INTRODUCTION

Spinach (Spinacia oleracea L.), a dark green leafy vegetable, belongs to the family Chenopodiaceae (Li et al., 2019) and is extensively consumed across the globe on account of its unique nutritional composition. Spinach stands out as one of the naturally enriched vegetables that hold an array of phytonutrients and bioactive compounds like β-carotene, lutein, zeaxanthin, ascorbic acid, flavonoids, and polyphenols with good biological properties (Manzoor et al., 2020; Salehi et al., 2019). Spinach is also referred to as a cheaper source of dietary fibers and minerals including calcium, phosphorus, potassium, magnesium, iron, zinc, copper, and manganese. Likewise, spinach has been considered as a potential source of carotenoids, folates, and iron and elicits ameliorative impacts against eye disorders like macular degeneration, nutritional anemia, and neural tube defects (Edelman & Colt, 2016; Shaheen et al., 2018). Spinach leaves...
also contain exceptionally higher amounts of phylloquinone that serves as a remedy to bleeding disorders (Edelman & Colt, 2016).

World Health Organization (WHO) estimated 190 million pre-school children to be the victims of deficiency of one or more micronutrients including vitamin A and iron (Paul et al., 2017). Available information suggests increased production of food crops as a means to bridge up inherent nutritional inadequacies and losses. In addition to food fortification, dietary diversification serves as a sustainable approach to subside micronutrient malnutrition and related health challenges (Lindsay et al., 2006). Staple food crops and the products made thereof are recommended as potential means to mitigate micronutrient deficiencies in developing world (Khan et al., 2015). Together with an array of bioactive compounds, spinach is regarded as a source of essential nutrients that may help in preventing a variety of nutritional disorders. Cereals based bakery products are the most common, viable, and acceptable consumable goods in various cultures. Sufficient literature demonstrates the application of vegetables as natural additives to improve nutritional and functional properties of baked goods, for example, carrot pomace-based bread and cakes (Kumar & Kumar, 2012), flaxseed powder-based muffins (Sudha et al., 2010), fenugreek flour-based biscuits (Hooda & Jood, 2005), and Lotus seed flour-based cookies (Shahzad et al., 2020).

Chapatti (unleavened flatbread) are considered as staple foods of populations in the Indian subcontinent. Different variants of leavened and unleavened flatbread include chapatti, tandoori roti, kulcha, paratha, puri, and doli roti regionally customized in various parts of Pakistan and other South Asian countries like India, Bangladesh and Afghanistan, and Iran (Gocmen et al., 2009). Around 1.8 billion people have been reported to consume flatbread as their primary source of energy in Middle Eastern regions, India, Southern Europe, Scandinavian countries, Central America, China, and South Africa (Malik et al., 2016).

A significant upsurge in nutritional inadequacies and associated health challenges necessitates the development of recipes and food formulations exploiting nonconventional functional ingredients. The present study aimed to investigate and evaluate the potential for supplemented spinach powder in wheat flour and its effect on textural and sensory properties to chapatti made thereof. The study further highlights various functional properties and nutritional significance of the vegetable powder supplemented chapattis suggesting wheat flour value addition a viable approach to mitigating food and nutritional insecurity among regional folk.

## 2 | MATERIALS AND METHODS

### 2.1 | Raw materials and chemicals

Fresh whole spinach leaves (20 kg) and whole wheat flour (20 kg) were procured from the vegetable and grain markets of Multan, Pakistan, respectively. All the chemicals and reagents used in the physicochemical analysis were of analytical grade and procured from Merck and Sigma Chemical Co., Ltd. unless otherwise mentioned in this study.

### 2.2 | Preparation of spinach powder (SP)

Fresh leaves of spinach were subjected to preliminary operations such as sorting, grading, washing, and dirt removal. Leaves were dipped in 40 ppm sodium hypochlorite (NaOCl3) solution for 30 min. Residues of sodium hypochlorite were removed by subsequent washing of shredded spinach leaves with potable water. Drying of processed spinach leaves was carried out to 15%-17% moisture contents in a cabinet dryer (PAKFS-40T) at 45 ± 2°C. Dehydrated leaves were ground to 72 mm mesh size in a heavy-duty grinder. Spinach powder thus obtained was packed in airtight polyethylene bags and stored at 4–6 ± 2°C for further experimentation (Galla et al., 2017).

### 2.3 | Functional properties of wheat flour (WF) and spinach powder (SP)

#### 2.3.1 | Bulk density (BD)

Spinach powder and wheat flour samples were evaluated for bulk density by the method followed by Jan et al. (2015). Briefly, 100g of each sample was poured into the tarred graduated cylinders (500 ml). The cylinder was tapped twice to fill any of the remaining space for homogeneity. BD was estimated using the following formula:

\[
\text{Bulk Density} = \frac{\text{Sample weight (g) \text{ Volume occupied by sample (ml)}}}{\text{Volume occupied by sample (ml)}}
\]

#### 2.3.2 | Rehydration Ratio (RR)

The rehydration ratio was determined by the method followed by Shaari et al. (2018). Five grams of each sample was soaked into 50 ml distilled water for 60 min at room temperature. Soaked samples were filtered using Whatman filter paper No. 41, and permeate was weighed. Samples’ ability to absorb water or rehydrate upon soaking was measured using the following formula:

\[
\text{Rehydration ratio} = \frac{\text{Weight of drained material (g)}}{\text{Weight of dried residues (g)}}
\]

#### 2.3.3 | Water absorption capacity (WAC)

The water absorption capacity of the samples was estimated following the method followed by Shafi et al. (2016). One gram of each sample was mixed in 10 ml of distilled water, and the mixture was subjected to incubation of 30 min. Thereafter, each sample was centrifuged (Hermle Z236K) at 2000 rpm for 10 min. The supernatant was decanted, and residues were inverted onto the filter paper to
allow water to be released for 5 min. WAC was estimated by weighing the residues and represented as the percentage of water absorbed per gram of the sample.

2.3.4 | Water solubility index (WSI)

The water solubility index was determined by following the method of Asaduzzaman et al. (2013). One gram of each sample was thoroughly mixed with 10 ml distilled water. The mixture was centrifuged (Hermle Z236K) for 30 min at 4,000 rpm. The supernatant thus obtained was oven-dried (Memmert) at 70°C for 15 min. Thereafter, the supernatant was decanted and oven-dried (Memmert) at 100 ± 5°C till constant weight. Dried samples were cooled in the desiccator and weighed.

WSI was calculated by the following formula:

\[
\text{WSI (\%)} = \frac{W_1 - W_2}{W} \times 100.
\]

W = Dried sample weight; W1 = Weight of petri dish and dried liquid; W2 = Weight of empty petri dish.

2.3.5 | Swelling power (Sp)

Swelling power was determined by the method outlined by Shafi et al. (2016). Samples weighing 0.5 g each were dispersed in 50 ml distilled water. The mixture was heated for 30 min at 90°C. Centrifugation of the homogenate was performed at 3,000 rpm for 15 min. Thereafter, the supernatant was decanted and oven-dried (Memmert) at 100 ± 5°C till constant weight. Results for Sp were represented in g/g of the dried sample.

2.3.6 | Hygroscopicity assay

Hygroscopicity values of the samples were determined by the method of Jaya and Das (2004). Each sample (10 g) was added to a petri dish and shifted to a desiccator containing sodium sulfate (Na2SO4) maintaining saturation level with approx. 81% relative humidity for one week. Results were calculated by determining differences in weight and expressed as g of moisture absorbed per 100g of the dry matter (g/100g) using the formula as mentioned below:

\[
\text{Hygroscopicity} = \frac{\Delta m}{(m + m_1)} + \frac{1}{(\Delta m/m)}.
\]

Where \(\Delta m\) shows the increase of powder’s weight at equilibrium (g), \(m\) is the primary mass of the powder (g), \(m_1\) is the water-free moisture of powder before exposure to external air humidity (g/100 g).

2.4 | Determination of nutritional composition

Moisture (Method No. 925.10), crude protein (Method No. 920.87), crude fat (Method No. 920.85), crude ash (Method No. 923.03), crude fiber (Method No. 32–10), and carbohydrate contents of all samples were determined using the following formula: carbohydrates (% = 100 – (moisture % + ash% + protein% + fat % + fiber%)) (Latimer, 2019). Mineral contents were estimated using atomic absorption spectrophotometer (Thermo Scientific iCE 3,000 series) and flame photometer (410, Sherwood Scientific Ltd-UK) (Latimer, 2019). Caloric contents of the samples were calculated by using the following formula:

Energy (Kcal/g) = (Proteins (g) \times 4.00) + (Fats (g) \times 9.00) + (Carbohydrates (g) \times 4.00) (Gallaetal, 2017).

2.5 | Preparation of chapattis premixes

Whole wheat flour chapattis premixes were prepared by supplementing with spinach powder at 0%–20% and were stored in airtight polyethylene bags until final preparation.

2.6 | Rheological measurements of chapattis premixes

Farinographic study was conducted and samples, that is, wheat flour and spinach powder supplemented premixes, were analyzed for water absorption, dough stability time, and dough development time by using the Brabender® Farinograph (Brabender GmbH and Co. KG) (Mehfooz et al., 2018). AACC (2000) method 54–40 was followed to determine mixographic measurements, that is, peak height and the peak time of wheat flour—spinach powder preblends using Brabender® Mixograph (National Mfg. Co).

2.7 | Preparation of chapattis

Wheat flour and spinach powder premixes were mixed in an optimum amount of water for developing composite chapattis. The dough was divided manually into dough balls each weighing 50 g. Dough balls were allowed to rest for 20 min and sheeted into 150 mm diameter chapattis with a roller pin. Chapattis were baked at 225 ± 5°C for 1.5–2.5 min (Kundu et al., 2019).

2.8 | Color, texture, and puffed height assessment

The color profile of freshly produced chapattis was determined by the method followed by Pekmez and Yılmaz (2018). Physical color parameters \(L^*\) (brightness), \(a^*\) (redness), and \(b^*\) (yellowness), hue angle (\(\theta\)), and chroma of chapattis were quantified using Hunter Lab mini-Scan XE Plus colorimeter (Model 45/0-L, HAL). Baked chapattis were evaluated for textural parameters including hardness, chewiness, and springiness by using a texture analyzer (TA. XT plus, Stable Micro Systems) (Panghal et al., 2017). Freshly baked chapattis were instantaneously evaluated for puffed height (cm)
using a stainless steel scale following the method documented by Rao et al. (1986).

2.9 | Sensory evaluation of supplemented chapattis

Sensory evaluation of spinach powder supplemented chapattis was conducted by a panel of experts on the 9-Point Hedonic Scale using sensory acceptability scale from 1—dislike extremely, to 9—like extremely. Chapattis prepared from flour without spinach powder (control) and spinach powder were evaluated for physical appearance, color, taste, texture, folding ability, and overall acceptability (Pathania et al., 2017).

2.10 | Statistical analysis

Each experiment was replicated twice, and means computed were presented as means ± S.D. Data collected from analyses of spinach powder, whole wheat flour, and spinach powder supplemented chapattis were statistically analyzed using the analysis of variance (ANOVA) technique on Statistics 8.1 (Tallahassee, FL). The level of significance among the means was analyzed by the least significance difference (LSD) at a 5% confidence interval (Steel et al., 1997).

3 | RESULTS AND DISCUSSION

3.1 | Functional properties of the dehydrated spinach and wheat flour

A comparison was made between the functional properties of wheat flour and spinach powder to elucidate spinach powder ability to be considered as a natural candidate for wheat flour enrichment. The results suggest significantly higher values for hygroscopicity (6.4%), swelling power (7.1 g/g), and water solubility index (4.2%) concerning spinach powder in comparison to the wheat flour (Table 1). Spinach powder holds higher swelling power and water solubility due to the presence of carbohydrates and higher amounts of dietary fibers. Earlier, a study by David et al. (2015) reported swelling power as an important functional property of starches and proteins from flours of various origins. Increased swelling power and water solubility index (WSI) have also been attributed to higher starch contents (Shafi et al., 2016). Our results were similar for swelling power (7.95 g/g) for chestnut flour (Shafi et al., 2016). Spinach powder was found to carry 120% higher protein contents than wheat flour that might have anticipated improved hygroscopicity, SP, and WSI as compared with wheat flour.

3.2 | Effect of spinach powder supplementation on rheological properties of chapattis premixes

Rheological properties of composite flour were evaluated to assess the impact of spinach powder supplementation on functional properties of dough. A significant decrease (p < .05) in water absorption, that is, from 63% to 55% and dough stability from 13.21 min to 10.67 min was noticed at 0% – 20% spinach powder supplementation level. However, a significant increase in peak height was recorded, that is, from 48.59BU to 66.39BU at 20% supplementation of spinach powder (Table 2). Increment in dough development time, reduction in dough stability, and water absorption with increasing levels of spinach powder may be attributed to a gradual reduction in mean gluten concentration of composite flours and lesser interactions between hydroxyl groups of fibers with water (Sharma et al., 2013). Similar trends in dough development time and dough stability properties were suggested by Sharma et al. (1995) wherein researchers reported a significant decrease in water absorption, that is, (58%–55%) at the level of 20% wheat flour replacement with chickpea flour. These researchers further observed a nonsignificant change in water absorption capacity of composite flour at 10% supplementation thereby suggesting an optimum level of supplementation to design a quality product.

3.3 | Nutritional composition of dehydrated spinach and value-added product

Spinach powder dried to moisture contents at ~8% was shown to carry a considerable amount of fiber (8.2%), ash (2.9%), and protein (19.2%). A relatively lower amount of fiber, ash, and protein contents, that is, 2.4%, 0.2%, and 8.6%, respectively, were recorded for wheat flour (Table 3). Increased variability was recorded for protein (21%–32%) and carbohydrate (21%–32%)}
inorganic contents (10%-18%) of spinach powder in comparison with retrospective studies (Galla et al., 2017; Khan et al., 2015). Similarly, variation in ash (%) and protein (%) contents may be linked to the varietal differences, geographical conditions, and degree of dehydration or total solid contents in dehydrated plant material. Enriching wheat flour with nutrient-dense ingredients like vegetable powder may result in improved nutritional status of the finished products. Significant (p < .05) effect of spinach powder supplementation was witnessed on the nutritional composition of unleavened flatbread, that is, chapattis (Table 3). The results suggested significant improvement in protein, ash, and fiber contents of composite chapattis with values ranging from 8.0% to 9.3%, 0.3 to 0.9%, and 2.4 to 4.1%, respectively. A significant increase (p < .05) in protein, ash, and fiber contents of wheat-spinach composite chapattis might be ascribed to spinach powder supplementation which had itself delivered higher amounts of these constituents (Table 3). A notable decrease in moisture contents of spinach powder supplemented chapattis was also noted which hinted at the lower water holding capacity of the spinach powder to be the reason as compared to wheat flour. Results of the present research are in agreement with the previous findings of Seleem and Omran (2014) who reported partial replacement of wheat flour with sorghum flour and noncereals crops like beans to anticipate comparatively higher levels of fiber, ash, and protein in supplemented chapattis, that is, 9.2%-10.2%, 1.6%-2.1%, and 0.4%-0.8%, respectively, while relatively lower values of the aforesaid nutrients were recorded for sorghum supplemented chapattis, that is, 9.0%-9.3%, 1.6%-1.7%, and 0.4%-0.5%.

### 3.4 Mineral contents of dehydrated spinach and value-added product

Comparing with wheat flour carrying Ca (41 mg/100 g) and Fe (3.8 mg/100 g), spinach powder exhibited significantly higher amounts (p < .05) of Ca and Fe, that is, 1304 mg/100 g and 40 mg/100 g, respectively. Wheat flour is not considered a good source of dietary iron and calcium which is exacerbated by whole grain processing and refining leading to a significant loss of the minerals’ reserves. Contrarily, vegetables hold a tremendous amount of micronutrients when offered in raw or as dehydrated powders. Results of the current study validate earlier reports wherein dehydrated spinach was reported to contain Ca 1020-1336 mg/100 g and Fe 30-69 mg/100 g (Galla et al., 2017; Khan et al., 2015).

A significant increase (p < .05) in levels of micro- and macrominerals in composite flour chapattis was observed indicating spinach powder supplementation to be directly associated with improved minerals profile of the final product (Table 4). Wheat flour enrichment with spinach powder (20%) increased K, Ca, and Fe contents of chapattis from 448 to 494 mg/100 g, 40 to 301 mg/100 g, and 3.3 to 11.6 mg/100 g, respectively, and such an elevation in minerals concentration of chapattis is attributed to a better micronutrients profile of spinach powder (Table 4). Our findings for the mineral composition of the composite chapattis are in line with those of Seleem and Omran (2014) who demonstrated a significant increase in Ca, Fe, and Zn contents of bean flour supplemented chapattis, that is, 15.3 to 21.6 mg/100 g, 6.0 to 7.1 mg/100 g, and 0.9 to 1.2 mg/100 g, respectively.

### 3.5 Effect of spinach powder supplementation on textural properties of chapattis

Color measurements of dried spinach substituted chapattis are presented in Table 5. Lightness (L*) and redness (b*) values of composite chapattis significantly decreased (p < .05) in a dose-dependent manner from 70 to 52 and 2.9 to 1.0, respectively, with an increasing level of spinach powder supplementation. Reduction in L* values depicts that chapattis are darker in color. In the same way, yellowness (b*) values of

| Parameters | T₀ | T₁ | T₂ | T₃ | T₄ | T₅ | T₆ |
|------------|----|----|----|----|----|----|----|
| Farinographic measurements | | | | | | | |
| Water absorption (%) | 62.67 ± 0.78a | 58.64 ± 0.50bc | 59.79 ± 0.32b | 57.98 ± 0.04c | 57.49 ± 0.71cd | 56.22 ± 0.95de | 54.89 ± 0.79e |
| Dough stability (min) | 13.21 ± 0.00a | 12.49 ± 0.06b | 12.02 ± 0.01bc | 11.91 ± 0.18c | 11.60 ± 0.37c | 11.10 ± 0.34d | 10.67 ± 0.01d |
| Dough development (min) | 5.56 ± 0.16a | 4.12 ± 0.16d | 4.67 ± 0.00c | 4.71 ± 0.06bc | 4.93 ± 0.08b | 5.44 ± 0.01a | 5.60 ± 0.06a |
| Mixographic measurements | | | | | | | |
| Peak height (BU) | 48.59 ± 0.51g | 49.16 ± 0.06f | 50.43 ± 0.00e | 51.43 ± 0.16d | 55.39 ± 0.08c | 62.22 ± 0.14b | 66.39 ± 0.08a |
| Peak time (min) | 5.37 ± 0.04a | 5.02 ± 0.01b | 4.53 ± 0.02c | 4.35 ± 0.01d | 4.03 ± 0.01e | 3.97 ± 0.01f | 3.44 ± 0.01g |

Note: Values are means ± S.D. Values having identical lettering in each column are nonsignificant at p < .05. T₀ = 100% whole wheat flour (control), T₁ = 2.5% spinach powder, (SP), T₂ = 5% SP, T₃ = 7.5% SP, T₄ = 10% SP, T₅ = 15% SP, T₆ = 20% SP.
**Table 3** Proximate composition of spinach powder supplemented Chapattis (g/100g)

| Parameters      | Samples | $T_0$ | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ | $T_6$ |
|-----------------|---------|-------|-------|-------|-------|-------|-------|-------|
| Moisture        |         | 37.65 ± 0.04a | 37.25 ± 0.36a | 35.25 ± 1.77ab | 34.00 ± 0.00ab | 32.98 ± 1.06bc | 31.60 ± 0.56cd | 29.25 ± 1.77d |
| Ash             |         | 0.31 ± 0.01g   | 0.39 ± 0.00f   | 0.47 ± 0.01e   | 0.55 ± 0.03d   | 0.63 ± 0.03c   | 0.77 ± 0.02b   | 0.92 ± 0.02a   |
| Protein         |         | 8.03 ± 0.02g   | 8.85 ± 0.01f   | 9.33 ± 0.04e   | 9.78 ± 0.04d   | 10.26 ± 0.03c  | 11.25 ± 0.03b  | 12.21 ± 0.05a  |
| Fat             |         | 1.66 ± 0.04a   | 1.64 ± 0.00a   | 1.52 ± 0.03b   | 1.32 ± 0.03c   | 1.24 ± 0.03d   | 1.16 ± 0.01d   | 1.07 ± 0.02e   |
| Fiber           |         | 2.44 ± 0.01g   | 2.64 ± 0.01f   | 2.86 ± 0.02e   | 3.05 ± 0.01d   | 3.27 ± 0.02c   | 3.78 ± 0.17b   | 4.09 ± 0.04a   |
| Carbohydrates   |         | 49.91 ± 0.04c  | 49.27 ± 0.34c  | 50.57 ± 1.74bc | 51.20 ± 0.04b  | 51.63 ± 0.95ab | 51.41 ± 0.32ab | 52.46 ± 1.68a  |
| Caloric value   |         | 247.53 ± 0.29e | 247.80 ± 1.36e | 254.23 ± 6.79d | 257.18 ± 0.25bc| 259.73 ± 4.18c | 262.40 ± 1.53b | 269.53 ± 6.77a |

Note: Values are means ± S.D. Values having identical lettering in each column are nonsignificant at $p < .05$. $T_0 = 100\%$ whole wheat flour (control), $T_1 = 2.5\%$ spinach powder, (SP), $T_2 = 5\%$ SP, $T_3 = 7.5\%$ SP, $T_4 = 10\%$ SP, $T_5 = 15\%$ SP, $T_6 = 20\%$ SP.

**Table 4** Mineral composition of spinach powder supplemented Chapattis (mg/100g)

| Parameters      | Spinach powder supplementation levels |
|-----------------|--------------------------------------|
|                 | Whole wheat flour | Spinach powder | $T_0$ | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ | $T_6$ |
| Sodium          | 5.06 ± 0.08b      | 98.20 ± 0.78a  | 5.34 ± 0.32g | 8.10 ± 0.14f | 10.47 ± 0.04e | 12.90 ± 0.03d | 15.27 ± 0.08c | 20.16 ± 0.06b | 25.37 ± 0.40a |
| Calcium         | 40.80 ± 0.35b     | 1,303.90 ± 3.78a | 39.83 ± 0.05g | 72.71 ± 0.25f | 105.54 ± 0.48e | 137.81 ± 0.08d | 170.70 ± 0.24c | 235.65 ± 0.29b | 301.26 ± 0.11a |
| Potassium       | 445.50 ± 0.71a    | 233.38 ± 1.34b | 448.25 ± 1.77g | 452.01 ± 1.14f | 458.13 ± 0.69e | 464.82 ± 0.55d | 469.84 ± 0.58c | 481.99 ± 0.18b | 493.86 ± 0.53a |
| Iron            | 3.78 ± 0.02b      | 40.36 ± 0.21a  | 3.27 ± 0.02f  | 4.16 ± 0.20e  | 5.60 ± 0.42d  | 6.51 ± 0.28c  | 7.16 ± 0.22c  | 9.59 ± 0.39b  | 11.62 ± 0.41a |
| Zinc            | 3.91 ± 0.02b      | 13.38 ± 0.23a  | 3.44 ± 0.14g  | 3.91 ± 0.04f  | 4.28 ± 0.09e  | 4.58 ± 0.04d  | 4.89 ± 0.00c  | 5.64 ± 0.09b  | 6.35 ± 0.14a |

Note: Values are means ± S.D. Values having identical lettering in each column are nonsignificant at $p < .05$. $T_0 = 100\%$ whole wheat flour (control), $T_1 = 2.5\%$ spinach powder, (SP), $T_2 = 5\%$ SP, $T_3 = 7.5\%$ SP, $T_4 = 10\%$ SP, $T_5 = 15\%$ SP, $T_6 = 20\%$ SP.
Chapattis increased from 18.8 to 27.8 with an increasing level of spinach powder supplementation. Color variations in wheat-based chapattis are generally attributed to Maillard reaction during baking, however; higher incidence of variability in color profile of spinach powder supplemented chapattis may better be correlated with spinach pigments like carotenoids. Substituting wheat flour with spinach powder significantly influenced the color index of the baked product that may lead to a significant decline in securing consumer acceptability score. Replacing wheat flour with pigmented grains (sorghum) and dark-colored vegetables like spinach at levels beyond 10% and 30%, respectively, have been documented to attribute the decline in consumer acceptability score of baked goods. Comparable findings were reported by several researchers, wherein L* values were decreased on the addition of spinach powder in extrusion products (Galla et al., 2017; Singh et al., 2015). Similarly, other studies reported similar findings for b* values in chapattis made with jering seeds flour (Cheng & Bhat, 2015).

Hardness and chewiness of spinach powder supplemented chapattis significantly increased (p < .05) from 22 to 90 g and 67 to 138 g, respectively, with increasing spinach powder supplementation level (Table 5). A study by Singh et al. (2015) reported higher fiber and protein contents of spirulina flour to mark a significant increase in hardness of wheat-based spirulina flour supplemented biscuits. Results on textural properties observed in the present study are in agreement with the findings of an earlier report, wherein an increase in hardness was recorded for biscuits supplemented with spinach powder at 15% supplementation level (Galla et al., 2017). Likewise, substituting wheat flour with jering seed at 0 to 100% substitution level significantly increased hardness in chapattis, that is, 332.4 g to 1627.5 g (Cheng & Bhat, 2015).

Puffing of chapattis is a desirable quality attribute that significantly influences consumers’ preference (Wani et al., 2016). Textural profiling of spinach powder supplemented chapattis revealed a significant decline in puffing quality of the baked good and puffing height score declined from 5.45 to 4.03 cm at 0 to 20% supplementation (Table 5). Reduction in chapattis puffing height might be attributed to higher amounts of the dietary fibers and nongluten proteins of spinach powder.

### 3.6 Effect of spinach powder supplementation on the sensory acceptability of chapattis

Data extracted from the organoleptic acceptability study of spinach powder supplemented composite chapattis are presented in Table 6. Acceptable scores for various sensory variables of spinach powder supplemented chapattis were recorded by the sensory panellists at 7.5% supplementation. The results delineated a significant decline in sensory scoring with increasing levels of spinach powder supplementation, however; 10 to 20% substitution of wheat flour with spinach powder resulted in undesirable sensory attributes when compared with the normal control. Spinach-based products, that is, biscuits, have already been reported for sensory acceptability wherein researchers documented better consumer acceptability.

| TABLE 5 Effect of spinach powder supplementation on color values, instrumental texture, and puffed height of Chapattis |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Parameters      | T₀             | T₁             | T₂             | T₃             | T₄             | T₅             | T₆             |
| Hunter lab color|                |                |                |                |                |                |                |
| Lightness L*    | 69.83 ± 0.69a  | 67.35 ± 0.53b  | 64.43 ± 0.00c  | 62.98 ± 0.94c  | 59.04 ± 0.71d  | 57.04 ± 0.71e  | 51.66 ± 0.77f  |
| Redness a*      | 5.02 ± 0.04c   | 4.39 ± 0.00f   | 4.39 ± 0.00e   | 4.39 ± 0.00e   | 4.39 ± 0.00e   | 4.39 ± 0.00e   | 4.39 ± 0.00e   |
| Yellowness b*   | 18.87 ± 0.16f  | 19.22 ± 0.14f  | 20.07 ± 0.07e  | 23.65 ± 0.16c  | 25.38 ± 0.54b  | 27.82 ± 0.23a  | 27.47 ± 0.28a  |
| Hue angle ġ      | 81.19 ± 0.16f  | 81.80 ± 0.35e  | 82.14 ± 0.01de | 82.56 ± 0.17d  | 84.65 ± 0.06c  | 86.38 ± 0.23b  | 87.95 ± 0.06a  |
| Instrumental texture analysis |                |                |                |                |                |                |                |
| Hardness (g)    | 22.39 ± 0.00g  | 43.49 ± 0.00f  | 43.93 ± 0.00e  | 48.80 ± 0.02d  | 82.43 ± 0.04c  | 86.13 ± 0.00b  | 89.55 ± 0.48a  |
| Springiness (g) | 66.70 ± 0.20f  | 60.86 ± 0.01g  | 95.76 ± 0.13e  | 102.50 ± 0.25d | 118.61 ± 0.09c | 137.85 ± 0.12b | 147.48 ± 0.09a |
| Chewiness (g)   | 67.02 ± 0.03g  | 79.22 ± 0.30f  | 95.16 ± 0.23e  | 116.28 ± 0.40d | 126.38 ± 0.54c | 132.05 ± 0.07b | 138.23 ± 0.32a |
| Puffed Height (cm) | 5.45 ± 0.01a | 5.02 ± 0.04b  | 4.97 ± 0.09c   | 4.92 ± 0.05d   | 4.55 ± 0.06e   | 4.35 ± 0.12f   | 4.03 ± 0.20g   |

Note: Values are means ± S.D. Values having identical lettering in each column are nonsignificant at p < .05. T₀ = 100% whole wheat flour (control), T₁ = 2.5% spinach powder, (SP), T₂ = 5% SP, T₃ = 7.5% SP, T₄ = 10% SP, T₅ = 15% SP, T₆ = 20% SP.
scores at 5% spinach powder supplementation (Galla et al., 2017). Another study by Khan et al. (2015) reported an organoleptically acceptable sensory score for chapattis developed at 5% spinach powder supplementation.

4 | CONCLUSIONS

Growing micronutrient deficiencies especially in lower-middle-income countries are a leading cause of increased disease burden. Novel intervention strategies to confront the challenges associated with malnutrition and food insecurities are imperative. Archetypical consumption of vegetables is now transitioning to novel approaches to foster their enhanced intake. The application of dehydrated vegetables is being widely practiced in a variety of recipes and food preparations. Spinach powder is considered a valuable source of dietary fibers, micronutrients, and bioactive compounds that can ameliorate several nutritional and health disorders. The present investigation confirmed the addition of spinach powder in wheat flour-based baked goods at ~10% level of supplementation not to contribute undesirable sensory attributes to unleavened bread, that is, chapattis. Our findings conclude that spinach powder supplementation at 7.5% could be a viable and practical approach to develop value-added baked goods. The results further indicate that the utilization of green leafy vegetables as powder formulae or premixes could help abridge nutritional inadequacies and food insecurities cost-effectively among vulnerable population groups.

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CONFLICT OF INTEREST

Authors declare to not have any conflict of interest.

ETHICAL APPROVAL

This does not involve human or animal modeling.

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REFERENCES

American Association of Cereal Chemists (AACC) (2000). Approved methods of American association of cereal chemists, 10th ed.: AACC.

Asaduzzaman, M., Haque, M. E., Rahman, J., Hasan, S. K., Ali, M. A., Akter, M. S., & Ahmed, M. (2013). Comparisons of physiochemical, total phenol, flavanoid content and functional properties in six cultivars of aromatic rice in Bangladesh. African Journal of Food Science, 7(8), 198–203.

Cheng, Y. F., & Bhat, R. (2015). Physicochemical and sensory quality evaluation of chapati (Indian flat bread) produced by utilizing underutilized jering (Pithecellobium jiringa Jack.) legume and wheat composite flours. International Food Research Journal, 22(6), 2244–2252.

David, O., Arthur, E., Kwadwo, S. O., Badu, E., & Sakyi, P. (2015). Proximate composition and some functional properties of soft wheat flour. IJRSET, 4(2), 753–758.

Edelman, M., & Colt, M. (2016). Nutrient value of leaf vs. seed. Frontiers in Chemistry, 4, 32.

Galla, N. R., Pamidighantam, P. R., Karakala, B., Gurusiddaiah, M. R., & Akula, S. (2017). Nutritional, textural and sensory quality of biscuits supplemented with spinach (Spinacia oleracea L.). International Journal of Gastronomy and Food Science, 7(1), 20–26.

Gocmen, D., Inkaya, A. N., & Aydin, E. (2009). Flat breads. Bulg. Journal of Agricultural Science, 15(4), 298–306.

Hooda, S., & Jood, S. (2005). Organoleptic and nutritional evaluation of wheat biscuits supplemented with untreated and treated fenugreek flour. Food Chemistry, 90(3), 427–435.

Jan, U., Gani, A., Ahmad, M., Shah, U., Baba, W. N., Masoodi, F. A., & Wani, S. M. (2015). Characterization of cookies made from wheat flour blended with buckwheat flour and effect on antioxidant properties. Journal of Food Science and Technology, 52(10), 6334–6344.

Jaya, S., & Das, H. (2004). Effect of maltodextrin, glycerol monostearate and tricalcium phosphate on vacuum dried mango powder properties. International Journal of Food Engineering, 63(2), 125–134.

Khan, M. A., Mahesh, C., Semwal, A. D., & Sharma, G. K. (2015). Effect of spinach powder on physico-chemical, rheological, nutritional and sensory characteristics of chapatti premixes. Journal of Food Science and Technology, 52(4), 2359–2365.

Kumar, K., & Kumar, N. (2012). Development of vitamin and dietary fibre enriched carrot pomace and wheat flour based buns. Journal of Pure and Applied Science, 2(1), 107–115.

TABLE 6 Effect of spinach powder supplementation on sensory acceptability of Chapattis

| Parameters      | T0     | T1     | T2     | T3     | T4     | T5     | T6     |
|-----------------|--------|--------|--------|--------|--------|--------|--------|
| T0              | 4.71 ± 0.35a | 4.72 ± 0.34b | 4.73 ± 0.33c | 4.74 ± 0.32d | 4.75 ± 0.31e | 4.76 ± 0.30f | 4.77 ± 0.29g |
| T1              | 4.72 ± 0.34b | 4.73 ± 0.33c | 4.74 ± 0.32d | 4.75 ± 0.31e | 4.76 ± 0.30f | 4.77 ± 0.29g | 4.78 ± 0.28h |
| T2              | 4.73 ± 0.33c | 4.74 ± 0.32d | 4.75 ± 0.31e | 4.76 ± 0.30f | 4.77 ± 0.29g | 4.78 ± 0.28h | 4.79 ± 0.27i |
| T3              | 4.74 ± 0.32d | 4.75 ± 0.31e | 4.76 ± 0.30f | 4.77 ± 0.29g | 4.78 ± 0.28h | 4.79 ± 0.27i | 4.80 ± 0.26j |
| T4              | 4.75 ± 0.31e | 4.76 ± 0.30f | 4.77 ± 0.29g | 4.78 ± 0.28h | 4.79 ± 0.27i | 4.80 ± 0.26j | 4.81 ± 0.25k |
| T5              | 4.76 ± 0.30f | 4.77 ± 0.29g | 4.78 ± 0.28h | 4.79 ± 0.27i | 4.80 ± 0.26j | 4.81 ± 0.25k | 4.82 ± 0.24l |
| T6              | 4.77 ± 0.29g | 4.78 ± 0.28h | 4.79 ± 0.27i | 4.80 ± 0.26j | 4.81 ± 0.25k | 4.82 ± 0.24l | 4.83 ± 0.23m |

Note: Values are means ± S.D. (n = 30). Values having identical lettering in each column are nonsignificant at p < .05. T0 = 100% whole wheat flour (control), T1 = 2.5% spinach powder, (SP), T2 = 5% SP, T3 = 7.5% SP, T4 = 10% SP, T5 = 15% SP, T6 = 20% SP.
Kundu, M., Khatkar, B. S., Gulia, N., & Kumar, R. (2019). Functional characterization of whole wheat flours for chapatti quality and acceptability. *Journal of Pure and Applied Science & Technology, 5*(4), 1–9.

Latimer, G. W. (2019). *Official methods of analysis*, 19th ed. : Association of Official Analytical Chemists.

Li, S. F., Guo, Y. J., Li, J. R., Wang, B. X., Li, N., Deng, C. L., & Gao, Y. (2019). The landscape of transposable elements and satellite DNAs in the genome of a dioecious plant spinach (*Spinacia oleracea* L.). *Mobile DNA, 10*(1), 3.

Lindsay, A., De-Benoist, B., Dary, O., & Hurrel, R. (2006). *Guidelines on food fortification with micronutrients*. : World Health Organization (WHO) and Food and Agricultural Organization (FAO) of the United Nations.

Malik, H., Nayik, G. A., & Dar, B. N. (2016). Optimization of process for development of nutritionally enriched multigrain bread. *International Journal of Food Processing Technology, 7*(1), 1–6.

Manzoor, M. F., Ahmed, Z., Ahmad, N., Aadil, R. M., Rahaman, A., Roobab, U., Rehman, A., Siddique, R., Zeng, X.-A., & Siddeeg, A. (2020). Novel processing techniques and spinach juice: Quality and safety improvements. *Journal of Food Science, 85*(4), 1018–1026. https://doi.org/10.1111/1750-3841.15107

Mehfuz, T., Ali, T. M., Arif, S., & Hasnain, A. (2018). Effect of barley husk addition on rheological, textural, thermal and sensory characteristics of traditional flat bread (chapatti). *Journal of Cereal Science, 79*(1), 376–382.

Panghal, A., Chhikara, N., & Khatkar, B. S. (2017). Characterization of Indian wheat varieties for chapatti (flat bread) quality. *Journal of the Saudi Society of Agricultural Sciences, 18*(1), 107–111.

Pathania, S., Kaur, A., & Sachdev, P. A. (2017). Chickpea flour supplemented high protein composite formulation for flatbreads: Effect of packaging materials and storage temperature on the ready mix. *Food Packag Shelf Life, 1*(1), 125–132.

Paul, J. Y., Khanna, H., Kleidon, J., Hoang, P., Geijskes, J., Daniells, J., Milalazi, B., & Deo, P. (2017). Golden bananas in the field: Elevated fruit pro-vitamin A from the expression of a single banana transgene. *Plant Biotechnology Journal, 15*(4), 520–532.

Pekmez, H., & Yilmaz, B. B. (2018). Quality and antioxidant properties of black carrot (*Daucus carota* ssp. *sativus* var. *atrorubens* Alef) fiber fortified flat bread (*Gaziantep Pita*). *Journal of Agriculture, Science and Technology, 8*(2), 533–541.

Rao, R. P., Leelavathi, K., & Shurpalekar, R. (1986). Test baking of chapatti-development of a method. *Cereal Chemistry, 63*(4), 297–303.

Salehi, B., Tumer, T. B., Ozleyen, A., Peron, G., Dall’Acqua, S., Rajkovic, J., Labanca, F., & Milella, L. (2019). Plants of the genus *Spinacia*: From bioactive molecules to food and phytopharmacological applications. *Trends in Food Science & Technology, 88*, 260–273.

Seleem, H. A., & Omran, A. A. (2014). Evaluation quality of one layer flat bread supplemented with beans and sorghum baked on hot metal surface. *Food and Nutrition Science, 5*(22), 2246–2256.

Shaari, N. A., Sulaiman, R., Rahman, R. A., & Bakar, J. (2018). Production of pineapple fruit (*Ananas comosus*) powder using foam mat drying: Effect of whipping time and egg albumen concentration. *Journal of Food Processing and Preservation, 42*(2), 13467.

Shafi, M., Baba, W. N., Masoodi, F. A., & Bazaz, R. (2016). Wheat-water chestnut flour blends: Effect of baking on antioxidant properties of cookies. *Journal of Food Science and Technology, 53*(12), 4278–4288.

Shaheen, S. M., Islam, O., Azad, A. K., Rahman, M. M., Alam, A. K., Khairuzzaman, M., Ferdous, J., & Islam, M. (2018). Phytochemical profiling and evaluation of antioxidant and antidiabetic activity of methanol extract of spinach (*Spinacia oleracea* L.) leaves. *International Journal of Pharmaceutical Sciences and Research, 3*(8), 24–27.

Shahzad, M. A., Ahmad, N., Ismail, T., Manzoor, M. F., Ismail, A., Ahmed, N., & Akhtar, S. (2020). Nutritional composition and quality characterization of lotus (*Nelumbo nucifera* Gaertn.) seed flour supplemented cookies. *Journal of Food Measurement Characterization, 1–8.*

Sharma, P., Velu, V., Indrani, D., & Singh, R. P. (2013). Effect of dried guduchi (*Tinospora cordifolia*) leaf powder on rheological, organoleptic and nutritional characteristics of cookies. *Food Research International, 50*(2), 704–709.

Sharma, S., Sekhon, K. S., & Nagi, H. P. S. (1995). Legume supplemented flat bread: Nutritive value, textural and organoleptic changes during storage. *Journal of Food Processing and Preservation, 19*(3), 207–222.

Singh, P., Singh, R., Jha, A., Rasane, P., & Gautam, A. K. (2015). Optimization of a process for high fibre and high protein biscuit. *Journal of Food Science and Technology, 52*(3), 1394–1403.

Steel, R. G. D., Torrie, J. H., & Dickey, D. (1997). *Principals and procedures of statistics*, 3rd ed. McGraw Hills.

Sudha, M. L., Begum, K., & Ramasarma, P. P. R. (2010). Nutritional characteristics of linseed/flaxseed (*Linum usitatissimum*) and its application in muffin making. *Journal of Texture Studies, 41*(4), 563–578.

Wani, I. A., Sogi, D. S., Sharma, P., & Gill, B. S. (2016). Physicochemical and pasting properties of unleavened wheat flat bread (chapatti) as affected by addition of pulse flour. *Cogent Food Agriculture, 2*(1), 1124486.

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