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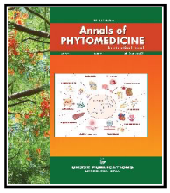

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Therapeutic potential and nutritional composition of *Murraya koenigii* L. leaves and its application for the development of β-carotene enriched buns

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Abstract

Murraya koenigii L. leaf is also known as curry leaf and is one of the finest aromatic herbs utilized as a special ingredient in culinary preparations in most Indian cuisines. Traditionally, it has been used in Unani and Ayurveda medicine to treat several ailments. This study was undertaken to study the therapeutic potential of *M. koenigii*; to analyse the nutritional composition of freeze-dried leaf powder and development and sensory and nutritional analysis of β-carotene enriched buns. Four types of buns were prepared, *i.e.*, using refined flour only and refined flour substituted with 5, 7.5 and 10 per cent of *M. koenigii* leaf powder. The freeze-dried *M. koenigii* leaves contained 53.68 g total dietary fibre, 9.63 g soluble dietary fibre, 155.6 mg RE total flavonoids, 624.3 mg GAE total phenols, 650.4 mg TEE FRAP, 21.23 mg iron, 2147 mg calcium and 104100 µg β-carotene. In terms of sensory attributes, all the supplemented buns were accepted by the judges and adjudged between 'liked moderately' to 'liked very much'. The amount of β-carotene in buns prepared with refined flour was found to be 12.15 µg/100 g which was increased enormously to 4176.21, 6258.22 and 8340.20 µg/100 g in the buns prepared by incorporating 5, 7.5 and 10 per cent of *M. koenigii* leaves powder. The consumption of two buns in a day can meet more than 40 per cent of the recommended dose of vitamin A in adults and more than 60 per cent in children (1-12 y).

1. Introduction

Murraya koenigii L. the spice leaf, belonging to the family Rutaceae, is a tropical to sub-tropical plant. It is also known as curry leaf, a native of India, Sri Lanka, and other Asian countries and grows all around the year, with minimum or no agriculture inputs (Siddique *et al*., 2022). The color of the *M. koenigii* stems is dark green to brownish and grows to a height of around 2.5 meters (Singh *et al.,* 2014). *M. koenigii* leaf is one of the finest aromatic herbs utilized as a special ingredient in culinary preparations in most Indian cuisines. *M. koenigii* is a tiny plant with fragrant and sweet-smelling leaves. It has a strong spicy and seasoning flavor with a characteristic aroma. The organoleptic properties, *i.e.,* color, flavor, odor, and taste are accompanied by the culinary value of *M. koenigii* leaf (Singh *et al*., 2014; Aslam *et al*., 2017).

As per scientific evidence, *M. koenigii* leaf possesses strong antioxidants (Ramnath *et al*., 2023), antimicrobial (Abeysinghe *et al*., 2021), antidiabetic (Tabashiri *et al*., 2022), antifungal (Sari *et al.,* 2024), anticancer (Aniqa *et al*., 2022), anti-inflammatory (Goel *et al*., 2020), hepatoprotective (Jan *et al*., 2021), and antidiarrheal activity. Traditionally, *M. koenigii* has been used in Unani and Ayurveda medicine to treat nausea, stomach pain, indigestion constipation, rashes, spots, and snake bites. It is widely used as an agent for relieving influenza, flatulence, fever, treating piles, odema, itching, vomiting, diarrhoea, outbrusts, dysentery, insect bites, tubercular asthma, body aches, fresh cuts, and kidney pains (Vijayalakshmi *et al*., 2022; Verma *et al*., 2022a; Rani *et al*., 2023). The various bioactive components and therapeutic benefits of *M. koenigii* leaves have been explained in Table 1.

Though, the *M. koenigii* leaf is an excellent source of β-carotene, iron, calcium, dietary fibre, and antioxidants and possesses medicinal properties however, its potential for human nutrition and health has not been fully utilized due to its bit stiff texture and generally squeezed and discarded from the dishes. To ensure the best consumption, leaves should be dried and incorporated into the daily consuming dishes. Generally, dried leaves have 3-4 times higher nutrition than fresh leaves besides these are easy to store and handle for long-term uses. Various methods have been used to dry leaves, *i.e.,* cabinet, freeze-drying and hybrid drying microwave and oven drying, sun, tray, shade, solar drying, infrared and inert gas drying, (Choo *et al*., 2020). The *M. koenigii* leaves are naturally packed with 65.33 g moisture, 16.83 g total dietary fibre, 7.41 g protein, 4.86 g ash, 21,862 µg carotene, 659 mg calcium, 83 mg phosphorus, 117 µg folic acid, 7663 µg β-carotene, and 8.67 mg iron per 100 g of fresh leaves (Longvah *et al*., 2017). *M. koenigii* leaf has a promising amount of β-carotene (preformed vitamin A) (Khoo *et al*., 2011). However, it was observed that the dehydrated *M. koenigii* leaves also contain considerable amounts of phytates and oxalates, *i.e.,* 86.52 and 501.55 mg/100 g, respectively (Lal and Kaur, 2019) that further might be a constraint in its utilization in product development.

In India, the prevalence of subclinical showed around 62 per cent deficiency of vitamin A in preschool children (Laxmaiah *et al*., 2011; NNMB, 2006). Scientific studies from the developing world indicated

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that pro-vitamin A rich food sources meet up to 80 per cent of the dietary intake of vitamin A. Therefore, the inclusion of pro-vitamin A rich ingredients for the development of functional foods such as traditional, bakery, and fermented products can meet the increased demand of the target population. Moreover, after the corona era, people have become conscious about health and prefer functional foods with therapeutic applications; therefore, demand for such products has increased tremendously (Jyoti *et al*., 2022; Verma *et al*., 2022b). The traditional products have been developed by incorporating *M. koenigii* leaf powder prepared with dry heat methods so far. This study is novel as efforts have been made to develop baked product by incorporating *M. koenigii* leaf powder prepared using the freeze-drying method. While keeping into account the easy availability, low cost, and β-carotene content of *M. koenigii* leaves, this study was planned to develop β-carotene enriched buns by incorporating *M. koenigii* leaf powder and to analyse their nutritional composition.

Table 1: Bioactive components and therapeutic benefits of *M. koenigii* leaves

Medicinal properties	Bioactive component	Application	References
Antioxidants	Di-α-phellandrene, D-sabinene, D-α-pinene, dipentene, D-α-terpinol and caryophyllene	Defend cells from the harm produced by free radicals	Tripathi *et al*. (2018) Nagarjuna *et al*. (2023) Ramnath *et al*. (2023)
Antimicrobial	Carbazole alkaloids mahanine and mahanimbicine, girinimbine, murrayanine	Suppress proliferation of microbial cells, acts as preservative	Negi *et al*. (2020) Rana (2022) Abeysinghe *et al*. (2021)
Antidiabetic	Alkaloids, koenimbine, 9-carbethoxy-3-methylcarbazole and 9-formyl-3-methylcarbazole	Protect cell damage, inhibit aldose reductase, inhibit α-glycosidase and control blood sugar	Malode *et al*. (2021) Abeysinghe *et al*. (2021) Tabashiri *et al*. (2022)
Antifungal	Formyl carbazole, mahanine, mahanimbine, isomahanimbine	Effective against fungus, Combat skin infections	Goel *et al*. (2020) Sari *et al*. (2024)
Anticancer	Girinimbine, myricetin murrayanine, murrayazolinine, koenimbine, 9-formyl-3- methylcarbazole, catechin	Potential to fight against certain cancer cells, Inhibit cell proliferation and acts as cytotoxic	Abeysinghe *et al*. (2021) Aniqa *et al*. (2022)
Anti-inflammatory	Phenolic compounds, murrayanol, mahanine, mahanimbine, isomahani-mbinegirinimbine	Antihistaminic action, it lessens arthritic inflammation and aids in wound healing	Goel *et al*. (2020) Abeysinghe *et al*. (2021)
Hepatoprotective	Tocopherol, mahanine, mahanimbine, murrayazolinine, girinimbine	Protect liver cells, prevent liver damage	Batool *et al*. (2020) Goel *et al*. (2020) Jan *et al*. (2021)
Antidiarrheal	Kurryam, koenimbine, koenine	Act against harmful intestinal bacteria, aid digestion, and support gastrointestinal health	Goel *et al*. (2020) Abeysinghe *et al*. (2021)

2. Materials and Methods

2.1 Procurement of materials

The fresh *M. koenigii* leaves were procured in a single lot from the Medicinal, Aromatic, and Underutilized Plants Section, Department of Genetics and Plant Breeding, CCSHAU, Hisar. The *M. koenigii* leaves Batch No. 03022019 were identified and authenticated by the Department of Botany and Plant Physiology, CCSHAU, Hisar. The *M. koenigii* leaves powder was developed in the laboratory of Department of Foods and Nutrition, CCSHAU, Hisar by using the freeze-drying method mentioned previously (Sonia, 2020). The other basic ingredients required for the preparation of buns such as refined flour, yeast, salt, sugar, fat, milk powder, gluten and packaging of buns were purchased from the local market in a single lot.

2.2 Chemical analysis

Fresh *M. koenigii* leaves were blanched for 15 sec and freeze-dried using the standard methodology mentioned previously by Sonia (2020). Developed *M. koenigii* leaf powder was analysed for proximate composition (moisture, crude protein, crude fat, crude fibre and ash) using standard methods of AOAC (2010). Moisture was analysed using an automatic moisture analyser. Nitrogen content was digested and distilled using Kjeldahl Kel Plus, ether extraction to analyse fat content was done using Socs Plus, crude fibre was analysed as acid and alkali-resistant and dietary fibre constituents using the enzymatic method as earlier mentioned by Rani *et al*. (2022) and was estimated in Fibra plus. Ash was estimated in muffle furnace.

The acid-digested (HNO_3:$HClO_4$; 5:1 v/v) samples were evaluated for total calcium, iron, and zinc by Atomic Absorption Spectrophotometer 240 FS (Australia) using the methodology explained earlier by Jyoti *et al*. (2022). The examination of antioxidant properties, including DPPH radical scavenging activity, total phenolic content as described by Singleton *et al*. (1999), total flavonoids content based on the method by Zhishen *et al*. (1999), and ferric reducing antioxidant power by the protocols of Benzie and Strain

(1996) and Tadhani *et al*. (2009) earlier explained by Verma *et al*. (2022b), was carried out. Oxalates were determined by using the method of Abeza *et al*. (1968) and phytic acid content was determined by the method of Davies and Reid (1979).

2.3 Determination of β-carotene

β-carotene from *M. koenigii* leaves was extracted by the method described earlier (Chandra-Hioe *et al*., 2017). The HPLC was equipped with a photodiode array detector (SPD-M20A). Carotenoids were separated using a C18 column in a 25 min run. The flow rate and injection volume were 1.2 ml/min and 15 µl, respectively. The chromatogram was monitored at visible wavelengths and the signal intensities detected at 450 nm were used for quantification.

2.4 Development of β-carotene enriched buns

Firstly, dispersed the yeast in lukewarm water, added a pinch of refined flour and sugar then kept in an incubator for 6 to 8 min to develop a flying ferment. Gluten was added to the sieved flour and mixed well. Flying ferment was added to flour and mixed well. The measured quantity of sugar, salt, and milk powder was added to the flour. Fat was added as a last ingredient and the mixing time was around 12 min to get the final dough. The first proofing was done for 30 min, the dough was knocked back, and the intermediate proofing was done for 15 min. Afterwards, the dough was scaled in equal parts and kept for final proofing for 50 min. After final proofing, the buns were baked at 220-230°C temperature for six to eight min.

2.5 Sensory and nutritional evaluation of buns

Buns prepared with refined flour alone served as control whereas the buns prepared with refined flour substituted with 5, 7.5 and 10 per cent of *M. koenigii* leaves were tagged as T_1, T_2 and T_3. Developed buns were evaluated in terms of colour, taste, aroma, appearance, texture and overall acceptability using 9-point Hedonic rating scale by a panel of 30 semi-trained judges. Rating of buns was expressed on a 9 to 1 point rating scale as liked extremely, liked very much, liked moderately, liked slightly, neither liked nor disliked, disliked slightly, disliked moderately, disliked very much and disliked extremely, respectively. An overall acceptability score of 6 or above was considered acceptable and further evaluated for nutritional parameters mentioned in points 2.2 and 2.3 except antioxidants.

2.6 Statistical analysis

The data obtained were subjected to statistical analysis for analysis of variance in a complete randomized design using SPSS software version 20.

3. Results

3.1 Nutritional composition of *M. koenigii*

The results presented in Table 2 indicated that the freeze-dried powder of *M. koenigii* leaves had 3.91 % moisture, 11.44 % crude protein, 3.19 % crude fibre, 9.19 % crude fat and 10.79 % ash. Further, results indicated that the freeze-dried *M. koenigii leaves contained* 53.68 g total dietary fibre, 9.63 g soluble dietary fibre, 155.6 mg RE total flavonoids, 624.3 mg GAE total phenols, 650.4 mg TEE FRAP, 21.23 mg iron, 2147 mg calcium and 104100 µg β-carotene.

Table 2: Nutritional composition of fresh *M. koenigii* leaves and dried leaf powder

Parameter	Fresh leaves	Dried leaf powder	CD (p<0.05)
Moisture (g)	67.5 ± 0.16	3.91 ± 0.03	44.8*
Crude fat (g)	0.96 ± 0.01	3.19 ± 0.03	50.9*
Crude protein (g)	3.75 ± 0.05	11.44 ± 0.10	31.2*
Crude fibre (g)	2.80 ± 0.05	9.19 ± 0.04	12.9*
Ash (g)	3.40 ± 0.05	10.79 ± 0.09	53.1*
Soluble dietary fibre (g)	3.16 ± 0.04	9.63 ± 0.05	3.8*
Insoluble dietary fibre (g)	13.55 ± 0.07	41.22 ± 0.06	23.7*
Total dietary fibre (g)	17.72 ± 0.11	53.68 ± 0.06	15.4*
DPPH scavenging activity* (mg TE)	56.05 ± 1.04	51.67 ± 0.57	5.3*
Total flavonoids* (mg RE)	187.32 ± 0.28	155.6 ± 0.57	9.3*
Total phenols* (mg GAE)	677.08 ± 0.88	624.3 ± 1.32	37.2*
FRAP* (mg TE)	775.03 ± 0.72	650.4 ± 0.54	13.9*
Calcium (mg)	678.63 ± 0.05	2147 ± 3.48	42.8*
Iron (mg)	8.19 ± 0.05	21.23 ± 0.06	77.07*
Zinc (mg)	1.16 ± 0.05	3.59 ± 0.06	25.06*
Oxalates (mg)	219.65 ± 0.23	497.52 ± 0.18	25.00*
Phytic acid (mg)	38.71 ± 0.09	119.41 ± 0.14	11.00*
β-carotene (µg)	45890.4 ± 5.23	104100 ± 4.16	16.20*

Values are mean ± SD of three independent determinations

Besides nutrients, *M. koenigii* leaves are endowed with certain antinutrients such as oxalates and phytates. In present study, results indicated that curry leaves powder contained considerable amounts of oxalic acid (497.52 mg/100 g); however, comparative less amounts of phytic acid (119.41 mg/100 g) (Table 2). Results indicated that fresh leaves of *M. koenigii* contained 45890.4 µg of β-carotene with a 32.5 per cent of dry matter, whereas dried leaves contained 104100 µg of β-carotene with a dry matter of 96 per cent. If the conversion of β-carotene is done based on dry matter a 23.0 per cent loss of β-carotene was observed during freeze-drying. Similarly, on a dry matter basis, a 24.0 per cent reduction for oxalic acid was observed during freeze-drying.

3.2 Sensory evaluation of *M. koenigii* leaves supplemented β-carotene enriched buns

Mean sensory scores of overall acceptability of T_1, T_2 and T_3 buns ranged from 7.62 to 8.29 and indicated that all three types of buns were adjudged within 'liked moderately' to 'liked very much' by the judges and all the buns were found acceptable by the judges (Figure 1). Buns (T_2) prepared using 7.5 per cent of *M. koenigii* leaves were scored maximum and liked as equal to or more than the control buns.

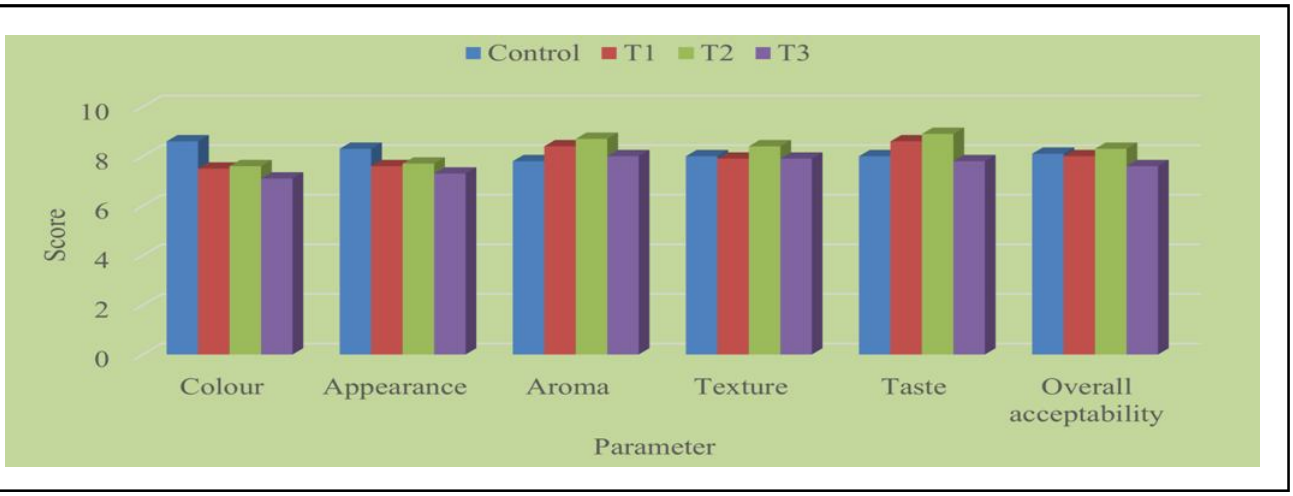

Figure 1: Mean sensory scores of *M. koenigii* supplemented β-carotene enriched buns.

3.3 Nutritional composition of *M. koenigii* supplemented β-carotene enriched buns

Results presented in Table 3 indicated that the control buns prepared with 100 per cent refined flour contained 10.37 % crude protein, 8.54 % crude fat, 0.85 % crude fibre and 1.31 % ash, which were found to be increased significantly ($p \geq 0.05$) in T_1, T_2 and T_3 buns except fat.

Table 3: Nutritional composition of *M. koenigii* supplemented β-carotene enriched buns

Parameter	Control	T_1	T_2	T_3	CD (p<0.05)
Moisture (%)	28.65 ± 0.05	27.87 ± 0.05*	27.11 ± 0.05*	26.45 ± 0.07*	0.19
Crude protein (%)	10.37 ± 0.01	10.89 ± 0.01*	11.17 ± 0.03*	11.38 ± 0.04*	0.09
Crude fat (%)	8.54 ± 0.01	8.32 ± 0.02*	8.10 ± 0.02*	7.92 ± 0.02*	0.08
Crude fibre (%)	0.85 ± 0.03	1.02 ± 0.01*	1.51 ± 0.03*	1.71 ± 0.03*	0.09
Ash (%)	1.31 ± 0.01	1.94 ± 0.03*	2.44 ± 0.01*	2.75 ± 0.01*	0.06
Soluble dietary fibre (%)	0.63 ± 0.01	0.86 ± 0.02*	0.95 ± 0.02*	1.08 ± 0.02*	0.06
Insoluble dietary fibre (%)	2.11 ± 0.02	4.85 ± 0.02*	6.24 ± 0.02*	7.63 ± 0.01*	0.06
Total dietary fibre (%)	2.74 ± 0.03	5.71 ± 0.01*	7.19 ± 0.03*	8.71 ± 0.04*	0.09
Calcium (mg/100 g)	41.47 ± 0.26	147.7 ± 0.05*	201.1 ± 0.00*	251.2 ± 0.02*	0.44
Iron (mg/100 g)	1.71 ± 0.04	2.59 ± 0.01*	3.11 ± 0.01*	3.66 ± 0.03*	0.08
Zinc (mg/100 g)	1.80 ± 0.02	1.97 ± 0.02*	2.09 ± 0.03*	2.17 ± 0.05*	0.10

Values are mean ± SD of three independent determinations

Control: 100 % RF; T_1: 95 % RF + 5 % LP; T_2: 92.5 % RF + 7.5 % LP; T_3: 90 % RF + 10 % LP; RF: Refined flour; LP: leaf powder

A significant decrease was observed in crude fat in *M. koenigii* supplemented buns. Crude protein, crude fat, crude fibre and ash of three types of *M. koenigii* leaves supplemented buns ranged from 10.89 to 11.38, 7.92 to 8.32, 1.02 to 1.71 and 1.94 to 2.75 per cent, respectively. Further, results indicated that the soluble and total dietary fibre content of control buns was 0.63 and 2.74 per cent, respectively. With the incorporation of 5, 7.5 and 10 per cent of *M. koenigii* leaves powder the soluble and total dietary fibre content of buns was increased significantly and ranged from 0.86 to 1.08 and 5.71 to 8.71 per cent, respectively.

Results presented in Table 3 showed that the calcium content of control buns was observed as 41.47 mg/100 g, which varied from 147.75 to 251.22 mg/100 g within three types of *M. koenigii* leaves powder supplemented buns. The iron content of control buns was observed as 1.71 mg/100 g, which was found to be increased significantly (p<0.05) with the supplementation of *M. koenigii* leaves powder and ranged from 2.59 to 3.66 mg/100 g. The zinc content of control buns was 1.80 mg/100 g, whereas it ranged from 1.97 to 2.17 mg/100 g in the *M. koenigii* leaves powder supplemented buns.

3.4 Antinutrient composition of *M. koenigii* supplemented β-carotene enriched buns

The results presented in Table 4 showed that the oxalate content of control buns was 18.78 mg/100 g which varied from 43.56 to 67.63 mg/100 g within the three types of buns prepared using *M. koenigii* leaves powder, being highest in T_3 and lowest in T_1 buns. All three types of *M. koenigii* leaves supplemented buns had significantly higher contents of oxalates than that of control buns.

Table 4: Antinutrient content of *M. koenigii* supplemented β-carotene enriched buns

Treatments	Oxalates (mg/100 g)	Phytic acid (mg/100 g)
Control	18.78 ± 0.11	316.40 ± 0.17
T_1	43.56 ± 0.04*	309.35 ± 0.07*
T_2	55.34 ± 0.09*	291.40 ± 0.14*
T_3	67.63 ± 0.11*	283.55 ± 0.19*
CD (p<0.05)	0.30	0.47

Values are mean ± SD of three independent determinations

Control: 100 % RF; T_1: 95 % RF + 5 % LP; T_2: 92.5 % RF + 7.5 % LP; T_3: 90 % RF + 10 % LP; RF: Refined flour; LP: leaf powder

Control buns had 316.40 mg/100 g of phytic acid, which was reduced significantly in the buns prepared using 5, 7.5 and 10 per cent of curry leaves powder. The contents of phytic acid in T_1, T_2 and T_3 buns ranged from 283.55 to 309.35 mg/100 g, being lowest in T_3 and highest in T_1 buns as shown in Table 4.

3.5 β-carotene content of *M. koenigii* supplemented buns

The amount of β-carotene in control buns was found to be 12.15 µg/100 g. *M. koenigii* leaves powder supplemented T_1, T_2 and T_3 buns had 4176.21, 6258.22 and 8340.20 µg/100 g amount of β-carotene, respectively. All three types of *M. koenigii* leaves supplemented buns had more than 300 to 600 times higher contents of β-carotene than that of control buns as illustrated in Figure 2.

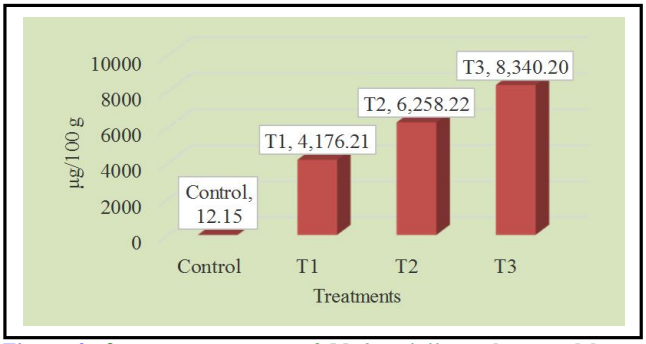

Figure 2: β-carotene content of *M. koenigii* supplemented buns.

4. Discussion

Freeze-dried powder of *M. koenigii* leaves contained significant contents of dietary fibre, antioxidants, calcium, iron, and β-carotene. It is also endowed with oxalates. Antinutritional factors have been known to hinder the bioavailability of certain nutrients such as protein, calcium, iron and zinc. Oxalates and phytates form insoluble complexes, hamper minerals and protein availability (Frontela *et al*., 2008). The effective temperature to reduce the antinutrient level was 90°C for 15 min. In a previous study, dehydrated *M. koenigii* leaves contained extensive amounts of oxalates; however, comparatively less amounts of phytate phosphorous, *i.e.,* 501.55 and 86.52 mg/100 g, respectively, which have been observed near the results of the present study (Lal and Kaur, 2019).

The findings of previous co-workers (Longwah *et al*., 2017; Lal and Kaur, 2019) corroborate the results of nutrient composition of dried leaf powder observed in the current study. Variability in drying techniques and analytical methods resulted in a modest rise and decrease in moisture, protein, ash, and fibre contents. Joshi and Mehta (2010) found that shade-dried drumstick leaves exhibited a 72 per cent increase in protein and a 75 per cent increase in fat content when compared to fresh leaves. According to Longwah *et al*. (2017), *M. koenigii* leaves had the highest amount of β-carotene when it came to fresh spices. According to the cited literature, there is a wide range in the amount of β-carotene in fresh and dried leaves (2100-12600 µg/100 g for fresh leaves and 1148-39600 µg/100 g for dried leaves) (Khatoon *et al*., 2011; Shivanna and Subban, 2013; Pritwani and Mathur, 2017; Chaudhary, 2020). The significant discrepancies in the amount of β-carotene found in both fresh and dried leaves could be attributed to various factors such as extraction technique, drying process, analytical approach, soil quality, amount of rainfall, and leaf maturity.

Results of the sensory acceptability of buns observed in present study are in close agreement with those of earlier workers who also incorporated *M. koenigii* leaves powder at various levels, *i.e.,* 3, 4, 5, and 10 % for the development of *chapatti*, cooked rice, and seasoned potatoes (Shanthala and Prakash 2005), mathri, uttapam, idli and lemon rice (Khatoon *et al*., 2011), buns (Sudha *et al.,* 2014), biscuits (Drisya *et al*., 2015), idli (Chelliah *et al.,* 2016), naan, vadiyan, bhatura, vada (Lal and Kaur, 2017) and shrikhand (Jerish *et al*., 2020). It was observed in the present study and cited literature that levels beyond eight per cent adversely affected the sensory acceptability as the scores for the crust colour, crumb colour, grain and overall quality were decreased in developed products.

Results of the proximate composition of *M. koenigii* leaves supplemented buns are in close agreement with those reported earlier (Drisya *et al*., 2015; Chelliah *et al.,* 2016; Lal and Kaur, 2017; Jerish *et al*., 2020). The increased amounts of crude protein, ash and crude fibre in *M. koenigii* leaves supplemented buns have been attributed to higher contents of the same in dried leaves powder. Other workers as Sudha *et al.* (2014) and Chelliah *et al.* (2016) also found a similar increase in the dietary fibre content of the products prepared using *M. koenigii* leaves powder. Our results are supported by earlier findings where supplementation of products with *M. koenigii* leaves (3-5 %) raised the level of iron, calcium, and iron (Khatoon *et al.,* 2011). Jerish *et al*. (2020) used *M. koenigii* leaf extract to create a unique shrikhand that was enhanced with iron. Buns fortified with *M. koenigii* leaves had an increase in iron content from 0.62 to 2.68 mg/100 g (Sudha *et al*., 2014).

The current study's findings on β-carotene content of developed buns were found to be in close accord with those of Lal and Kaur (2019). Shanthala and Prakash (2005) discovered that the seasoned potatoes and chapattis containing 5% *M. koenigii* leaves powder contained 37 and 43% more β-carotene, respectively, than the control products. Other researchers also discovered a rise in the amount of β-carotene in the products supplemented with *M. koenigii* leaves (Khatoon *et al*., 2011; Sudha *et al*., 2014; Wani and Sood, 2014). Thatte *et al*. (2011) revealed that adding natural sources to buns resulted in 62-72 % retention of β-carotene. This may be explained by the fact that natural sources have comparatively higher moisture content and that carotenoids are shielded from water by hydrogen bonding between hydroperoxides. This study had a limitation as the rheological parameters of developed buns were not examined. Future research may be undertaken to study the rheological parameters of *M. koenigii* leaves incorporated baked products and a six-month intervention study to observe the effect of feeding such products in a subclinical deficient population may be conducted.

5. Conclusion

It may be concluded that blanching of *M. koenigii* leaves for upto 15 sec at boiling temperature was found suitable for the proper retention of colour. Freeze drying was found suitable for the optimum retention of the β-carotene. *M. koenigii* leaves powder can be successfully incorporated up to 10 per cent to develop β-carotene rich products without affecting the sensory acceptability except colour. Overall sensory acceptability of products prepared using 7.5 per cent level of incorporation of *M. koenigii* leaf powder was found maximum, though all the products were found acceptable. β-carotene rich products can be successfully developed by incorporating *M. koenigii* leaves powder as the content in developed buns ranged from 4176.21 to 10596.93 µg/100 g. The consumption of two buns can meet *more* than 40 per cent of the recommended dose of vitamin A in adults and more than 60 per cent of the recommended dose of vitamin A in children (1-12 y). Besides β-carotene, these products had significantly higher contents of calcium, iron, fibre and protein than the control products. Consumption of such products may improve the subclinical deficiency of vitamin A in vulnerable groups.

Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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