Journal of Scientific & Industrial Research
Vol. 84, October 2025, pp. 1051-1058
DOI: 10.56042/jsir.v84i10.12129

Formulation of *Corchorus olitorius* Leaves and Jowar-based Ready-to-Eat Snack

Kanneboina Soujanya[1]*, B. Anila Kumari[1] & E. Jyothsna[2]

[1]Department of Food and Nutrition, Postgraduate & Research Centre, PJTS Agricultural University, Rajendranagar, Hyderabad 500 030, India

[2]Krishi Vigyan Kendra, Professor Jayashankar Telangana Agricultural University, Palem 509 215, Nagar Kurnool, Telangana, India

Received 28 June 2024; revised 23 June 2025; accepted 10 October 2025

India has a great heritage of traditional snack foods. Murukku is a traditional snack of Telangana state, India, which has a distinct culture and food habits. A ready-to-eat, nutritious snack was developed by blending sorghum flour, *Corchorus olitorius* leaves, and other ingredients in optimal proportions. The developed product's sensory evaluation, nutrient, and phytonutrient composition were analysed. This nutritional powerhouse and sensory delight snack was crafted with a perfect blend of taste and texture. The unique combination of ingredients, carefully balanced flavours, and textures makes it a treat for the senses. Based on the sensory data, 10% *Corchorus olitorius* leaves incorporated murukku (JMCO- Jowar murukku with 10% incorporation of *Corchorus olitorius*) was selected for further study and compared with the control (JMC). The addition of *Corchorus olitorius* in murukku significantly ($p < 0.01$) enhanced the ash content (4.26%), crude protein level (16.87%), and crude fibre (3.84%), while reducing the carbohydrate content (45.56%) and energy content (480.6 kcal/100g). Adding leaf powder significantly ($p < 0.01$) enhanced the vitamin and mineral content of murukku, providing a wealth of nutritional benefits. Total phenol, flavonoid, tannin, and antioxidant activity of murukku (JMCO) were 122.14 mg GAE/100g, 60.3 mg RE/100g, 20.97 mg TAE/100g, and 5.57% respectively. *Corchorus olitorius* leaves and jowar-based ready-to-eat murukku have good sensory, nutritional, and phytonutrient properties.

Keywords: Leaf powder, Murukku, Nutritious, Phytonutrients, Sensory evaluation

Introduction

Small portions consumed in between meals are termed snacks. They are the fourth meal, accounting for 25% of daily meals. Convenience-ready-to-eat foods are consumed on a large scale as snacks, including chips, bakery products, namkeen, and other processed foods.[1] Snacks are popular worldwide due to their convenience, affordability, portability, and availability in a broad category. They are the most preferred delicacies in India.[2] The consumption of processed foods is growing considerably due to globalisation, urbanisation, increased double-income nuclear families, and changed lifestyles and food preferences.[3,4] Potato chips production alone contributes to the 80% market share of the snacks.[1] High consumption of empty-calorie processed and junk foods, with a decline in consumption of coarse cereals and whole grains, is associated with various health problems like obesity, hypertension, gastrointestinal problems, metabolic syndrome, cancers, and micronutrient deficiencies.[1,3,4] To address these problems, the demand for healthy and nutritious foods is rising.[5,6] In recent years, there has been an increased interest in plant-originated products due to the presence of an abundant amount of health-promoting bioactive compounds.[7]

Millets, such as sorghum, are nutrient-dense grains that can help prevent diseases and promote overall health. They are rich sources of dietary fibre, protein, micronutrients, and phytochemicals[1]. In India, Sorghum (*Sorghum bicolor* L.), known as jowar or great millet, is the most widely consumed cereal crop after rice and wheat. Its protein has a higher biological value than wheat protein, 2,8, and is also an ideal gluten-free energy source for people with gluten intolerance. The FAO declared sorghum a lifesaver and a staple crop for impoverished people.[9] With its unique nutritional properties, Sorghum is a good source of carbohydrates, dietary fibre, essential fatty acids like oleic and linoleic acid, B complex vitamins, minerals, and phytonutrients.[6,10–12] Moreover, despite its nutritional and phytonutrient profile richness, sorghum is recognised for its hardness and remarkable adaptability to adverse climatic conditions,[12] providing reassurance about its resilience. In India, Maharashtra, Madhya Pradesh, parts of Karnataka, Andhra Pradesh, Tamil Nadu, and Gujarat are the central sorghum-cultivating states.[9,13]

*Author for Correspondence
E-mail: kanneboinasoujanya16@gmail.com

Corchorus olitorius, commonly known as Tossa jute, is a plant of cultural and traditional significance, belonging to the Malvaceae family. It is primarily cultivated in India and Bangladesh[14,15] and is widely consumed in Nigeria, Bangladesh, the Philippines, Malaysia, Egypt, Sudan, India, and Japan.[16–18] With their unique nutritional properties, the plant's leaves are a rich source of protein, dietary fibre, chlorophyll, beta carotene, vitamins, minerals, and other bioactive compounds.[18–20] *Corchorus olitorius* leaves contain 73.56% carbohydrate, 8.51% crude fibre, 15.16–4.4% protein, 2.48–2.81% ash, and 2.65–3.15% fat on a dry weight basis.[21,22] The various parts of the plant have been utilised in traditional medicinal systems, demonstrating a wide array of properties including antitumour, anti-pyretic, anticholesterolemic, anti-inflammatory, anticonvulsive, antioxidant, gastro-protective, diuretic, anticarcinogenic, anaemia treatment, diabetes management, and hypertension management.[17–20]

Despite a rich source of nutrients and nutraceutical properties, it is a climatically resilient plant that adapts to adverse climatic conditions.[18] In India, *Corchorus olitorius* is widely grown mainly for the jute industry. However, it is available naturally during the rainy season and is still consumed by rural people when it is available as a traditional green leafy vegetable. As it is a perishable and seasonal green, leafy vegetable, its availability is limited during the off-season. Therefore, dehydration is one of the oldest and most widely used preservative techniques, which decreases waste, enhances the shelf life of products that are easy to store and handle, and can also be used to formulate functional and nutraceutical products.[19,23]

Chakli is a traditional, extrusion-based, deep-fried savoury snack made with various ingredients, including flours, spices, and oil. It's a very popular crisp and friable in texture, available in various shapes and preparations.[2,8,24–29] It is known by different names in various Indian states, such as Jantikalu (Telangana), Chakralu (Andhra Pradesh), Chakkuli (Karnataka), Chakri (Gujarat), or Chakli (Maharashtra), and Murukku (in South India). Among the various names, chakli is highly referred.[2,8]

Many studies are available on developing and standardising several traditional murukku products based on the different raw materials.[1,5,13,25,27,30–35,38,39] The availability of minor millet-based ready-to-eat snacks is still scant compared to rice, corn, and wheat products.[11] Considering the nutritional and functional properties of both sorghum and *Corchorus olitorius*, a ready-to-eat murukku has not been reported. Hence, the present study standardised Nutri-dense murukku and evaluated its sensory, physicochemical, and phytonutrient properties.

Materials and Methods

The experiment was conducted at the Post-Graduate and Research Centre, PJTAU, Hyderabad, Telangana, India. The fresh leaves of *Corchorus olitorius were* collected from the field areas of Nalgonda district, Telangana state. The edible portions of selected leaves were washed, blanched, and shade-dried until the samples became crisp and brittle to the touch. After drying, the samples were ground into a powder and used for product development. All the raw materials required for the product are sourced from local markets in Hyderabad, India.

Incorporation of *Corchorus olitorius* Leaves Powder into Jowar Murukku

All the required ingredients were weighed individually according to the proportions, then mixed with butter and hot water, and kneaded until a smooth dough formed. Then the prepared dough was kept aside for 10 minutes for conditioning. The next step, the shaping of the dough, is a crucial part of the process that requires careful attention to detail. The prepared dough was then extruded to the desired shape with the help of a murukku pressor. The prepared murukku was deep-fried in preheated oil and allowed to cool. After cooling, the murukku was stored in air-tight containers and at room temperature for further analysis. The leaf powder was incorporated at 5% (JMCO1), 10% (JMCO2), and 15% (JMCO3). as given in Table 1. The process of preparation of Jowar Murukku is demonstrated as flow chart in Fig. 1.

Table 1 — Proportions of the ingredients used in the standardisation of *Corchorus olitorius* incorporated murukku (All formulae were repeated three times; All ingredients were measured in grams)

Ingredients	JMC	JMCO1	JMCO2	JMCO3
Corchorus olitorius	0.00	5.00	10.00	15.00
Jowar flour	65.00	60.00	55.00	50.00
Bengal gram flour	20.00	20.00	20.00	20.00
Butter	5.00	5.00	5.00	5.00
Zeera	1.00	1.00	1.00	1.00
Salt	2.50	2.50	2.50	2.50
Sesame	1.50	1.50	1.50	1.50

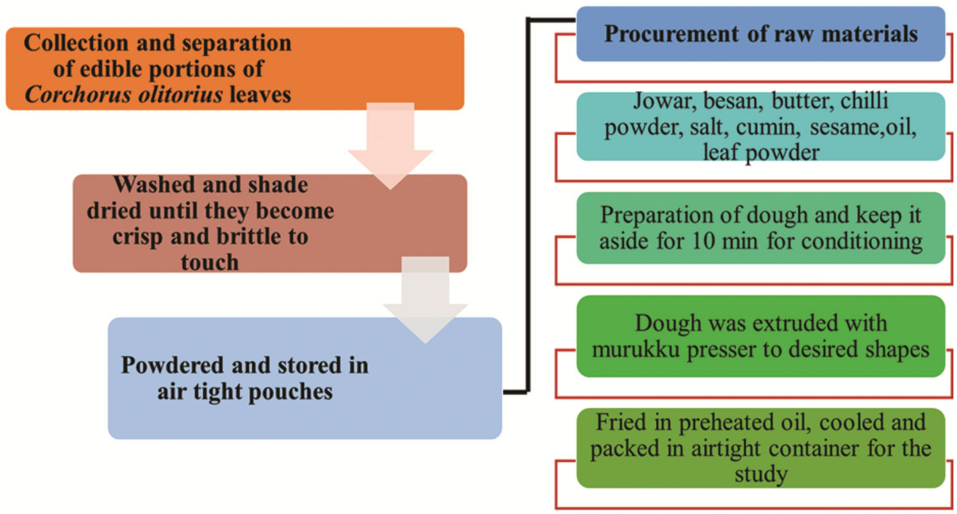

Fig. 1 — Flow chart for the preparation of the product

Sensory Evaluation of Jowar Murukku

To determine the organoleptically accepted formulation, a semi-trained panel of 15 members from PGRC, PJTAU, using a 9-point hedonic scale, evaluated the developed murukku for colour, texture, flavour, taste, and overall acceptability. Scores were based on a hedonic scale of 1 to 9, where = 1=I dislike immensely (very bad) and 9= I like extremely (excellent). The samples were presented in plates coded with three-digit numbers in individual booths in the sensory evaluation lab. Panellists rinsed their mouths with water after testing each sample.[40]

Colour Profile of Developed Products

Colour measurements were taken regarding Hunter values for L*, a*, and b*, which were determined with the help of colour Hunter. L values indicate lightness ranging from black to white (0–100); +a to -a correspond to red to green; +b to -b measuring yellow to blue.[41]Chroma, hue[42], and total colour difference[43]were analysed for the selected and control samples.

Nutritional Composition of the Developed Products

Moisture, ash, protein[44-46], crude fat[47], crude fiber[48], carbohydrate and energy[49], total carotenoids[50], β-carotene[51], calcium, iron, magnesium, manganese, copper, zinc, sodium, potassium and phosphorus were analysed by the standard procedures[52]. Bioavailable calcium, zinc[53] and iron[54] content was investigated for the selected and control samples.

Antioxidant Properties

Antioxidant screening[55], flavonoid content[56], total phenols[57], antioxidant activity by DPPH[58,59], and tannins44 were estimated.

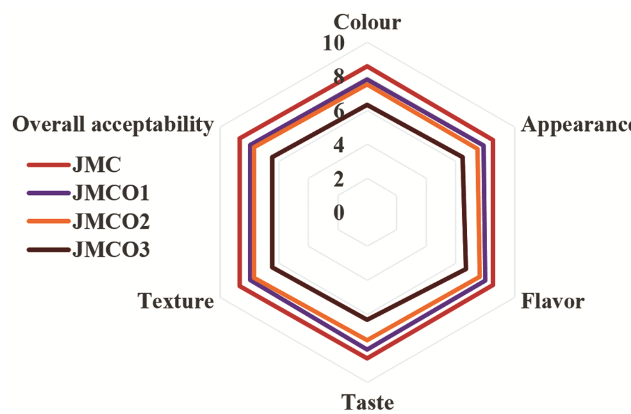

Fig. 2— Mean sensory scores of developed products

Statistical Analysis

The results obtained were statistically analysed to test the significance. The values obtained were presented as mean ± standard deviation of three parallel measurements. For statistical significance, differences between means were considered statistically significant at 5% if $p<0.05$.

Results and Discussion

Sensory Evaluation of *Corchorus olitorius* Leaves Incorporated Sorghum Murukku

The quality of the product is crucial for its acceptance. Both objective and sensory methods are used to determine the quality of any product. The most effective method is sensory evaluation (Fig. 2), in which human sensory organs assess food quality. The sensory evaluation results show a significant difference among all three treatments (JMCO1, JMCO2, JMCO3) and the control (JMC) murukku for all the attributes. The results for colour and appearance of JMC (control murukku) with no *Corchorus olitorius* leaves powder and JMCO1 scored the highest, whereas JMCO3 (15% leaf powder-incorporated murukku) scored the lowest. Similarly, control scored highest for flavour, taste, texture, and overall acceptability, followed by JMCO1, JMCO2, and JMCO3. The colour of the developed products decreased with the increased percentage of leaf powder incorporation. The sensory evaluation results revealed that up to 10% of *Corchorus olitorius* leaves-enriched murukku scored above seven and had better acceptability than the control murukku. Therefore, JMCO2 was selected for further study. Previous studies have reported that murukku, developed from besan, *Moringa oleifera*, and *Solanum nigrum* leaves, with a ratio of 85:10:5, scored higher than the control (100% besan).[30] In a study, 5% of Moringa leaves incorporated into murukku was better accepted than the 10% and 15% incorporation. An increase in the incorporation of leaf powder enhanced the dark green colour, and a decrease in the overall acceptability of the product was reported.

Colour Profile of Developed Products

Colour is a critical quality parameter that influences consumers' preferences and choices. The colour profile of JMC and JMCO are presented in Table 2. The L^* values (corresponding to brightness) increased significantly from 46.65 to 64.02 at $p < 0.05$. Likewise, significant variation was also noted in a^* and b^* values, indicating variation between red-green and blue-yellow colour indices, respectively. Chroma was highest for the control (48.59) and lowest for the JMCO (23.96). It could be hypothesised that incorporating leaf powder intensified greenness and reduced JMCO redness.

Nutritional Composition of Developed Products

The nutritional composition of control (JMC) and JMCO (10% leaf powder incorporated jowar murukku) was analysed and presented in Table 3. The moisture content of JMC and JMCO was 3.86 and 3.83% respectively. The moisture content of control and *Corchorus olitorius* leaves incorporated into murukku was similar, and no significant difference was observed between them. Ash content of JMC and JMCO is 3.34 g and 4.26 g/100g, respectively. The fat content of developed products was significantly different at $p \leq 0.05$. The crude fibre content of JMC and JMCO was 2.65 g/100 g and 3.84 g/100g, respectively. The protein content of JMCO (16.87 g/100g) was significantly higher ($p \leq 0.01$) than that of JMC (13.75 g/100g). The carbohydrate (45.56 g/100g) and energy (480.6 kcal/100g) content of JMCO was comparatively less than that of JMC, with values 51.77 g/100g and 483.6 kcal/100g, respectively. The study found that incorporating leaf powder significantly increased ash, fat, crude fibre, and protein content by 27.54, 4.25, 44.9, and 22.69% respectively.

Table 2 — Colour profile of developed products

Sample	L^*	a^*	b^*	E*	Chroma	Hue
JMC	$46.65^{a} \pm 0.26$	$20.48^{b} \pm 0.33$	$44.06^{b} \pm 1.07$	$67.17^{a} \pm 0.58$	$48.59^{b} \pm 0.90$	$57.77^{b} \pm 2.54$
JMCO	$64.02^{b} \pm 0.81$	$9.13^{a} \pm 0.13$	$22.16^{a} \pm 0.71$	$68.37^{b} \pm 0.89$	$23.96^{a} \pm 0.70$	$57.28^{a} \pm 0.24$
F-value	20.34	32.46	17.11	1.12	21.59	0.19
p value	0.00**	0.00**	0.00**	0.16^{NS}	0.00**	0.43^{NS}

Note: Values are expressed as mean ± standard deviation of three determinations; Means within the same column followed by a common letter do not differ significantly at ($p \leq 0.01$) NS: not significant; ** significant at ($p \leq 0.01$); * significant at ($p \leq 0.05$); JMC: Jowar murukku control; JMCO: Jowar murukku with 10% incorporation of *Corchorus olitorius* leaves

Table 3 — Proximate Composition of RTE jowar murukku (Per 100 g)

Nutrient	JMC	JMCO	t value
Moisture (%)	3.86a ± 0.03	$3.83^{a} \pm 0.12$	0.16^{NS}
Ash (g)	$3.34^{a} \pm 0.03$	$4.26^{b} \pm 0.00$	29.18**
Fat (g)	$24.65^{a} \pm 0.32$	$25.70^{b} \pm 0.15$	2.97*
Protein (g)	$13.75^{a} \pm 0.00$	$16.87^{b} \pm 0.00$	661.85**
Crude fibre (g)	$2.65^{a} \pm 0.00$	$3.84^{b} \pm 0.00$	204.52**
Carbohydrate (g)	$51.77^{b} \pm 0.01$	$45.56^{a} \pm 0.04$	160.94**
Energy (kcal)	$483.6^{b} \pm 0.10$	$480.6^{a} \pm 0.00$	25.77**

Note: Values are expressed as mean ± standard deviation of three determinations; Means within the same column followed by a common letter do not differ significantly at ($p \leq 0.01$) NS: not significant; ** significant at ($p \leq 0.01$); * significant at ($p \leq 0.05$); JMC: Jowar murukku control; JMCO: Jowar murukku with 10% incorporation of *Corchorus olitorius* leaves

Vitamin and mineral content of the prepared RTE jowar murukku is given in Table 4. Vitamins are essential in small quantities for the body's healthy growth and development. They act as coenzymes or cofactors for several metabolic pathways.[60] The JMCO exhibited high total carotenoids and beta carotenoid content, with 280.43 µg/100g and 24.28 µg/100g, respectively, compared to the control with 10.55 µg/100g and 5.02 µg/100g. Compared to the control sample, the total carotene and beta-carotene content of murukku (JMCO) increased by 383.66% and 2558.10%, respectively. Minerals are inorganic compounds that the human body cannot synthesise. Consuming a variety of foods can help you obtain them. They are the essential elements of the body and are involved in the buildup and proper functioning of crucial biomolecules.[60] The calcium content of JMC and JMCO was 200.60 mg/100g and 512.50 mg/100g, respectively. A statistically significant difference ($p \leq 0.01$) was found in the iron and zinc content of the developed products. The iron and zinc content of JMCO increased significantly by 116.49% and 18.83%, respectively. The JMCO exhibited higher phosphorus and potassium content, at 171.20 mg/100g and 417.80 mg/100g, respectively, compared to the control (JMC), which had 168.10 mg/100g and 405.50 mg/100g, respectively. In a study, the addition of 5% moringa leaf powder ($p < 0.05$) increased the calcium, iron, and zinc content of multi-millet murukku.[1]

Bioavailability refers to the proportion of an inorganic nutrient in the diet that is absorbed and utilised for essential metabolic functions. Unlike macronutrients, the bioavailability of minerals varies widely across different foods and is influenced by various dietary components and gastrointestinal conditions.[61] Anti-nutritional factors such as oxalic acid, phytic acid, tannins, and dietary fibre can significantly impair the absorption of minerals by forming insoluble complexes or interfering with transport mechanisms. In the present study, the bioavailable calcium, iron, and zinc contents of the developed product (JMCO) were analysed, and the results are summarised in Table 5. Notably, the bioavailability of calcium (101.27%) and iron (142.23%) showed a substantial increase, whereas zinc bioavailability decreased by 26.53% in JMCO. The decline in zinc bioavailability might be due to residual phytic acid or increased fibre content, which have a strong affinity for zinc and form insoluble complexes, reducing intestinal absorption. Zinc absorption is more sensitive to phytate:zinc molar ratios than to those of other minerals, which may explain this selective reduction.[62]

Antioxidant Composition of Developed Products

Carbohydrates, lipids, protein, vitamins, and minerals are the primary nutrients in food, playing a crucial role in maintaining the body's basic functions. In addition to these nutrients, certain physiologically active compounds called phytonutrients play a vital role in human health. These compounds are beneficial and crucial in preventing and mitigating various diseases and physiological disorders.[63] Phytonutrients, or antioxidants, are compounds that stabilise, scavenge, and suppress the generation of oxidants and

Table 4 — Vitamin and mineral content of RTE Jowar murukku

Nutrient	JMC	JMCO	t value	Nutrient	JMC	JMCO	t-value
Total carotenoids (µg)	$10.55^{a} \pm 0.06$	$280.43^{b} \pm 0.10$	1400.95**	Copper (mg)	$0.48^{a} \pm 0.00$	$0.58^{a} \pm 0.00$	70.00**
Beta carotene(µg)	$5.02^{a} \pm 0.00$	$24.28^{b} \pm 0.21$	91.26**	Manganese (mg)	$2.43^{b} \pm 0.00$	$1.78^{a} \pm 0.00$	1111.53**
Calcium (mg)	$200.60^{a} \pm 0.30$	$512.5^{b} \pm 0.20$	974.54**	Phosphorus (mg)	$168.10^{a} \pm 0.00$	$171.2^{b} \pm 0.00$	281.91**
Iron (mg)	$6.67^{a} \pm 0.12$	$14.44^{b} \pm 0.21$	32.14**	Sodium (mg)	$1113.00^{b} \pm 0.00$	$988^{a} \pm 0.00$	413.83**
Zinc (mg)	$1.54^{a} \pm 0.00$	$1.83^{b} \pm 0.00$	1522.22**	Potassium (mg)	$405.5^{a} \pm 0.30$	$417.8^{b} \pm 0.10$	45.24**

Note: Values are expressed as mean ± standard deviation of three determinations; Means within the same column followed by a common letter do not differ significantly at ($p \leq 0.01$) NS: not significant; ** significant at ($p \leq 0.01$); * significant at ($p \leq 0.05$); JMC: Jowar murukku control; JMCO: Jowar murukku with 10% incorporation of *Corchorus olitorius* leaves

Table 5 — Bioavailable Mineral Content of JMCO-incorporated Jowar Murukku

Sample	Bioavailable calcium		Bioavailable iron		Bioavailable zinc	
	mg/100g	%	mg/100g	%	mg/100g	%
JMC	$156.4^{a} \pm 0.20$	77.96	$4.57^{a} \pm 0.01$	68.51	$0.49^{b} \pm 0.00$	31.81
JMCO	$315.2^{b} \pm 0.00$	61.50	$11.07^{b} \pm 0.03$	76.66	$0.36^{a} \pm 0.00$	19.67

Note: Values are expressed as mean ± standard deviation of three determinations; Means within the same column followed by a common letter do not differ significantly at ($p \leq 0.05$); JMC: Jowar murukku control; JMCO: Jowar murukku with 10% incorporation of *Corchorus olitorius* leaves

Table 6 — Phytonutrient composition of JMCO-incorporated Jowar murukku

Sample	Phenols (mg GAE)	Flavonoids (mg RE/g)	Tannins (mg TAE)	Antioxidant activity (%)
JMC	78.04^{a} ± 0.03	5.35^{a} ± 0.06	11.09^{a} ± 0.00	1.86^{a} ± 0.00
JMCO	122.14^{b} ± 0.12	60.73^{b} ± 0.08	20.97^{b} ± 0.01	5.57^{b} ± 0.00
t value	345.31	517.64	1481.50	3937.88
p value	0.00**	0.00**	0.00**	0.00**

Note: Values are expressed as mean ± standard deviation of three determinations; Means within the same column followed by a common letter do not differ significantly at ($p \leq 0.01$). NS: not significant; ** significant at ($p \leq 0.01$); * significant at ($p \leq 0.05$); JMC: Jowar murukku control; JMCO: Jowar murukku with 10% incorporation of *Corchorus olitorius* leaves

free radicals. Their role in protecting the body from these harmful elements is significant, and their consumption based on natural resources may help to shield one from oxidants and free radicals without side effects. [64] Methanol was selected as an extracting agent because phenolic compounds are more soluble in polar organic solvents.[65] The methanolic extracts of developed products (JMC and JMCO) were identified to contain proteins, amino acids, carbohydrates, phenols, flavonoids, tannins, alkaloids, terpenoids, glycosides, phlobatinins, and steroids.

Natural antioxidants found in leafy vegetables play a vital role in protecting against the damaging effects of free radicals. Nowadays, diets rich in phenolic compounds, flavonoids, and antioxidants have sparked interest in food science and nutrition.[64] JMC and JMCO phenolic content were 78.04 and 122.14mg GAE/100g, respectively. The addition of *Corchorus olitorius* significantly increased the phenolic content of murukku by 56.51%. The phenolic compounds are effective electron donors and prevent oxidative disease burden by inhibiting free radicals, decomposing peroxides, inactivating metals, or scavenging oxygen in biological systems.[66] Flavonoids are secondary metabolites with antioxidant activity. They are a large group of plant compounds and usually occur as glycosides.[67] The flavonoid content of the developed products was determined quantitatively by using aluminium chloride in a spectrophotometric method, and the results are reported in Table 6. The flavonoid content of JMC and JMCO was 5.35 and 60.73 mg RE/100g, respectively. The tannin content of JMC and JMCO was 11.09 and 20.97 mg TAE/100g, respectively. The tannin content of JMCO was significantly ($p \leq 0.01$) increased by 89.08% due to the incorporation of leaf powder.

Many compounds, including Polyphenols, chlorophylls, and carotenoids, influence the antioxidant activity.[67] The DPPH method is a simple, acceptable, and widely used technique for evaluating the potency of free radical scavenging. The antioxidants can enact the visually noticeable quenching of the stable purple-coloured DPPH radical to the yellow-coloured DPPH63. The total antioxidant activity of JMC and JMCO was 1.86% and 5.57%, respectively.

Conclusions

In recent years, the consumption of ready-to-eat (RTE) snacks has increased significantly due to changing lifestyles and growing demand for convenience foods. In this context, a ready-to-eat murukku enriched with 10% *Corchorus olitorius* leaf powder demonstrated the highest organoleptic acceptability among the tested formulations. The developed snack was a good source of protein, crude fibre, essential minerals, and phytonutrients. The inclusion of *Corchorus olitorius*, a locally available and underutilised seasonal green leafy vegetable, enhanced the product's nutritional profile and contributed to its functional and sensory qualities. Furthermore, incorporating jowar (sorghum) as the base cereal promotes the utilisation of traditional, climate-resilient grains. Thus, the developed snack can serve as a healthy dietary addition, supporting nutritional improvement and the value addition of indigenous crops and greens.

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