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Ganesh S Kahar
M Tech. Scholar, Department of Processing and Food Engineering, CAET, Dr. BSKKV, Dapoli, Maharashtra, India

AA Sawant
Professor and Head, Department of Processing and Food Engineering, CAET, Dr. BSKKV, Dapoli, Maharashtra, India

Vikram P Kad
Professor and Head, Department of Food Science and Technology, Dr. ASCAET, MPKV, Rahuri, Maharashtra, India

SB Kalse
Assistant Professor, Department of Processing and Food Engineering, CAET, Dr. BSKKV, Dapoli, Maharashtra, India

PP Chavan
Assistant Professor, Department of Renewable Energy Engineering, CAET, Dr. BSKKV, Dapoli, Maharashtra, India

PB Bansode
Assistant Professor of Statistics, Department of Soil and water Conservation, CAET, Dr. BSKKV, Dapoli, Maharashtra, India

Ganesh N Shelake
Assistant Professor, Department of Processing and Food Engineering, Dr. ASCAET, MPKV, Rahuri, Maharashtra, India

KK Kashid
M Tech. Scholar, Department of Processing and Food Engineering, CAET, Dr. BSKKV, Dapoli, Maharashtra, India

Corresponding Author:
Ganesh S Kahar
M Tech. Scholar, Department of Processing and Food Engineering, CAET, Dr. BSKKV, Dapoli, Maharashtra, India

Textural and colorimetric profiling of idli pre-mix formulated with finger millet (*Eleusine coracana*)

Ganesh S Kahar, AA Sawant, Vikram P Kad, SB Kalse, PP Chavan, PB Bansode, Ganesh N Shelake and KK Kashid

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Abstract
This study assessed the effects of incorporating finger millet into idli premixes on their texture and color characteristics. Six treatments with varying millet levels were evaluated for parameters such as cutting force, compressive strength, springiness, chewiness, gumminess, cohesiveness, and color attributes. The millet-enriched idlis demonstrated increased firmness, with cutting force reaching up to 21.38 N and chewiness up to 33.06 N. Specifically, treatment T_3 exhibited a moderate cutting force of 17.42 N and chewiness of 22.57 N, reflecting a balanced texture with good firmness. Compressive peak force rose with millet content, whereas springiness remained stable across all treatments, including T_3. Cohesiveness decreased in millet-containing samples, likely due to the coarse fiber content disrupting internal structure. Color analysis showed that millet incorporation darkened the idli and increased redness, with T_3 showing notable reductions in lightness and higher red values, caused by natural pigments and Maillard browning during cooking. The total color difference (ΔE) confirmed a significant but acceptable visual change from the rice-based control. These results suggest that finger millet addition enhances the textural strength and nutritional profile of idli but requires formulation optimization to maintain desirable sensory qualities.

Keywords: Finger millet, idli, texture, color, fortification

1. Introduction

Idli is a traditional fermented steamed cake from South India, known for its soft texture, mild tanginess, and easy digestibility. In recent years, instant idli premixes have gained popularity due to their convenience. Traditionally, idli batter is made from rice and black gram, which together create its unique texture and flavor (Steinkraus *et al*., 1967; Reddy *et al*., 1981) [22, 17]. However, many commercial premixes use polished white rice that, while offering good texture and longer shelf life, lack important nutrients like iron, calcium, and dietary fiber.

To improve the nutritional profile of instant idli mixes, finger millet (Eleusine coracana) has emerged as a promising ingredient (Krishnamoorthy *et al*., 2013) [13]. Finger millet is some nutrient-dense grain rich in minerals such as iron, calcium, magnesium, phosphorus, potassium, and dietary fiber. It also contains antioxidants and has a low glycemic index, making it beneficial for health (Shashi, Sharan, Hittalamani, *et al*., 2007) [19]. However, finger millet contains compounds like tannins and phytic acid that can reduce the absorption of minerals by forming insoluble complexes. Meanwhile, black gram contributes to fermentation by providing essential microbes and fermentable substrates (Radhakrishnamurthy *et al*., 1961) [16]. Incorporating finger millet into idli batter can alter the batter's viscosity, fermentation behavior, and ultimately the texture, structure, and color of the final product, which may affect consumer acceptance (Balasubramanian and Viswanathan, 2007) [2]. Finger millet is available in multiple colors such as yellow, white, tan, red, brown, and violet, with the red variety being most widely cultivated globally. It primarily consists of carbohydrates, with roughly 1% free sugars, 65.5% starch, and 11.5% dietary fiber, mostly non-starchy polysaccharides (Gopalan, Rama Sastri, & Balasubramanian, 2009) [5].

Texture and appearance are key factors influencing idli's appeal. The addition of finger millet increases batter thickness and tends to make the cooked idli harder, while decreasing its springiness. The polyphenols in finger mill*et al*so darken the idli, decreasing its lightness

(L*) and increasing red (a*) and yellow (b*) tones. While these changes enhance nutritional value, they can conflict with traditional expectations of idli's soft texture and pale color. Research suggests that finger millet can be added up to about 40% without compromising acceptability, but higher amounts typically cause undesirable hardness and color changes. Techniques like soaking, malting, or adding hydrocolloids can improve texture. Additionally, blending finger millet with lighter grains or using dehusked millet can help reduce color darkening (Kahar *et al*., 2024) [7]. Although finger millet results in denser, darker idli compared to other millets, its superior nutrition makes it a valuable ingredient. A balanced blend with other grains or legumes might provide the best compromise between nutrition and sensory qualities.The final quality of idli depends on many factors, including fermentation time, batter composition, and processing conditions. Studies have found that using alternative grains such as millets, brown rice, or germinated seeds can improve both the nutritional content and sensory appeal of idli (Kaur *et al*., 2020; Pandey & Awasthi, 2015) [4, 15]. Softness, cohesiveness, and springiness are influenced by how starch and protein interact during fermentation (Balasubramanian & Viswanathan, 2007; Koh & Singh, 2009) [7, 11].

The rheological and pasting properties of the batter are critical because they affect gas retention and water holding capacity—both essential for a good texture and volume in steamed idli (Nazni & Sangeethalakshmi, 2017) [14]. Using statistical methods like response surface methodology to optimize ingredient ratios has led to better sensory scores and consumer preference (Dhillon *et al*., 2020) [4]. Moreover, natural preservatives such as mustard essential oil have been tested to extend shelf life without negatively affecting flavor or texture (Regubalan & Ananthanarayan, 2018) [18]. Advanced modeling techniques have helped simulate how texture changes during steaming and better understand starch gelatinization, allowing for consistent quality in instant mixes (Sinha & Bhargav, 2018a, 2018b) [20, 21]. Functional idli mixes developed with diverse grains and stabilizers show commercial promise (Krishikosh, n.d.).

Despite these advances, most research has been limited in scale and often fails to combine sensory analysis with instrumental data. Also, studies on storage stability and microbial safety for commercial premixes remain scarce. Addressing these gaps is important for wider adoption of finger millet-enriched idli premixes. This review aims to bring together current knowledge on the texture and color characteristics of finger millet-fortified idli premixes, highlight challenges, and propose practical processing approaches to create nutritious, market-friendly, and consumer-acceptable products.

2. Materials and Methodology

2.1 Idli Pre-mix Formulation

The study involved six sample treatments labeled T_1 through T_6, where T_6 served as the control group. Each sample was subjected to texture analysis to measure key physical properties including the force required to cut the sample, the maximum force exerted during compression, and the ability of the sample to return to its original shape after deformation.

Six instant idli pre-mix formulations (T_1-T_6) were developed by varying the proportions of rice, finger millet, and black gram to a total weight of 100 g. Formulations were as follows: T_1 (50% rice, 30% finger millet, 20% black gram), T_2 (40% rice, 40% finger millet, 20% black gram), T_3 (30% rice, 50% finger millet, 20% black gram), T_4 (20% rice, 60% finger millet, 20% black gram), T_5 (10% rice, 70% finger millet, 20% black gram), and T_6 control (70% rice, 30% black gram). These were evaluated for batter viscosity, extensibility, and texture.

2.1.1 Idli Steaming

Idlis were prepared using instant pre-mixes formulated with varying levels of finger millet incorporation. Each formulation, including the control, was mixed with water in a 1:2 (w/w) ratio and stirred thoroughly for 15 minutes to ensure uniform consistency. The batter was then rested for another 15 minutes at ambient temperature to allow proper hydration. Following this, the batter was poured into an idli steamer mould and steamed for approximately 15-20 minutes until fully cooked. After steaming, the idlis were allowed to cool at room temperature before evaluation. The control sample was prepared using a traditional rice-based pre-mix, while all other treatments included different proportions of finger millet flour in place of rice flour to assess its effect on the final product's textural, nutritional, and sensory attributes. The prepared idlis are illustrated in the photographs shown in Figure 13.

2.2 Textural Analysis

Texture analysis was performed using a Universal Testing Machine (Shimadzu Corporation, Japan; 2500 N capacity) and a Texture Analyzer (Food Technology Corporation, USA; 500 N capacity). Idli samples were placed on the loading cell and compressed at a crosshead speed of 50 mm/min with a maximum load of 1 kg and compression distance of 75%. Cutting force, maximum compressive peak force, and springiness were recorded in Newtons (N), indicating firmness, cutting resistance, and elasticity respectively (Karma *et al*., 2018) [9] (AOAC, 2016) [1].

2.2.2 Chewiness

Chewiness reflects the energy needed to chew food until it becomes ready to swallow. It was calculated by multiplying the cutting force, the maximum compressive force, and the springiness ratio: (AOAC, 2016) [1].

$$\text{Chewiness} = \text{Cutting Force} \times \text{Max Compressive Peak Force} \times \text{Springiness Ratio} \qquad \text{(Eq. 1)}$$

2.2.2 Gumminess

Gumminess describes the energy required to disintegrate a semi-solid food to a swallowable state. Since direct cohesiveness data was unavailable, gumminess was approximated as: (AOAC, 2016) [1].

$$\text{Gumminess} = \text{Cutting Force} \times \text{Springiness Ratio} \qquad \text{(Eq. 2)}$$

2.2.3 Cohesiveness

Cohesiveness is a measure of the internal bonding within the sample, commonly calculated as the ratio of the area under the second compression curve to the first. Due to missing data on compression curves, cohesiveness was roughly estimated using: (AOAC, 2016) [1].

$$\text{Cohesiveness} = \frac{\text{Max Compressive Peak Force}}{\text{Cutting Force}} \qquad \text{(Eq. 3)}$$

2.3 Colour Measurement

Color measurements were made using a Premier Colorimeter based on the CIE L*, a*, b* system. The instrument was calibrated with white and black standards before analyzing idli and pre-mix powder samples. Total color difference (ΔE*) relative to control was calculated using differences in lightness (ΔL*), redness (Δa*), and yellowness (Δb*) (Gulia *et al*., 2010; AOAC, 2016) [1, 6].

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad \text{(Eq. 4)}$$

2.4 Statistical Analysis

Data obtained from all measurements were analyzed statistically to determine significant differences between treatments at a confidence level of $p < 0.05$. (AOAC, 2016; Gulia *et al*., 2010) [1, 6].

3. Results Discussion

3.1 Textural Analysis of Idli

3.3.1 Cutting force, maximum compressive peak force, and springiness ratio of Idli

The results presented in Table 1 clearly indicate that different treatments had a significant impact on the textural properties of the idli prepared from premix.

The cutting force for the control sample (T_6) was recorded at 15.25 N and increased notably to 21.38 N in T_5. Among the millet-based samples, T_3 showed the lowest cutting force at 17.42 N, while T_2 and T_4 exhibited values of 18.32 N and 17.72 N, respectively. T_1 registered a relatively higher force of 20.04 N. This trend suggests that higher levels of millet incorporation tend to increase structural firmness, thereby requiring greater force to cut through the product. The graphical representation of the cutting force is provided in Figure 1.

The maximum compressive peak force was 1.42 N for the control (T_6) and peaked at 1.50 N in T_5. Samples T_3 and T_4 had identical values of 1.27 N, while T_1 and T_2 showed lower peak forces of 0.97 N and 0.99 N, respectively. The increase in peak force with certain treatments may be attributed to the denser structure resulting from millet addition, which enhances the compressive resistance of the product. Compressive peaks is illustrated in Figure 2.

The springiness values remained fairly consistent across all treatments, ranging narrowly from 1.02 to 1.03. Specifically, T_1 and T_5 recorded 1.03, while T_2, T_3, T_4, and T_6 each stood at 1.02. This uniformity indicates that millet incorporation had minimal impact on the elastic recovery of the idli, likely due to the air cell structure formed during steaming that helps maintain springiness. Figure 3 demonstrates the Springiness ratio's.

The standard error of difference (S.E. (D)) values for cutting force, peak force, and springiness were 0.045 N, 0.010 N, and 0.006, respectively. The critical difference (C.D.) values were 0.096 N for cutting force, 0.020 N for peak force, and 0.014 for springiness, confirming that the differences were statistically significant. The coefficient of variation (C.V.) values were 0.050 for cutting force, 0.160 for peak force, and 0.129 for springiness.

In summary, the study concluded that the treatments notably influenced both cutting resistance and compressive strength of the product. The addition of millet enhanced firmness and compressive resistance but did not significantly alter the elasticity of the idli.

Table 1: Effect of Treatments on Cutting Force, Compressive Force, and Springiness of Idli

Treatments	Cutting Force (N)	Max Compressive Peak Force (N)	Springiness Ratio
T_1	20.04	0.97	1.03
T_2	18.32	0.99	1.02
T_3	17.42	1.27	1.02
T_4	17.72	1.27	1.02
T_5	21.38	1.50	1.03
T_6 Control	15.25	1.42	1.02
S.E(D)	0.045	0.010	0.006
C.D	0.096	0.020	0.014
C.V.	0.050	0.160	0.129

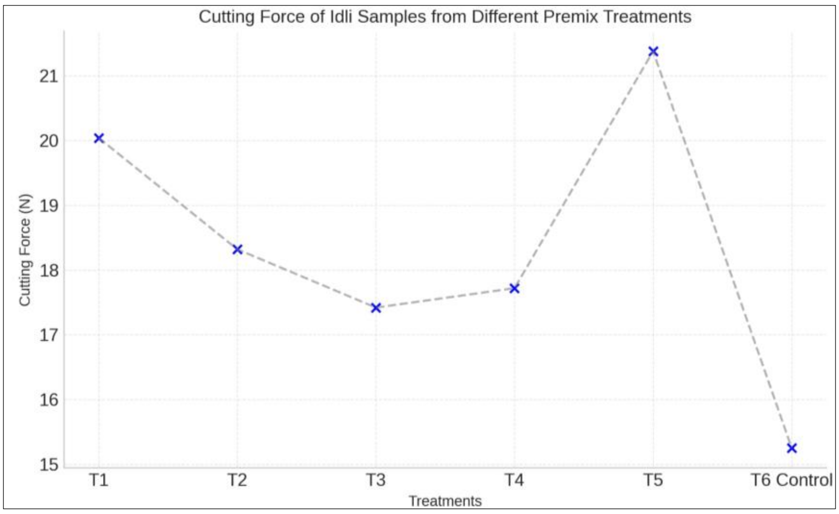


Fig 1: Cutting Force of Idlis Prepared from Premix Samples across Different Treatments

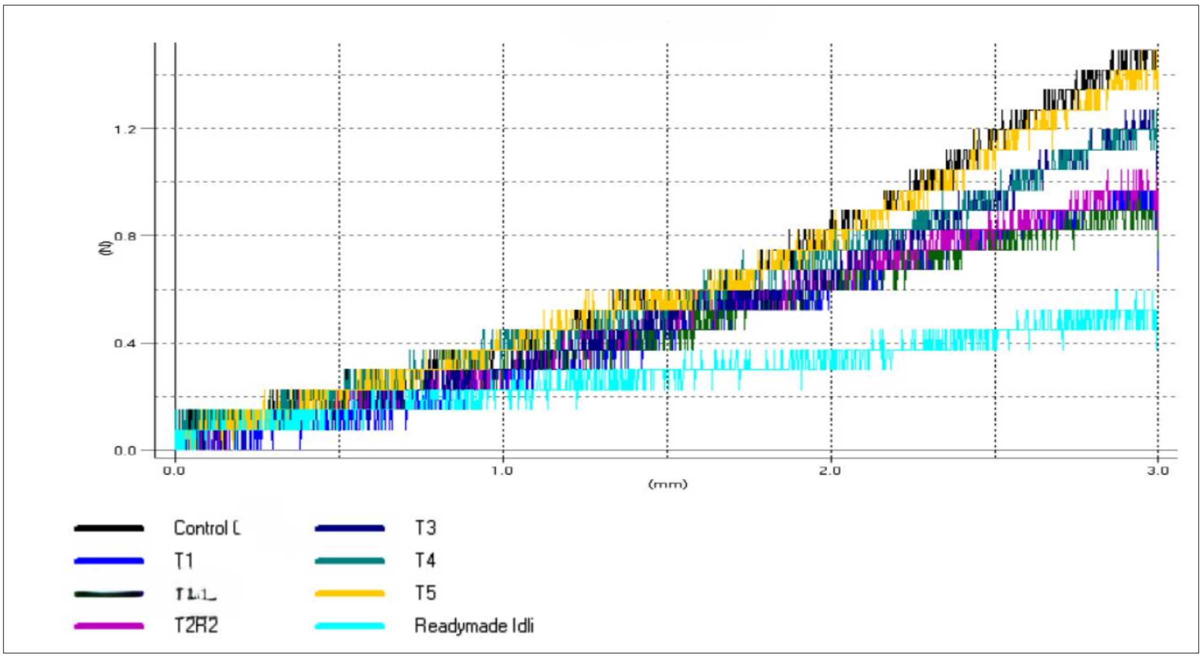


Fig 2: Max Compressive Peak Force (N) of Prepared Idli from Pre mix Across Treatments:

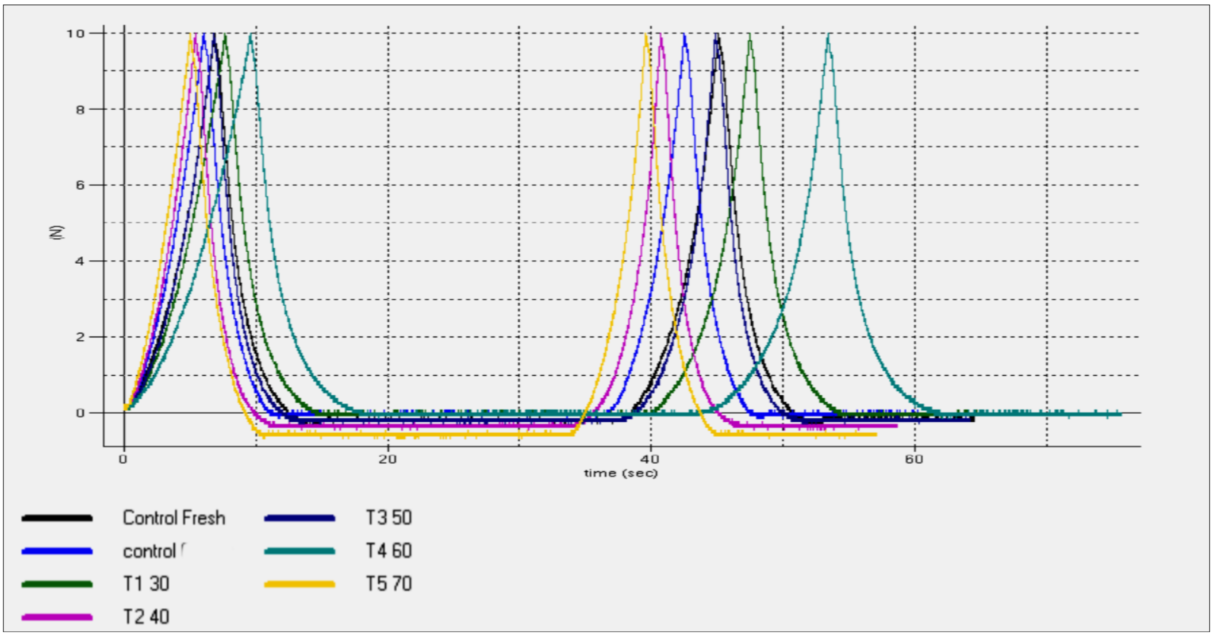


Fig 3: Springiness Ratio Profiles of Idli Prepared from Premix Samples across Treatments

3.3.2 Chewiness, gumminess & Cohesiveness profiles of Idli

The chewiness was highest in T_5 (33.06 N), indicating a firmer and more resistant texture, likely due to increased millet content enhancing structural density. T_2 recorded the lowest value (18.51 N), suggesting a softer bite. T_3, T_4, and T_6 showed moderate chewiness ranging from 22.10 to 22.97 N.

In terms of gumminess, T_5 again showed the highest value (22.02 N), while the control sample T_6 had the lowest (15.56 N). The results suggest that millet incorporation contributes to a stronger and more compact internal structure, increasing resistance during mastication.

Cohesiveness was highest in T_6 (0.0931), indicating better internal bonding of the control sample. Treatments T_3, T_4, and T_5 showed slightly lower cohesiveness (around 0.070), while T_1 and T_2 recorded the lowest values, implying a less integrated texture. The lower cohesiveness in millet-based treatments may result from the coarse fiber disrupting internal bonding. The graphical representation of the Chewiness, Gumminess, and Cohesiveness are provided in Table 2 Figure.

Statistical parameters showed significant treatment effects, with S.D values of 5.12 (chewiness), 2.27 (gumminess), and 0.0157 (cohesiveness). The coefficients of variation (CV) further confirmed acceptable variability in the results.

Table 2: Effect of Treatments on Chewiness, Gumminess, and Cohesiveness

Treatment	Chewiness (N)	Gumminess (N)	Cohesiveness
T_1	20.03	20.64	0.0483
T_2	18.51	18.69	0.0540
T_3	22.57	17.77	0.0729
T_4	22.97	18.07	0.0717
T_5	33.06	22.02	0.0702
T_6	22.10	15.56	0.0931
S.D	5.12	2.27	0.0157
CV (%)	22.06	12.08	22.95
SE (d)	2.09	0.93	0.0064

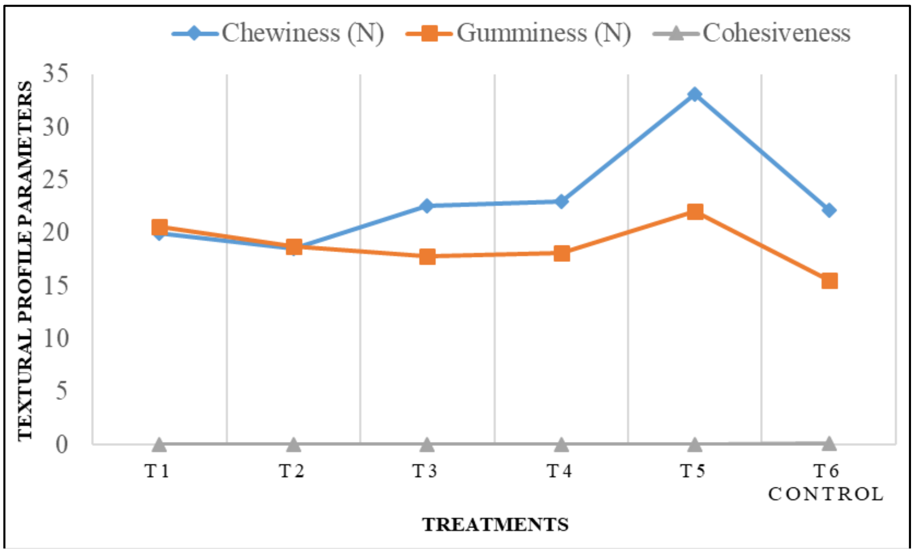


Fig 4: Textural Profile Parameters of Idli Fortified with Finger Millet

3.2 Colour Analysis of Idli

Color measurements revealed significant differences among treatments, as shown in Table 3 and Figure 6 to 11. These variations were primarily influenced by the level of millet incorporation in the premix.

The lightness (L*) value was highest in the control (T_6) at 74.04, indicating a lighter and more appealing color. In contrast, T_4 exhibited the lowest lightness (41.77), suggesting a darker appearance. This reduction in lightness is attributed to the darker natural pigment of millet flour and its influence during steaming. The a* values (red-green scale) increased across all millet treatments, with T_4 showing the highest redness (5.81). The control sample showed a negative value (-1.13), reflecting a slight greenish hue. As shown in the table and figure, the increase in redness among treatments is likely a result of Maillard reactions and pigment changes caused by millet incorporation.

In terms of b* (yellow-blue scale), the control had the highest yellowness (12.02), while T_5 had the lowest (6.03). The decline in b* values in millet-added samples may be due to browning reactions and reduced presence of yellow pigments in the formulation. The total color difference (ΔE) was highest in T_4 (33.32), followed by T_5 and T_3, indicating a noticeable visual color shift from the control. The control and T_1 showed the lowest ΔE values (21.96), meaning their overall color difference was minimal compared to others.

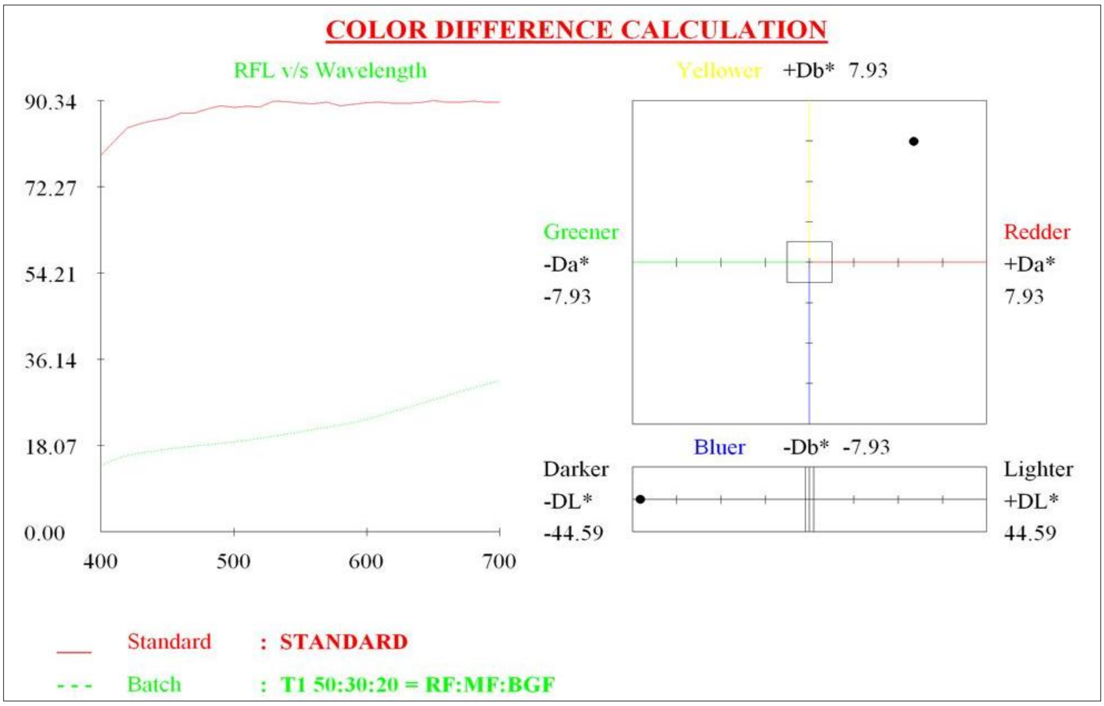
These results, supported by low coefficients of variation and confirmed by the statistical values presented in Table 3, demonstrate that millet incorporation significantly alters the visual quality of the final product by reducing lightness and enhancing red tones.

The color difference analysis between the millet-based and rice-based idli premixes revealed significant variations in visual appearance. The millet-based premix exhibited a higher total color difference (ΔE = 23.37) compared to the rice-based premix (ΔE = 16.41), indicating a more pronounced deviation from the reference sample.as shown in Fig 12 The millet-based sample was considerably darker (ΔL = -23.37) and showed a strong shift toward green (Δa = -11.94) and blue (Δb = -11.94) hues. In contrast, the rice-based premix was moderately darker (ΔL = -16.41) with a less intense shift toward green (Δa = -4.83) and blue (Δb = -4.83). These differences can be attributed to the presence of natural pigments such as polyphenols and anthocyanins in finger millet, which contribute to the darker and cooler color tones in the millet-based formulation.

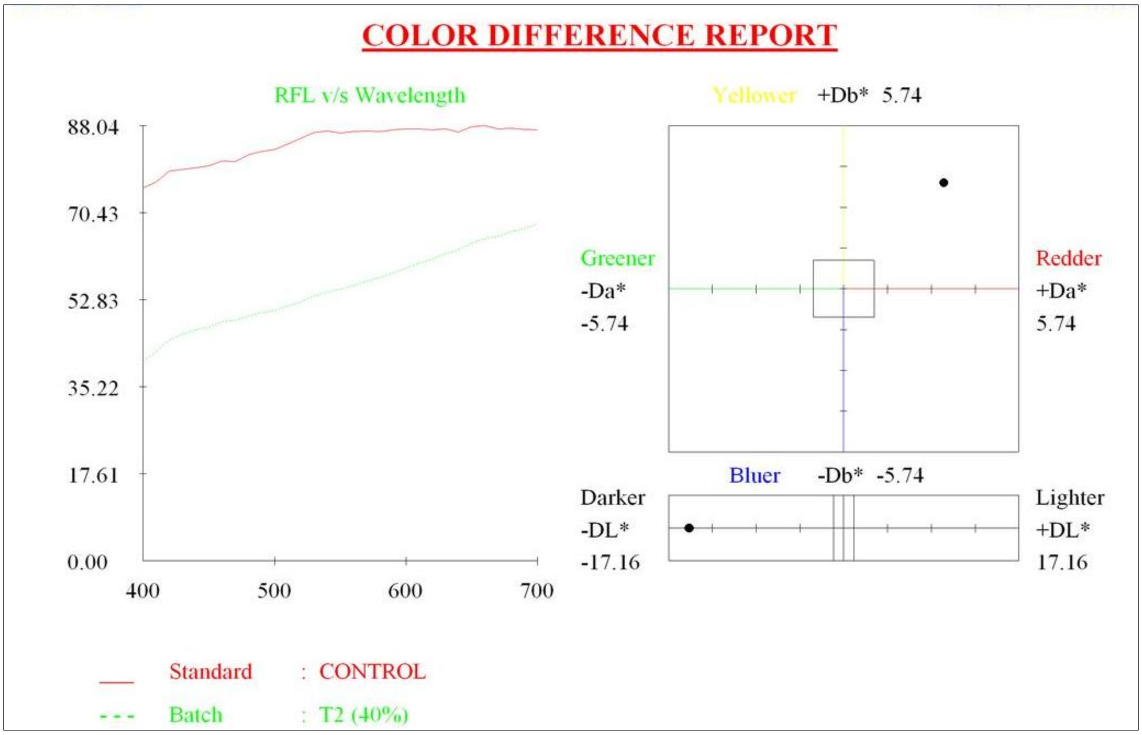
The finger millet-based idli premix exhibited a higher total color difference (ΔE = 23.37) compared to the rice-based premix (ΔE = 16.41), indicating a greater visual deviation from the reference. The millet-based sample was significantly darker (ΔL = -23.37) with noticeable green (Δa = -11.94) and blue (Δb = -11.94) shifts. In contrast, the rice-based premix was moderately darker (ΔL = -16.41) with milder green (Δa = -4.83) and blue (Δb = -4.83) tones. The darker and cooler appearance of the millet-based mix is attributed to the presence of natural pigments in finger millet. As shown in Fig 13

Table 3: L, a, b* Values of Idli Flour under Various Treatments

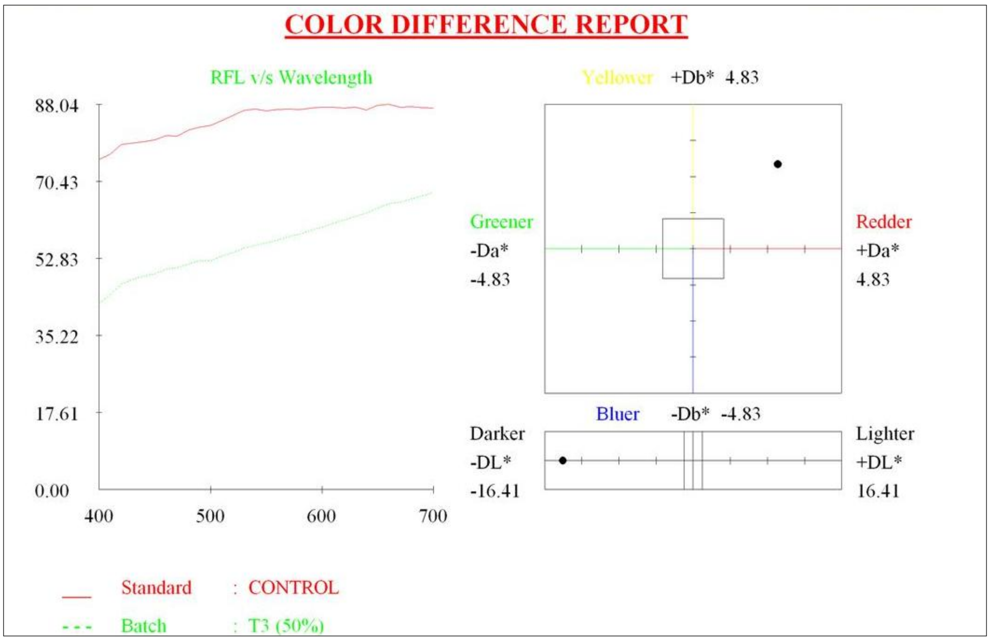
Treatment	L* (Lightness)	a* (Red-Green)	b* (Yellow-Blue)	ΔE
T_1	53.10	4.05	7.84	21.96
T_2	48.94	5.58	8.54	26.22
T_3	46.91	5.60	7.67	28.28
T_4	41.77	5.81	7.45	33.32
T_5	44.87	5.11	6.03	30.42
T_6 (Control)	74.04	-1.13	12.02	21.96
S.E(D)	0.315	0.036	0.070	0.341
C.D	0.665	0.076	0.148	0.720
C.V (%)	0.125	0.176	0.174	0.258



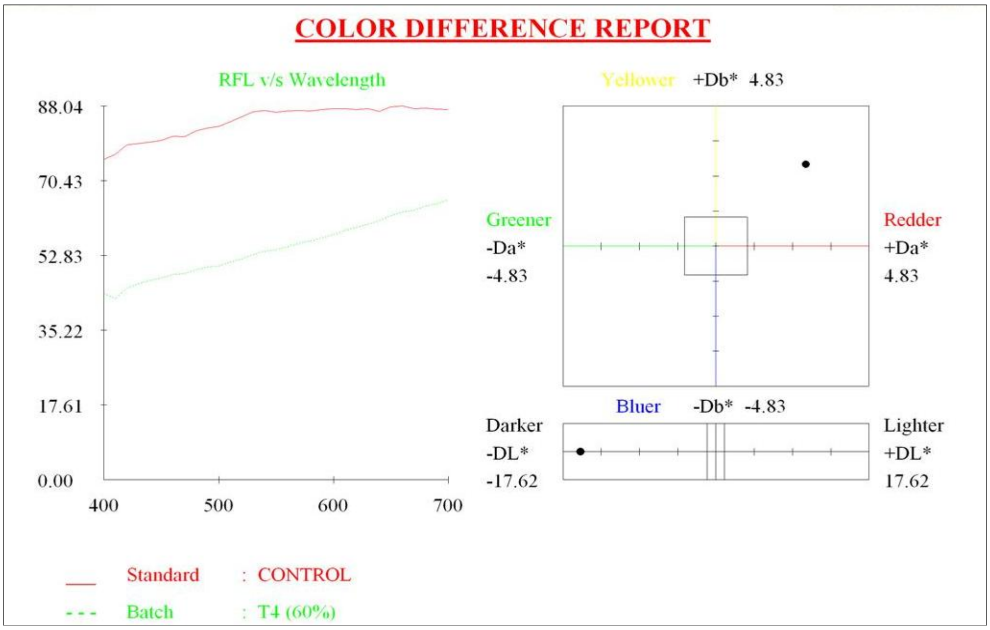
T_1 Fig 5: Spectral Reflectance and CIE Lab-Based Color Difference Analysis between Standard and Composite Blend



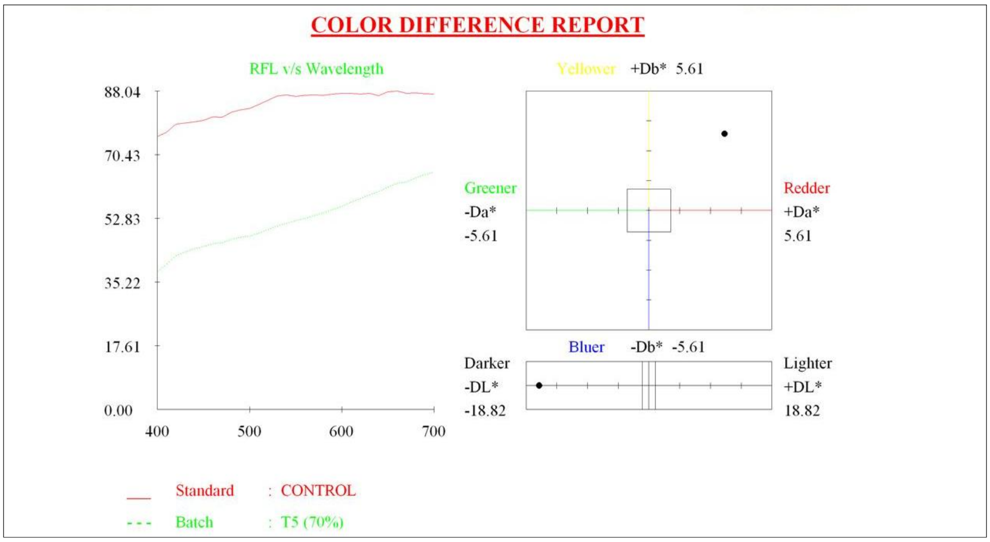
T_2 Fig 6: Spectral Reflectance and CIE Lab-Based Color Difference Analysis between Standard and Composite Blend



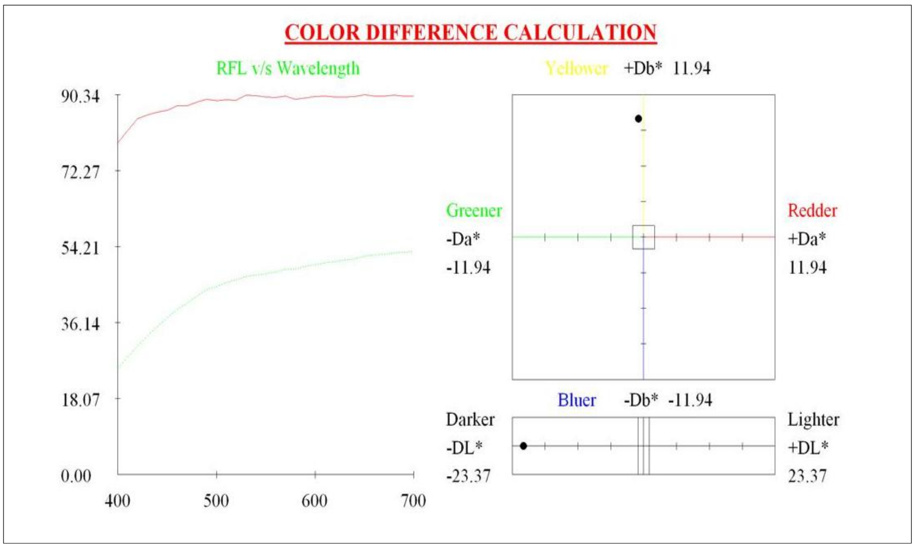
T3 Fig 7: Spectral Reflectance and CIE Lab-Based Color Difference Analysis between Standard and Composite Blend



T4 Fig 8: Spectral Reflectance and CIE Lab-Based Color Difference Analysis between Standard and Composite Blend



T5 Fig 9: Spectral Reflectance and CIE Lab-Based Color Difference Analysis between Standard and Composite Blend



T_6 Control Fig 10: Spectral Reflectance and CIE Lab-Based Color Difference Analysis between Standard and Composite Blend

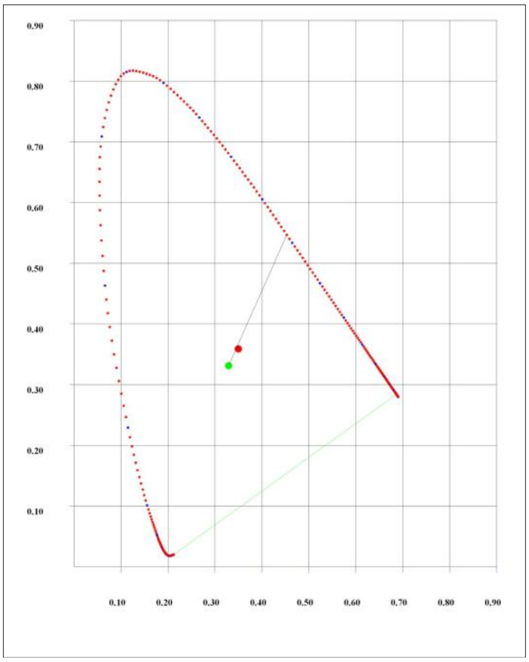


Fig 11: Chromaticity Plot of Rice Idli Pre mix Selected T_3

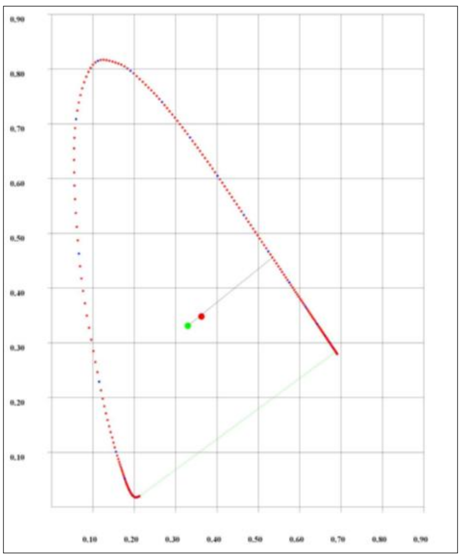


Fig 12: Chromaticity Plot of Finger millet Idli Pre mix Selected T_3

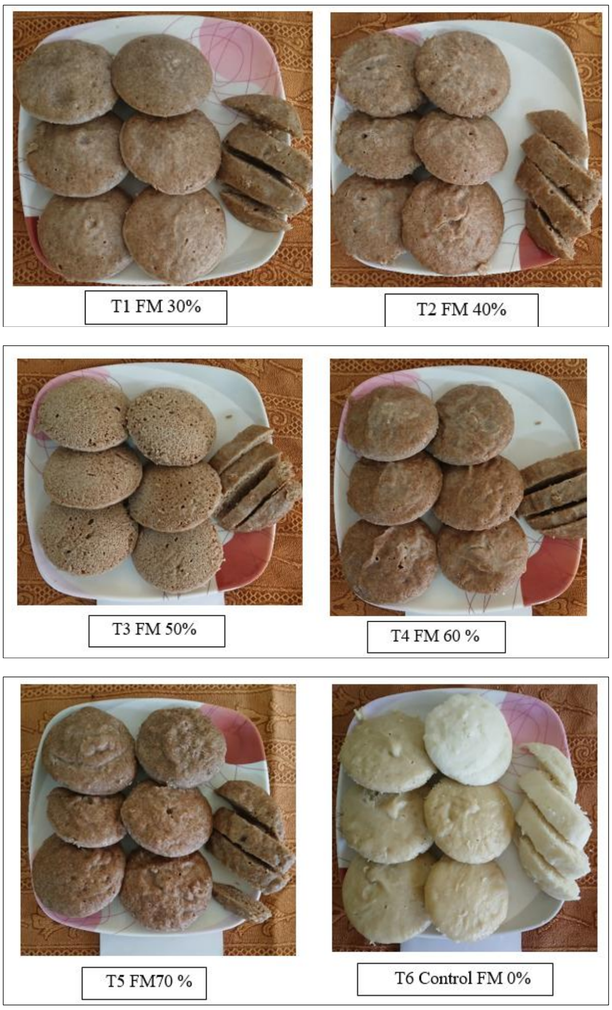


Fig 13: Photographs of Prepared Idli from Pre mix

4. Conclusion

The study clearly demonstrates that millet incorporation significantly affects the textural and color characteristics of idli prepared from premixes. The addition of finger millet notably increased the firmness and compressive strength, as evidenced by higher cutting and peak compressive forces in millet-enriched samples compared to the control. Chewiness and gumminess also rose with increasing millet content, reflecting a denser, more resistant texture. However, millet addition reduced cohesiveness, likely due to the coarse fiber disrupting the internal matrix, while springiness remained largely unaffected, suggesting that the elastic recovery of idli was maintained. Color analysis revealed a pronounced darkening effect with higher millet levels, as indicated by decreased lightness (L*) and increased redness (a*). These changes are primarily attributed to the natural pigments and Maillard browning reactions associated with millet flour. The total color difference (ΔE) was markedly higher in millet-based samples than in the rice-based control, confirming a significant visual shift. The millet premix appeared considerably darker with shifts towards green and blue hues, caused by polyphenols and anthocyanins present in finger millet.

Overall, while millet incorporation enhances the nutritional and structural firmness of idli, it also leads to noticeable changes in texture and color that may impact consumer acceptance. These findings highlight the importance of balancing millet content and processing conditions to optimize both sensory and nutritional quality in fortified idli premixes.

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