthetic antioxidants, in line with present market trends and conforming to FSSAI and ISO 22000 standards.

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