PLANT SCIENCE TODAY
Vol XX(1): 1-XX
https://doi.org/10.14719/pst.16936

eISSN 2348-1900
OPEN ACCESS

Research Article | Horticulture
2026, Volume XX, Issue X, pp. 1-XX

Nutritional profiling of turmeric rhizomes and development of a ready-to-mix curry powder

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Abstract

The development of functional foods from nutrient-rich turmeric (*Curcuma longa* L.) requires the identification of superior genotypes with enhanced bioactive compounds and validated health benefits. This study evaluated 10 elite turmeric genotypes for 16 biochemical traits, including proximate composition, mineral nutrients, curcumin content and antioxidant activity. The study was conducted at the Horticultural Research Station, Lam, Guntur District, Andhra Pradesh, during the year 2022–23. Among the evaluated genotypes, Lam Swarna (LTS-2) was identified as the most promising based on its balanced nutritional composition, high curcumin content (1.25 %) and antioxidant activity (87.68 %). A ready-to-mix curry was standardised using fresh LTS-2 rhizomes. Sensory evaluation identified the formulation containing 25 g of fresh turmeric with a common spice base as the most acceptable, with sensory scores for colour (8.5), flavour (8.7), taste (8.9), texture (8.4), mouth feel (8.6) and overall acceptability (8.8). The curry was tray-dried to obtain a shelf-stable curry powder. The biological efficacy of the tray-dried product was validated in Swiss albino male mice subjected to folic acid-induced oxidative stress. Oral administration of the curry powder equivalent to 7 mg curcumin kg^{-1} body weight (Group 5) significantly increased body weight (5.8 % more than the initial), total erythrocyte count (7.37 millions/µL), haemoglobin content (10.15 g %), packed cell volume (40.43 %), platelets (7.18 × 10^5/µL), total proteins (6.30 grams per decilitre (g/dL)) and glutathione (4.41 and 5.36 µM/mg), superoxide dismutase (41.48 and 45.53 units per milligram (U/mg)) and antioxidant activity (52.02 and 46.61 %) in liver and kidney respectively. However, decreased blood urea nitrogen (N) (37.53 mg/dL), creatinine (1.45 mg/dL), aspartate transaminase (165.03 International units per litre (IU/L)), alanine transaminase (64.98 IU/L) and total leucocyte count (TLC) (9.22 thousands/µL) were recorded on the 28th day of the experiment. The thiobarbituric acid-reactive substances (TBARS) test to determine malondialdehyde (MDA) was conducted to assess lipid peroxidation and cell damage. The relative reduction in MDA levels with an increase in curcumin concentration was evinced and the lowest MDA levels in the livers and kidneys of the mice in Group 5 were 3.47 and 6.04 nanomoles per gram (nmol/g) respectively, exhibiting the highest ameliorative effect of the product. These findings indicate that tray-dried raw turmeric-based curry powder prepared from genotype LTS-2 has antioxidant, hepatoprotective and nephroprotective potential, with possible immunomodulatory benefits. The product also shows potential for value addition in turmeric processing and further commercial exploration.

Keywords: antioxidant activity; *in vivo* evaluation; nutrient composition; rodent model

Received: 22 July 2026. **Accepted:** 22 September 2026. **Available online:** Version 1.0: 18 November 2026.

Cite this article: Pallavi SPC, Tanuja PB, Sailaja V, Giridhar K, Sudha VV, Vijaya KA, Sravathi V. Nutritional profiling of turmeric rhizomes and development of a ready-to-mix curry powder. Plant Science Today. 2026;XX(X):1-XX. https://doi.org/10.14719/pst.16936

1. Introduction

India holds a leading position in the global turmeric market, accounting for nearly 80 % of the share, driven by its high levels of production, domestic consumption and exports. The latest agricultural data reveals that the area under turmeric cultivation is 2.91 lakh hectares, yielding 1.116 million tonnes with a productivity of 3835 kg/ha (1). Bangladesh, the United Arab Emirates (UAE), the United States, Malaysia, Morocco and Iran are the top turmeric-importing countries from India. The value of this versatile crop lies predominantly in its rhizome, containing curcumin, which imparts a distinctive golden-yellow colour. Recent advancements in turmeric research have concentrated on enhancing curcumin and its properties. Scientists have explored innovative methods, leveraging metal ions like copper (Cu), zinc (Zn), magnesium (Mg), aluminium (Al) and iron (Fe) in conjunction with palygorskite, to intensify rhizome colour and boost its stability for enhancing medicinal properties (2). Turmeric plays a significant role in human health and offers considerable potential for promoting optimal health, longevity and quality of life. It has also been utilised for ages in Ayurvedic

medicine, which integrates herbal therapies with dietary intervention. *Curcuma longa* L. rhizomes have been widely utilised in the traditional systems of medicine in India, Japan, China and Southeast Asian countries. It has demonstrated potential for antidiabetic, anticarcinogenic, antimicrobial, anti-human immunodeficiency virus (HIV), hepatoprotective and ophthalmological treatment. Additionally, turmeric flowers are used traditionally to treat gonorrhea. The powder of turmeric rhizomes has a wound-healing effect, a protective effect on the human intestine, prevents ulcer formation, promotes bile flow, bile acid secretion and mucus content of gastric juice.

Curcumin is also a powerful antioxidant, helping to neutralise free radicals and reduce oxidative stress in the body. Turmeric is commonly used in its powdered form for culinary applications, while raw turmeric is increasingly acknowledged for its superior antioxidant properties compared to dried turmeric (3). This antioxidant activity contributes to the potential role of turmeric in preventing chronic diseases and promoting overall health. Turmeric and its primary bioactive compound curcumin are known to possess a claimed limited oral bioavailability in mice, rabbits and humans. However, it is proven to increase the efficiency of absorption when supplemented with other spices such as coriander, cumin, black pepper and red chilli (4). Further, following the COVID-19 pandemic, immunity-enhancing products have become of high interest amongst consumers. Therefore, there is a growing demand for novel raw turmeric formulations that are nutritious with extended shelf life, immunity-enhancing and beneficial for people. As global interest surges in health-promoting ingredients, turmeric emerges as a cornerstone in the pursuit of natural, beneficial products that are poised to meet diverse consumer demands. Furthermore, identifying promising turmeric genotypes, rich in curcumin, antioxidants and other optimal nutrients, is also very essential for developing functional products to enhance immunity. Turmeric-based products are mostly conventional turmeric powder or extract. The need for a standardised ready-to-use curry mixture made from raw turmeric and maintaining functional properties is less explored. Mixing raw turmeric with various other common kitchen spices may make the mixture more palatable and offer diverse phytochemicals. Nevertheless, the antioxidant/nutritional value and biological activities of such a mixture must be analysed. Hence, there arises a need for nutritional profiling of raw turmeric and formulating a ready-to-use curry powder with its biological/antioxidant value. Hence, this study focuses on identifying a curcumin-enriched genotype with optimal nutrients and high antioxidant content in both dry and fresh rhizomes, as well as developing a novel product tailored to contemporary needs, particularly for those seeking immune-enhancing solutions suitable for busy lifestyles.

2. Materials and Methods

Experimental site

Ten genotypes with optimal nutrient profiles and high antioxidant capacity were selected from 75 genotypes based on their favourable positioning along both principal components. Genotypes LTS-2, LTS-6, LTS-9, LTS-10, LTS-13, LTS-18, LTS-27, LTS-31, LTS-33 and LTS-81 were identified as promising genotypes possessing desirable nutritional and quality attributes. These genotypes were therefore selected for further investigation, planted under completely randomised design with 3 replications and used for the present study. Fresh rhizomes of the elite 10 genotypes were harvested at the maturity stage and nutrient profiling, curcumin and antioxidant activity were conducted at the Horticultural Research Station, Lam, Guntur District, Andhra Pradesh during the year 2022–23. It has an average rainfall of 900 mm at an altitude of 34 m (112 feet) above mean sea level and is located at 16.83 °N latitude and 81.5 °E longitude. During the study period, the average maximum and minimum temperatures were 32.94 and 23.41 °C respectively, while the average maximum and minimum relative humidities were 95.89 and 61.92 % respectively. The overall mean temperature and relative humidity were 28.17 °C and 78.90 % respectively. Subsequently, one elite genotype was used for product preparation and subsequent *in vivo* evaluation (Supplementary Tables 1–13).

Experimental materials

Turmeric raw rhizomes

The turmeric rhizomes under study were collected from the Permanent Repository block of AICRP on Spices, Horticultural Research Station, Lam Farm, Guntur. The Raw turmeric rhizomes were crushed using a mortar and pestle and used for analysis.

Nutrient profiling in fresh rhizomes

Total carbohydrates (%)

Dried turmeric powder sample of 100 mg was carefully weighed into a boiling tube and 5 mL of 2.5 N hydrochloric acid (HCL) was added. Samples were hydrolysed by incubating in a boiling water bath for 3 hr and then the tubes were brought to room temperature. Solid sodium carbonate was added to these tubes to neutralise until the effervescence ceased, then the volume was made to 100 mL with distilled water. An aliquot of 0.1 mL of this was taken for analysis and 0, 0.2, 0.4, 0.6, 0.8 and 1 mL of the working standards were taken in separate tubes, of which “0” served as the blank. Volume was made to 1 mL in all these tubes, including the sample tube, by adding distilled water. 4 mL of anthrone reagent was added to these tubes. The tubes were then incubated for 8 min in a boiling water bath, followed by cooling. Immediately after cooling, the absorbance of the contents at 630 nm was measured with a ultraviolet–visible (UV-VIS) spectrophotometer (Labindia analytical, Model: 3200). A standard curve was drawn

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by plotting the concentration of glucose on the X-axis and absorbance of standards at 630 nm on the Y-axis. Total carbohydrates content of the sample was determined by using the standard curve and expressed as milligram per gram (mg g^{-1}). The value obtained was converted and presented as a percentage (5).

Crude protein (%)

Finely ground sample (0.5 g) was digested with a minimum volume of conc. sulphuric acid (H_2SO_4) using hydrogen peroxide (H_2O_2). The digested sample was used to estimate nitrogen (N) by the Kjeldahl method. Percent N was multiplied by 6.25 to obtain percent crude protein (6).

Crude fibre and ash (%)

Two grams of powdered sample were weighed and transferred to the spoutless 1-L beaker and 200 mL of 1.25 % (w/v) H_2SO_4 was added. The beaker was then put on the hot plate. The mixture was reflexed for 12 hr and the contents were shaken every 5 min. Boiling was performed for 30 min and first the beaker was removed from the hot plate, then filtration was performed using a muslin cloth through suction. The residue was washed properly with boiling water so that it became totally free from acid.

Then the material and 200 mL of 1.25 % sodium hydroxide (NaOH) solution were transferred to the same beaker and the contents were washed with hot water so that they became free from alkali, but initially the material was filtered again through a muslin cloth with the help of a vacuum pump. After transferring the residue to a crucible, it was dried in a hot air oven at 80–110 °C until it reached a constant weight and the weight (w1) was recorded. The residue was ignited in a muffle furnace at 550–660 °C for 2–3 hr, then cooled and the weight (w2) was noted. The weight of crude fibre was the weight loss due to ignition (7). The per cent crude fibre in the ground sample was calculated using the formula:

$$\text{Crude fibre content (\%)} = \frac{W1 - W2}{Original\ weight\ of\ sample} \times 100$$

where,

w_1 = Weight of crucibles along with the sample after drying in oven

w_2 = Weight of crucibles along with the sample after ashing in muffle furnace

Ash content was determined from the crude fibre analysis.

$$\text{Ash (\%)} = \frac{W3 - W2}{weight\ of\ sample} \times 100$$

where,

w_3 = Weight of empty crucibles

w_2 = Weight of crucibles along with the sample after ashing in muffle furnace

Nitrogen (%)

Total N in plant samples is commonly determined by the Kjeldahl method (6).

Wet oxidation of plant material for minerals (phosphorus, potassium, calcium, magnesium, zinc, iron, manganese and copper)

0.5 g sample of powdered plant sample was taken in a 100 mL conical flask and digested with a di-acid mixture (nitric acid (HNO_3) and perchloric acid ($HClO_4$) in a 9 : 4 ratio). The sample digest was filtered through Whatman No. 42 filter paper by washing the residue with double distilled water till it was chloride-free and the volume was made up to 50 mL and the clear extract was used for the determination of phosphorus (P), potassium (K), calcium (Ca), Mg, Zn, Fe, manganese and Cu (8).

Phosphorus (%)

Phosphorus in the diacid extract of plant samples was estimated by the vanadomolybdophosphoric acid yellow colour method using a spectrophotometer at a wavelength of 420 nm (9).

Potassium (%)

Potassium in the diacid extract of plant samples was determined using a flame photometer (9).

Calcium and magnesium (%)

Calcium and Mg in the diacid extract of plant samples were estimated by ethylenediaminetetraacetic acid (EDTA) complexometric titration (10).

Sulphur (%)

Sulphur (S) was determined turbidimetrically using a known quantity of the diacid-digested plant extract. Turbidity developed by barium chloride ($BaCl_2$) was measured spectrophotometrically at a wavelength of 420 nm (11).

Micronutrients (mg/100 g)

Zinc, Fe, Mn and Cu in the diacid extract were determined using an atomic absorption spectrophotometer (12). Micronutrients were expressed as parts per million (ppm). The ppm values were converted and presented as milligram per 100 gram (mg/100 g).

Curcumin content (%)

The curcumin content of each sample was measured by a spectrophotometric method. Exactly 10 mg of turmeric powder was taken in a 10 mL volumetric flask and methanol was added to make the concentration up to 1000 ppm. Later, 1 mL of sample solution was taken in a 5 mL volumetric flask and the concentration was made to 200 ppm by adding methanol. This sample solution was taken in a cuvette and the absorbance was read at 425 nm using a UV spectrophotometer (Shimadzu, Model No. UV1800ENG240V, SOFT).

For the preparation of the standard curve of curcumin, 10 mg of standard curcumin (Hi Media)

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was dissolved in 10 mL of methanol. Solutions of different concentrations (2 ppm, 4 ppm, 6 ppm, 8 ppm and 10 ppm) were prepared from the stock solution. The absorbance value of these standard solutions at 425 nm was recorded by a UV spectrophotometric method and plotted on the graph (13).

Curcumin content (%) =

$$\frac{0.0025 \times A425 \times volume\ made\ up \times dilution\ factor}{0.42 \times weight\ of\ the\ sample(g) \times 1000} \times 100$$

Extract preparation for antioxidant activity

Two grams of sample were homogenised with 20 mL of methanol (80 %) in a mortar and pestle for 2–3 times. The extracts were pooled and the volume was made up to 50 mL. This extract was used for further analysis of total antioxidants.

Antioxidant activity (DPPH activity (%))

2,2-diphenyl-1-picrylhydrazyl (DPPH) was used as a source of free radicals. A quantity of 3.9 mL of 6 × 10^{-5} mol/L DPPH in methanol was put into a cuvette with 0.1 mL of the above sample extract and the absorbance was measured at 515 nm after 30 min with methanol as the blank (14). Antioxidant activity was calculated using the following equation:

$$\text{Antioxidant activity (\%)} = \frac{Ab(B) - Ab(S)}{Ab(B)} \times 100$$

where,

Ab (B) = Absorbance of blank and Ab (S) = Absorbance of sample

Standardisation and design of nutrient rich fresh/raw turmeric-based curry and curry powder

Considering the antioxidant potential, fresh rhizomes were chosen for product design. The genotype with high/optimum macro- and micronutrient, proximate and secondary metabolite contents was selected and used to prepare a nutrient-rich raw turmeric-based curry and curry powder. A total of 6 treatments with varied concentrations of raw turmeric, viz., 0 (control), 25, 50, 75, 100 and 125 g, in combination with common base (CB: ginger (27.3 g) + black pepper seeds (0.5 g) + cumin seeds (2.4 g) + coriander seeds (2.7 g) + curry leaves (1.1 g) + tamarind (19.3 g) + dry red chillies (3.7 g) + salt (7.7 g) + water (200 mL (d = g/mL)) + oil (20 mL (d = 0.92 g/mL)) were evaluated to standardise the formulation of a nutrient-rich raw turmeric-based curry and standardised. Organoleptic evaluation was conducted for 6 treatments with a panel of 10 semi-trained judges. The sensory characteristics, viz., colour, taste, flavour, texture, mouth feel and overall acceptability, were evaluated on a 9-point hedonic scale. The sensory evaluation was conducted using a panel of 10 semi-trained judges who were familiar with sensory evaluation of food products. The panellists were selected based on their willingness to participate and their ability to perceive and discriminate differences in sensory attributes. Prior to evaluation, the panellists were informed about the 9-point hedonic scale and the sensory attributes to be assessed. The six curry formulations were presented to the panellists using coded samples and the order of sample presentation was randomised to minimise order and carry-over effects. The samples were evaluated under standardised conditions, with panellists instructed to assess colour, flavour, taste, texture, mouthfeel and overall acceptability independently using the 9-point hedonic scale. The sensory scores were subjected to analysis of variance (ANOVA) according to the experimental design, with significance assessed at $p \leq 0.05$. Curcumin and antioxidant activity were also analysed.

Following standardisation, the optimised formulation was dehydrated to powder using a tray dryer and a freeze dryer to yield curry powder. Tray drying was performed at 60 °C for 8 hr by uniformly spreading the curry mixture on Al trays and placing them in a tray dryer. Freeze drying was carried out using a DELVAC DD-12 freeze dryer. The freeze-drying process involved two sequential stages: (i) a freezing stage, in which the product was frozen at −41 °C for 24 hr under atmospheric pressure, followed by (ii) a vacuum-drying stage, in which vacuum was applied and the temperature was controlled to facilitate moisture removal. During freeze drying, the chamber temperature was maintained at −21 °C and the vacuum pressure was maintained at 0.120 millibar (mbar). The final water activity values of the tray-dried and freeze-dried curry powders were 0.25 and 0.13 respectively. Sensory evaluation was conducted to identify and promote the best treatment with strong feasibility for *in vivo* evaluation.

***In vivo* biological efficacy assessment**

In the present study, Swiss albino male mice (SAMM), aged 6–8 weeks and weighing 20–25 g, with a total of 30 mice (6 mice per group), were procured from Jeeva Life Sciences, Hyderabad and classified into five groups, viz., G1: control, G2: 250 mg/kg body weight (b.wt.) of folic acid administered intraperitoneally (IP) on the first day, G3: G2 + 3 mg curcumin equivalent product (CEP)/kg b.wt., G4: G2 + 5 mg CEP/kg b.wt. and G5: G2 + 7 mg CEP/kg b.wt. Mice were injected with folic acid as a toxin and then the curry powder was administered orally by gavage daily for 28 days. The curcumin in the curry powder was quantified and it was found that it was 1 % in the tray-dried curry powder. It was converted into the administered doses (3, 5 and 7 mg/kg). The dosage was fixed based on the guidelines of the European Food Safety Authority, which concluded that the acceptable daily intake of curcumin is 3 mg/kg body weight per day for curcumin-based products (15) and consumption of 900 mg/day of curcumin is an acceptable daily intake (16). The efficacy of the product was subsequently evaluated for its capacity to alleviate toxin-induced effects. The study was

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conducted in a completely randomised design with 4 replications. The mice were housed in solid-bottom polypropylene cages at the laboratory animal house facility in the College of Veterinary Science (C. V. Sc.), Rajendranagar and maintained in a controlled environment (20–22 °C) throughout the course of the experiment. The experimental protocol was approved by the Institutional Animal Ethics Committee, C. V. Sc., Rajendranagar, Hyderabad (22/26/C.V.Sc, HYD. IAEC).

The observations on the body weights were recorded on the 7th, 14th, 21st and 28th days of the experiment, by using an electronic balance. Six mice from each group were sacrificed on the 29th day of the experiment and were subjected to necropsy examination. Prior to blood collection, the selected experimental mice were fasted for 12 hr prior to blood collection.

Haematology

Collection of blood for haematological parameters

Six mice from each group were sacrificed on 29th day of experiment. On the day of sacrifice, 0.5 mL of blood was collected from retro-orbital plexus with the help of capillary tube into an anticoagulant coated vaccutainers {(K3- EDTA tube, 13 mm × 75 mm, 4 mL (Rapid Diagnostics Pvt. Ltd., Delhi)} to carry out all hematological parameters. Prior to blood collection, the selected experimental rats were fasted for 12 hr. All the blood samples were used for estimation of total erythrocyte count (TEC-Millions/µL), total leukocyte count (TLC-Thousands/µL), hemoglobin (Hb-g per cent), packed cell volume (PCV) and platelets concentration by using automatic whole blood analyser (huma count, Med Source Ozone Biomedical Pvt. Ltd., Faridabad, Haryana) and results were tabulated for statistical analysis.

Serum biochemistry

Collection of blood for serum biochemical profile

Approximately, 1 mL of blood was collected from each mouse (retro-orbital plexus) through capillary tube into a plain serum vacutainer (BD vacutainer) and allowed to clot for 3–4 hr, later centrifuged (REMI COOLING CENTRIFUGE C-24 BL, a bench top laboratory centrifuge, India) at 4500 revolutions per minute (rpm) for 10 min (min), serum was separated into Eppendorf tubes and stored at -20 °C. The stored samples were used for serum biochemistry by using semiautomatic enzyme-linked immunosorbent assay (ELISA) reader (Multiskan GO Microplate (ELISA) Spectrophotometer, Thermo scientific, USA) by using Erba mannheim biochemical kits (Transasia Biomedicals Ltd., Solan, Himachal Pradesh, India). Alanine aminotransferase **(**ALT) and aspartate aminotransferase (AST) were estimated as per modified International Federation of Clinical Chemistry (IFCC) method; serum creatinine was measured by modified Jaffes reaction as per alkaline picrate techniques, serum total protein (TP) as per the standard Biuret procedure, serum albumin, evaluated by bromocresol green albumin (BCG) dye method by using Erba albumin assay kit (Erba diagnostics Mannheim GmbH, Mumbai), blood urea nitrogen (BUN) as per glutamate dehydrogenase (GLDH) - urease method, Alkaline phosphatase (ALP) were procured from Erba diagnostics by using ELISA kit, USA.

Necropsy observations

Experimental mice were sacrificed by cervical disarticulation after collection of blood and a detailed necropsy examination was carried out as per standard procedure suggested by Feinstein (2000). Small slices of respective tissue samples were collected for histopathology in suitable preservatives-10 % neutral buffered formalin (NBF). Small pieces of target tissues were also collected in liquid N and stored at -20 °C to study the organ antioxidant profiles (glutathione (GSH), superoxide dismutase (SOD) and thiobarbituric acid-reactive substances (TBARS)).

Tissue antioxidant profiles

Tissue homogenate preparation

One gram of tissue sample with 10 mL of 0.2 M Tris HCl buffer (pH 7.2) was taken into a tissue homogeniser to get 10 % homogenate to carry out all the tissue (liver and kidney) antioxidant parameters. The tissue oxidation was measured by the reaction of the lipid peroxidation (LPO) end products like MDA with TBARS, tissue protein, reduced GSH and activity of SOD to know the antioxidant status.

Thiobarbituric acid reactive substances

Thiobarbituric acid reactive substances (TBARS) were estimated by homogenising 1 g of tissue sample with 10 mL of 0.2 M Tris-HCl buffer (pH 7.2) using a tissue homogeniser to prepare a 10 % homogenate. Subsequently, 500 µL of the homogenate supernatant was mixed with 1 mL of 10 % trichloroacetic acid (TCA) and 1 mL of 0.67 % thiobarbituric acid (TBA) in a tightly stoppered tube. The mixture was heated at boiling temperature for 45 min and then allowed to cool to room temperature. The cooled mixture was centrifuged and the absorbance of the resulting supernatant was measured at 532 nm against an appropriate blank. The TBARS concentration was calculated using the molar extinction coefficient of MDA.

Calculation:

$$\underset{(\text{MDA})}{\mu\text{M}} = \frac{2 \times \text{volume of sample taken} \times \text{absorbance of sample}}{1.56 \times 10^5 \times \text{mg of tissue}} \times 10^9$$

Units of activity = µM of MDA/mg of tissue.

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Reduced glutathione

To 400 µL of homogenate, 100 µL of 25 % TCA was added and centrifuged. The Supernatant was collected and used as a sample. To the 0.1 mL of sample, 2.0 mL of 0.6 mM DTNB in 0.2 M sodium phosphate (pH 8) and 0.9 mL of 0.2 M phosphate buffer was added and the absorbance was recorded at 412 nm against a reagent blank. The standards (0.05–5 mg/mL) were also treated by the same procedure.

Calculation:

$$= \frac{\text{Absorbance of sample}}{\text{Absorbance of standard}} \times \frac{\text{Concentration of standard}}{\text{mg of protein}}$$

The values were expressed as µM GSH/ mg of protein.

Superoxide dismutase

The reagents were added to the sample, control and the blank as shown below. The absorbance was read at 570 nm against distilled water (DW) (blank). The sample, control and blank were incubated for 5 min at room temperature.

Calculation:

Superoxide dismutase was expressed as SOD units/ mg of protein

$$Y\ \% = \frac{\text{OD of test}}{\text{OD of standard}} \times 100$$

$$SOD = \frac{\text{mg of protein in 0.01 mL homogenate}}{Y\ \%} \times 50 \times 10$$

Statistical analysis

Principal component analysis (PCA) was conducted using software R 4.5.1. All other analyses, viz., descriptive statistics, perse mean performances and correlation studies were conducted using software Windostat 9.50. The experimental data were analysed using analysis of variance (ANOVA) appropriate to the experimental design followed in each experiment. Data obtained from experiments conducted under randomised block design (RBD) were analysed considering treatments and replications as the respective sources of variation, whereas data from experiments conducted under completely randomised design (CRD) were analysed according to the corresponding CRD model. Means were taken for the comparison and interpretation of results. The data from the nutrient profiling, product formulations, oxidative stress indices, total antioxidant activity, serum biochemical parameters and haematological parameters were subjected to analysis in CRD. Changes in body weights of the *in vivo* study were subjected to analysis in factorial completely randomised design (FCRD). Treatment effects were tested at the 5 % level of significance ($p \leq 0.05$). No separate post-hoc pairwise comparison test was performed. Accordingly, the statistical interpretation of treatment effects was based on the ANOVA results.

3. Results and Discussion

Principal component analysis for 75 genotypes to select top 10 elite genotypes

Principal component analysis (PCA) was employed to elucidate the complex relationships among the multiple biochemical traits and to reduce the dimensionality of the dataset. The PCA was conducted using 75 genotypes based on 16 biochemical traits. Seven principal components (PCs) exhibited eigenvalues ≥ 1 and collectively accounted for 73.43 % of the total variation. PC1 explained the largest proportion of variation (19.88 %), followed by PC2 (12.91 %), PC3 (10.98 %), PC4 (8.54 %) and PC5 (7.79 %). The distribution of genotypes based on the first two PCs was illustrated using a biplot, with PC1 represented on the x-axis and PC2 on the y-axis (Fig. 1). The contribution of individual PCs to the total variance was further depicted through a scree plot, which showed a progressive decline in the percentage of variation explained by successive components (Fig. 2). The factor-loading analysis revealed distinct contributions of the biochemical traits across the PCs. PC1 showed positive loadings for K, P, Ca, Mg, N, antioxidant activity, curcumin, protein and crude fibre (%), as well as Zn, Fe and Mn (mg/100 g), whereas S, carbohydrates, ash (%) and Cu (mg/100 g) exhibited negative loadings. In PC2, N, antioxidant activity, curcumin, protein and ash (%) showed negative loadings, while the remaining traits contributed positively. Together, PC1 and PC2 accounted for 32.79 % of the total variation. Based on their favourable positioning along both PCs, genotypes LTS-2, LTS-6, LTS-9, LTS-10, LTS-13, LTS-18, LTS-27, LTS-31, LTS-33 and LTS-81 were identified as promising genotypes possessing desirable nutritional and quality attributes. These genotypes were therefore selected for further investigation. Similar findings have been previously reported (17).

Nutrient profiling in fresh rhizomes

Correlation studies revealed a highly significant and positive association of 95.37 % for antioxidant content and 93.45 % for curcumin content between dry and fresh turmeric rhizomes. Furthermore, the antioxidant potential was found to be comparatively higher in fresh rhizomes than in dry rhizomes (Fig. 3). Data pertaining to the proximate composition, mineral content and secondary metabolites of the elite ten fresh turmeric rhizome genotypes are presented in Table 1. Significant variation was observed among the genotypes for the evaluated nutritional and bioactive constituents. Among the proximate constituents, the significantly highest carbohydrate content was recorded in LTS-2 (9.33 %), while the highest protein content was observed in LTS-6, LTS-18, LTS-10 and

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LTS-13 (2.63 %). The highest crude fibre content was recorded in LTS-13 (1.22 %), whereas LTS-31 exhibited the significantly highest ash content (0.62 %). Similar variability in the proximate composition of fresh turmeric rhizomes has been reported (18), with approximately 9.10 % carbohydrate, 1.20 % protein, 0.72 % crude fibre and 0.66 % ash being recorded in fresh turmeric rhizomes. The carbohydrate and ash values observed in the present genotypes were therefore comparable with the values reported previously, whereas the higher protein and crude fibre contents recorded in some of the present genotypes indicate the possibility of genotype-specific differences in nutrient accumulation.

Table 1. Analysis of 16 biochemical traits in raw/fresh rhizomes of elite 10 turmeric genotypes

Sl. No.	Genotype	Carbs (%)	CP (%)	CF (%)	Ash (%)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Zn (mg/ 100 g)	Fe (mg /100 g)	Mn (mg/ 100 g)	Cu (mg/ 100 g)	Cur (%)	AA (%)
1	LTS-2	9.33	2.33	0.92	0.53	0.37	0.05	0.50	0.16	0.29	0.14	0.23	8.31	2.78	0.26	1.25	87.68
2	LTS-6	9.14	2.63	0.77	0.60	0.42	0.04	0.51	0.32	0.10	0.15	0.23	8.35	2.73	0.31	1.10	84.72
3	LTS-9	9.09	2.19	1.13	0.60	0.35	0.03	0.43	0.24	0.05	0.05	0.22	8.26	2.69	0.21	1.23	86.50
4	LTS-10	9.08	2.63	0.70	0.58	0.42	0.03	0.53	0.24	0.14	0.12	0.21	8.29	2.68	0.22	1.22	86.05
5	LTS-13	8.78	2.63	1.22	0.61	0.42	0.05	0.46	0.24	0.24	0.02	0.22	8.32	2.75	0.19	1.25	86.76
6	LTS-18	8.62	2.63	0.81	0.57	0.42	0.06	0.49	0.16	0.10	0.10	0.22	8.25	2.70	0.17	1.17	85.27
7	LTS-27	8.88	2.19	0.87	0.59	0.35	0.03	0.47	0.16	0.11	0.13	0.21	8.30	2.65	0.13	1.28	87.83
8	LTS-31	9.17	1.75	0.75	0.62	0.28	0.02	0.44	0.13	0.10	0.11	0.20	8.27	2.64	0.13	1.14	85.61
9	LTS-33	9.28	1.88	1.06	0.56	0.30	0.05	0.55	0.16	0.19	0.13	0.21	8.33	2.66	0.28	1.15	84.90
10	LTS-81	9.03	1.31	0.81	0.56	0.21	0.04	0.45	0.32	0.14	0.08	0.22	8.37	2.71	0.11	1.12	84.56
	SEM±	0.55	0.07	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.00	0.01	0.12	0.11	0.07	0.01	0.09
	C.D. at 5 %	1.62	0.20	0.02	0.04	0.03	0.00	0.02	0.03	0.01	0.01	0.03	0.34	0.33	0.20	0.01	0.25

Carbs: carbohydrates; CP: crude protein; CF: crude fibre; N: nitrogen; P: phosphorous; K: potassium; Ca: calcium; Mg: magnesium; S: sulphur; Zn: zinc; Fe: iron; Mn: manganese; Cu: copper; Cur: curcumin; AA: antioxidant activity.

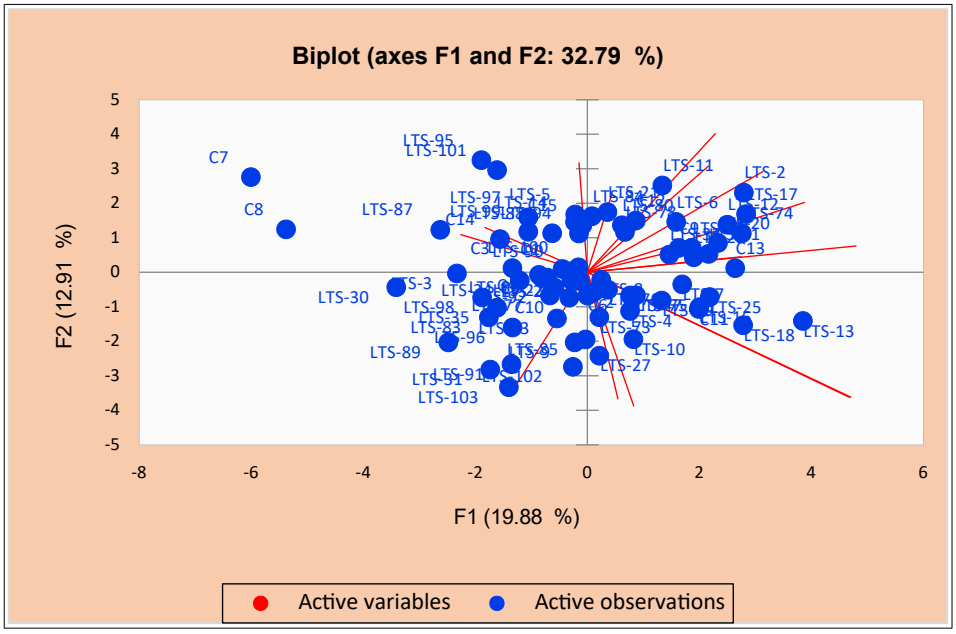


Fig. 1. Biplot of the first two principal components (PCs)- based on 16 biochemical characters in dry rhizomes of 75 turmeric genotypes.

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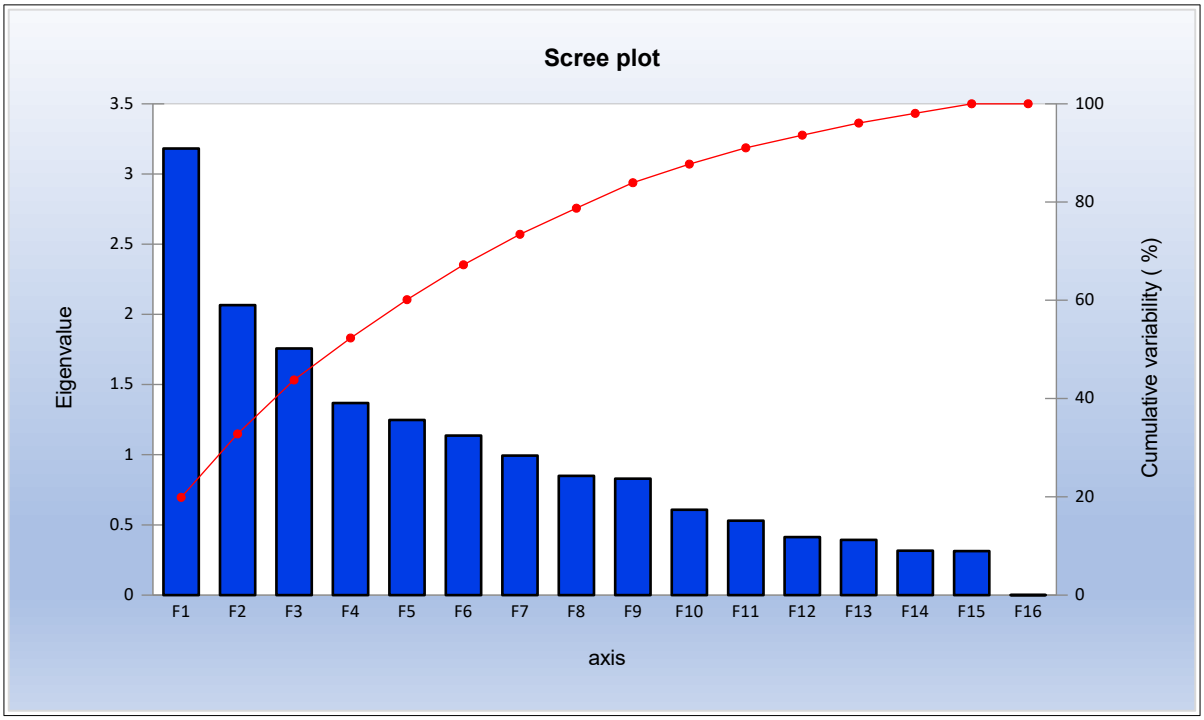


Fig. 2. Scree plot for studied traits of 75 turmeric genotypes.

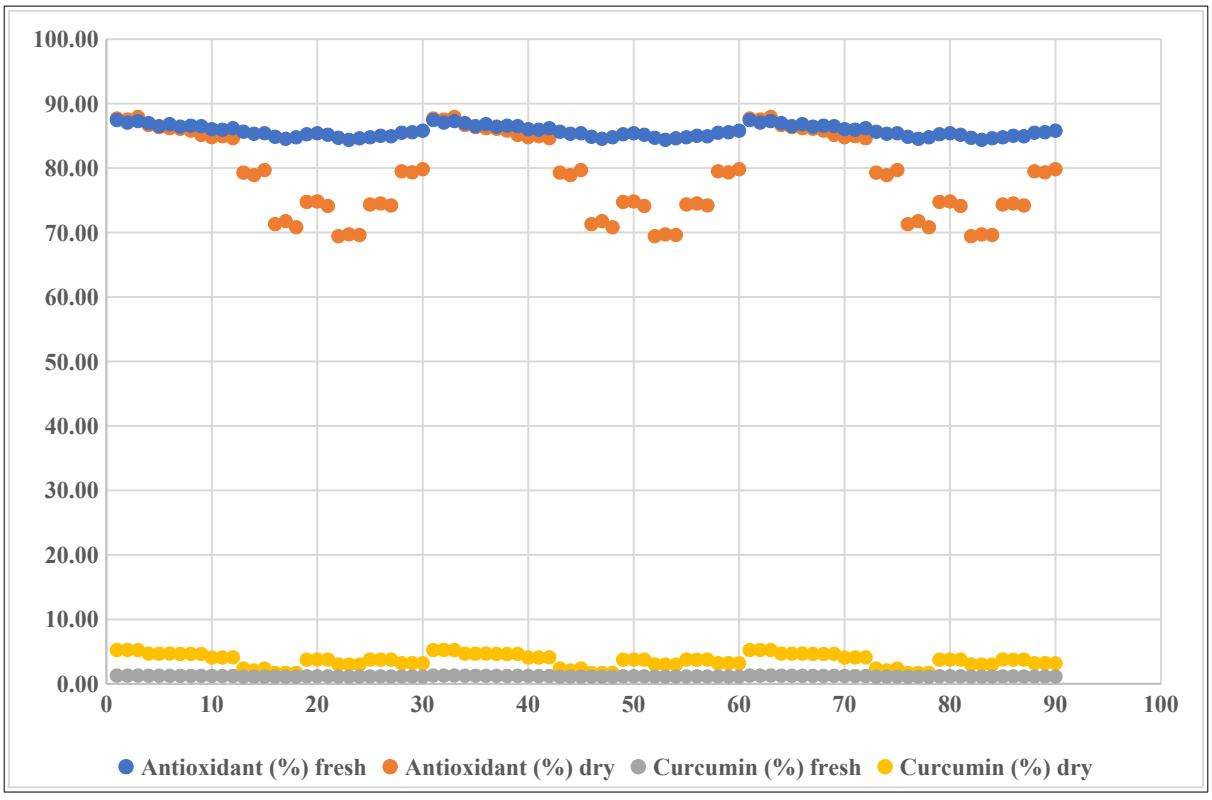


Fig. 3. Scatter diagram representing the correlation of fresh and dry rhizomes in 75 samples of turmeric for antioxidant and curcumin percentage.

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With respect to the primary macronutrients, the highest N content was recorded in LTS-18, LTS-13, LTS-10 and LTS-6 (0.42 %), while the significantly highest P and K contents were observed in LTS-18 (0.06 %) and LTS-33 (0.55 %), respectively. Among the secondary macronutrients, LTS-6 and LTS-81 recorded the significantly highest Ca content (0.32 %), while LTS-2 exhibited the highest Mg content (0.29 %). The significantly highest S content was recorded in LTS-6 (0.15 %).

Regarding micronutrients, the significantly highest Zn content was observed in LTS-6 and LTS-2 (0.23 mg/100 g), whereas LTS-81 recorded the highest Fe content (8.37 mg/100 g). The significantly highest Mn content was recorded in LTS-2 (2.78 mg/100 g), while LTS-6 exhibited the highest Cu content (0.31 mg/100 g). Variation was also observed for mineral composition, with different genotypes exhibiting superior values for N, P, K, Ca, Mg, S, Zn, Fe, Mn and Cu. Such differences may arise from genetic variation among genotypes as well as differences in nutrient uptake and translocation. The identification of genotypes combining desirable levels of several nutritional constituents is therefore important for nutritional profiling and selection of suitable raw material for value-added product development.

Among the secondary metabolites, the significantly highest curcumin content was recorded in LTS-27 (1.28 %), followed by LTS-2 (1.25 %), LTS-13 (1.25 %) and LTS-9 (1.23 %). Similarly, the significantly highest antioxidant activity was recorded in LTS-27 (87.83 %), which was statistically on par with LTS-2 (87.68 %). Varied proximate and mineral composition might be ascribed to G × E interaction. The genetic potential of the genotypes and the growing environment both played a role in the diversity observed among the genotypes. The variation in mineral components among the genotypes could be due to tightly controlled homeostatic mechanisms that modulate metal absorption, translocation and redeployment in plants, allowing adequate accumulation of nutrients in plant tissues. The amount of Fe, Zn and Ca in edible sections also depends on how well minerals are transferred from root tissues to edible plant organs and accumulated therein (19). The effect of drying on the antioxidant potential of turmeric is an important consideration in developing shelf-stable turmeric-based products. In the current study, it is evident that the antioxidant activity in fresh rhizomes was higher when compared to that in dry powder. Similar observations have been previously reported, where the authors reported that the antioxidant activity was higher in the essential oil and oleoresin of fresh rhizomes when compared to dry ones (20). It might be due to the loss of antioxidants during the processing of turmeric, which results in a reduction of medicinal properties in dry powder. Fresh rhizomes have higher antioxidant activity than dried ones (21). Drying reduced the DPPH radical-scavenging capacity of turmeric rhizomes across the four clones evaluated, while the effect on ferrous-ion chelating activity varied among genotypes. The authors suggested that postharvest drying may negatively affect antioxidant constituents present in turmeric rhizomes, although the magnitude of the effect can be influenced by genotype. This may be attributed to the thermal sensitivity of curcuminoids and other antioxidant phytochemicals, together with possible degradation or loss of heat-sensitive constituents during processing (22). Fresh tissue extracts significantly outperformed dry tissue extracts due to Fe chelators in cultivated turmeric rhizomes. In the present study, LTS-2 showed a particularly desirable nutritional profile, with high carbohydrate (9.33 %), Mg (0.29 %) and Zn (0.23 mg/100 g) contents, together with high curcumin content (1.25 %) and antioxidant activity (87.68 %). These characteristics contributed to its selection for subsequent product development.

LTS-2 was selected for product development from the top 10 genotypes based on its overall nutritional and functional profile rather than on the maximum value of an individual trait. The selection considered the combined performance of the genotypes with respect to nutrient composition, curcumin content and antioxidant activity. Although LTS-27 exhibited slightly higher curcumin content (1.28 %) and antioxidant activity (87.83 %), LTS-2 showed a more balanced composition across the evaluated nutritional and bioactive parameters. Therefore, LTS-2 was preferred as a representative genotype with a desirable balance of nutrients, curcumin and antioxidant activity for further product development. No formal multivariate ranking or weighted scoring system was applied; the genotype was selected based on an overall comparative assessment of the measured traits. As a result, fresh rhizomes of LTS-2 with moderate nutritional aspects and high antioxidant capacity were preferred and selected for making raw turmeric-based curry and curry powder in the present investigation.

Design of novel products viz., nutrient rich raw turmeric-based curry and curry powder

The nutrient-rich raw turmeric curry obtained from different formulations of the current study was evaluated for curcumin, antioxidant activity and sensory attributes. The significantly highest curcumin content (0.61 %) was observed in treatment T6 (125 g of turmeric rhizome + CB), followed by treatment T5 (100 g of turmeric rhizome + CB) (0.46 %) and the lowest in treatment T1 (0 g of turmeric rhizome + CB) (0.06 %), as presented in Table 2. Curcumin content ranging from 0.05–0.58 % in different curry powders was reported to be similar to the present study (23). This might be due to the higher quantity of turmeric used in T6 as compared to the rest of the treatments. Turmeric is a rich source of phenolic compounds such as curcumin. Curcumin acts as a good

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antioxidant (24). The significantly highest total antioxidant content was observed as 81.69 % in treatment T6 (125 g of turmeric rhizome + CB), followed by T5 (100 g of turmeric rhizome + CB) (77.25 %) and lowest in treatment T1 (0 g of turmeric rhizome + CB) (71.15 %) as presented in Table 2. This might be due to an increase in curcumin content, which may increase antioxidant activity. As a result, the highest antioxidant activity was recorded in T6 (125 g of turmeric rhizome + CB), which had the highest curcumin content.

The nutrient-rich raw turmeric curry obtained from the different formulations was evaluated for sensory attributes as presented in Table 3. The formulation containing 25 g of fresh turmeric rhizome with the common base (T2) recorded the highest scores for colour (8.5), flavour (8.7), taste (8.9), texture (8.4), mouthfeel (8.6) and overall acceptability (8.8). The superior sensory acceptance of T2 may be attributed to the optimum concentration of turmeric, which imparted a desirable characteristic colour and flavour while maintaining a balanced taste and mouthfeel. With further increases in turmeric concentration, stronger pungency, characteristic flavour and possible astringency of turmeric may have adversely affected sensory acceptance. Similar effects of turmeric concentration on sensory characteristics have been reported and increasing turmeric incorporation influenced the sensory quality and acceptability of the developed product (25). Thus, the present findings suggest that an optimum level of turmeric incorporation is essential to achieve a balance between the nutritional and functional benefits of turmeric and desirable sensory characteristics. The 25 g fresh turmeric + common base formulation was consequently selected as the optimised formulation for further processing into curry powder. Higher concentrations of turmeric might not be liked by sensory panellists due to undesirable colour, taste and astringency (26). Hence, T2 (25 g of turmeric rhizome + CB) got higher scores for sensory qualities. However, contrary to the depiction (27), treatment T6 (125 g of turmeric rhizome + CB) ranked next to T2 because of colour, taste, astringency and spiciness, which might have attracted certain members of sensory panels. Economics of different curry formulations are given in Supplementary Table 14.

The functional significance of curcumin in the developed turmeric-based product is further supported by recent advances in curcumin delivery systems. Casein–curcumin nanodispersions using microfluidisation and nanoprecipitation demonstrated that processing technology influenced particle size distribution, surface charge and curcumin release behaviour. Microfluidisation produced relatively smaller and more uniformly distributed particles, whereas nanoprecipitated nanodispersions exhibited comparatively greater electrostatic stability and a more controlled and sustained release of curcumin in a mango-based beverage. The authors further demonstrated the potential of these curcumin delivery systems as functional food ingredients, highlighting the importance of improving the physicofunctional properties and delivery of curcumin in food matrices (28). In the present study, although no nanoencapsulation or specialised curcumin-delivery technology was employed, the use of fresh LTS-2 turmeric rhizomes provided a naturally curcumin-rich ingredient for the formulation of a ready-to-mix curry. LTS-2 contained 1.25 % curcumin and exhibited high antioxidant activity (87.68 %), while increasing the proportion of turmeric in the formulation increased curcumin content and antioxidant activity, reaching 0.61 % and 81.69 %, respectively, in T6 (125 g turmeric + common base). Thus, the findings provide a contemporary perspective on strategies for improving the functional utilisation and delivery of curcumin, whereas the present study demonstrates an alternative food-based approach through the incorporation of naturally curcumin-rich fresh turmeric into a convenient ready-to-mix curry formulation (28).

The superior treatment comprising 25 g of fresh turmeric rhizome with the CBwas selected for further processing into curry powder. The fresh curry and the tray- and freeze-dried curry powders were evaluated for sensory quality. The tray-dried curry powder recorded the highest scores for flavour (8.5), taste (8.8), mouthfeel (8.3) and overall acceptability (8.7), whereas the freeze-dried product showed higher scores for colour (8.6) and texture (8.4). The better sensory performance of the tray-dried product may be associated with retention of the characteristic flavour and spiciness of the spice ingredients during processing. Both dehydration methods extended the storage stability of the product, with the tray- and freeze-dried curry powders remaining acceptable for 60 days, whereas the fresh curry had a comparatively shorter storage period.

Dehydration is an important preservation approach for converting high-moisture fresh turmeric curry into a shelf-stable product. However, drying and subsequent storage may influence the retention of individual nutrients and bioactive compounds. Dehydrated vegetable, herb and carrot powders could be stored for 60 days, although changes in nutritional constituents occurred during storage were reported (29). In their study, moisture content increased during storage, protein content decreased slightly and substantial losses of ascorbic acid and β-carotene were observed, whereas iron content remained relatively stable. These findings indicate that dehydration can improve the storage stability and convenience of plant-based products, but the stability of individual nutrients depends on their sensitivity to processing and storage conditions. In the present study, the tray- and freeze-dried turmeric curry powders remained sensorially acceptable throughout the 60-day storage period, indicating the practical potential of dehydration for extending the usability of the developed formulation.

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Table 2. Estimation of curcumin (%) and antioxidant activity (% DPPH activity) of raw turmeric-based nutrient rich curry

Treatments	Curcumin (%)	Antioxidant activity (%)
T_1 (0 g of turmeric rhizome + CB)	0.06	71.15
T_2 (25 g of turmeric rhizome + CB)	0.11	72.26
T_3 (50 g of turmeric rhizome + CB	0.20	73.93
T_4 (75 g of turmeric rhizome + CB)	0.32	74.76
T_5 (100 g of turmeric rhizome + CB)	0.46	77.25
T_6 (125 g of turmeric rhizome + CB)	0.61	81.69
SEM±	0.00	0.26
C.D. at 5 %	0.01	0.79

CB: common base (ginger + black pepper seeds + cumin seeds + coriander seeds + curry leaves + tamarind + dry red chillies + salt + water + oil).

Table 3. Organoleptic evaluation of raw turmeric-based nutrient rich curry for consumer acceptability at ambient temperature (based on hedonic scale)

Treatments	Colour	Flavour	Taste	Texture	Mouth feel	Overall acceptability
T_1 (0 g of turmeric rhizome + CB)	7.20	7.60	7.30	7.50	7.20	7.20
T_2 (25 g of turmeric rhizome + CB)	8.50	8.70	8.90	8.40	8.60	8.80
T_3 (50 g of turmeric rhizome + CB	8.20	7.80	7.50	7.90	7.90	7.70
T_4 (75 g of turmeric rhizome + CB)	7.80	8.20	7.80	8.00	7.60	7.90
T_5 (100 g of turmeric rhizome + CB)	7.70	8.50	8.10	8.10	8.30	8.50
T_6 (125 g of turmeric rhizome + CB)	8.30	8.60	8.70	8.20	8.40	8.60
SEM±	0.09	0.07	0.06	0.05	0.07	0.08
C.D. at 5 %	0.28	0.19	0.19	0.16	0.21	0.23

CB: common base (ginger + black pepper seeds + cumin seeds + coriander seeds +curry leaves + tamarind + dry red chillies + salt + water + oil).

The relationship between the curcumin content of the developed product and its biological activity was further examined through *in vivo* evaluation. The tray-dried product was subsequently selected for *in vivo* evaluation based on its sensory acceptability and economic feasibility, with a return per rupee of 1.39 compared with 1.22 for the freeze-dried product (Supplementary Tables 15–22). Thus, tray drying provided a practical balance between product acceptability, storage stability and economic feasibility. The development of this ready-to-mix turmeric-based curry powder also provides an opportunity for value addition and improved availability of turmeric products beyond the fresh-rhizome season. The associated patent for the ready-to-mix raw turmeric-based curry powder was published in The Patent Office Journal No. 23/2024 dated 07/06/2024 (Application number: 202441020964 A), further indicating the product-development potential of the formulation. Drying is an important processing step for converting the fresh turmeric-based curry into a shelf-stable product; however, thermal processing may influence the retention of antioxidant constituents. Thus, the present findings support the use of dehydration for extending the usability of fresh turmeric-based formulations, while emphasising the need for appropriate drying conditions to minimise losses of heat-sensitive antioxidant constituents.

The present study demonstrated that dehydration was effective in converting the fresh turmeric-based curry into a shelf-stable powder while maintaining acceptable sensory quality during the 60-day storage period. Furthermore, this ensures off-season availability of produce and products to stakeholders at reasonable prices. The product contained naturally derived curcumin from LTS-2 turmeric along with bioactive constituents contributed

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by the common spice base. This is relevant because the biological effectiveness of curcumin depends not only on its concentration but also on its stability, delivery and interaction with the food matrix. Recent research demonstrated that the physicochemical characteristics of curcumin delivery systems can influence particle distribution, stability and release behaviour, emphasising the importance of formulation strategies for effective utilisation of curcumin in functional foods (28). In the present study, the curry powder represented a food-based, non-encapsulated approach in which turmeric and commonly used culinary spices were combined into a convenient formulation. The subsequent biological evaluation therefore provided preliminary evidence regarding the antioxidant-related effects of the developed product under the experimental conditions used.

In vivo biological efficacy assessment

The tray curry powder was selected by considering economic feasibility and sensory attributes. It was subsequently evaluated *in vivo* at varied concentrations with respect to curcumin to study the antioxidant activity and therapeutic effects on mice.

Product influence on body weights (g)

The weekly body weights of different groups are shown in Fig. 4A. Group 5 exhibited a significant increase over 28 days (21.8–27.6 g), while Group 2 showed a decrease (24.9 to 21.9 g) in body weight. The percentage increase in body weight for Groups 5, 4 and 3 was 5.8 %, 5.3 % and 3.3 % respectively, compared with 2.4 % in the control. Group 2 showed a 3 % reduction, aligning with previous studies (30). The decrease in Group 2 may be due to folic acid-induced toxicity affecting vital organs, whereas significantly highest mean values in Group 5 could be due to the ameliorative and beneficial effects of curcumin in the product against folic acid-induced toxicity of cells. Curcumin, the principal bioactive polyphenolic compound derived from turmeric, might have emerged as a promising agent in mitigating folic acid-induced toxicity (3).

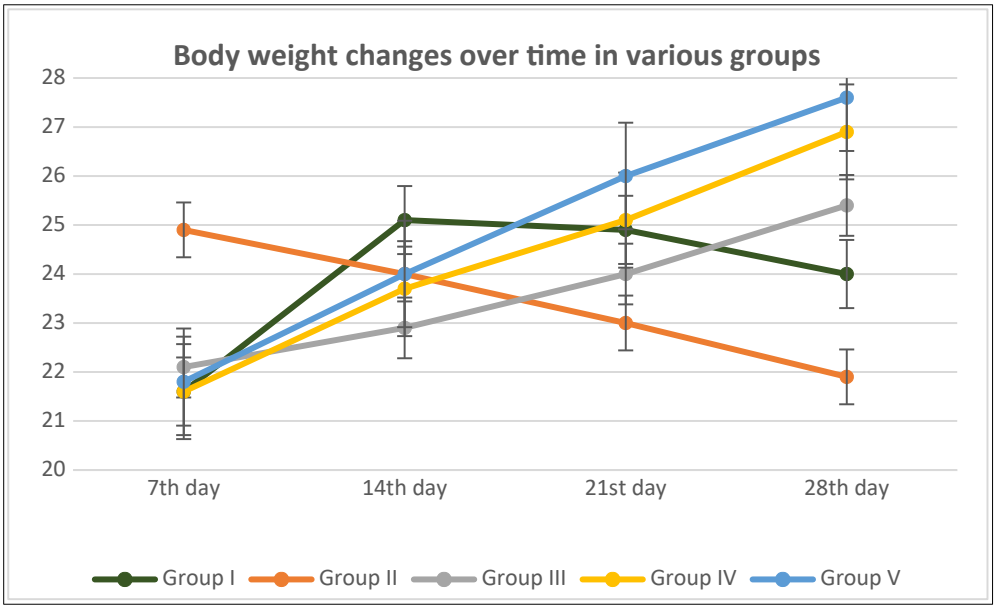
Oxidative stress indices

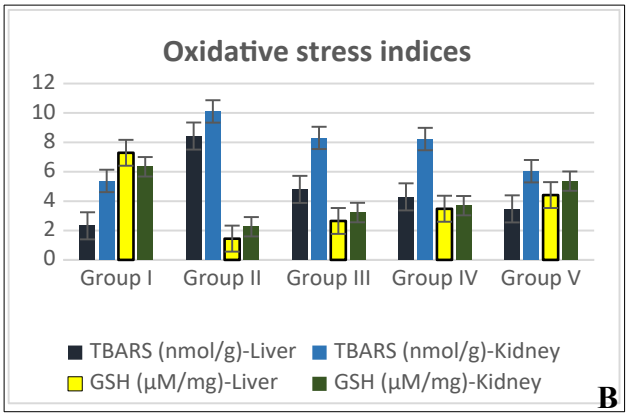
The oxidative stress findings provide further support for the antioxidant potential of the developed turmeric-based curry powder. The observations recorded on the level of TBARS-MDA, reduced GSH and SOD in the liver and kidney on the 28th day of the experiment are presented in Fig. 4B. Folic acid administration resulted in an increase in TBARS-MDA levels and a concomitant decrease in endogenous antioxidant markers, including GSH and SOD, in both liver and kidney tissues. TBARS-MDA levels were significantly elevated in Group 2 for both liver (8.43 nmol/g) and kidney (10.10 nmol/g) compared to controls, while Group 5 showed a significant reduction for both liver (3.47 nmol/g) and kidney (6.04 nmol/g), followed by Groups 4 and 3. Antioxidant markers, specifically GSH (1.45, 2.26 µM/mg) and enzyme SOD (25.15, 26.84 U/mg) levels significantly decreased in the liver and kidney of Group 2 respectively. A significant increase in GSH and SOD was noted in Group 5 (4.41, 5.36 µM/mg and 41.48, 45.53 U/mg) followed by Group 4 and Group 3 in liver and kidney respectively.

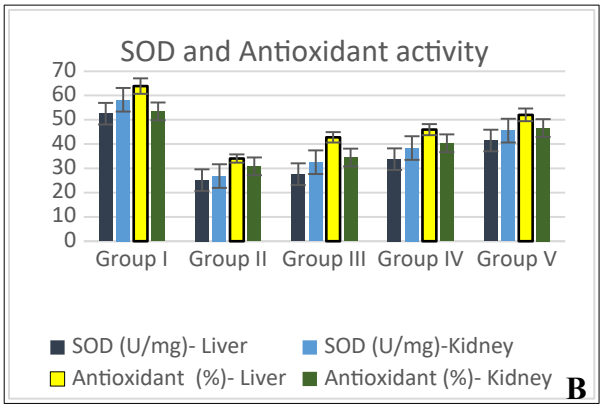
Supplementation with the turmeric-based curry powder progressively reduced MDA levels and enhanced GSH and SOD activities, with the most pronounced response observed in Group 5, which received the product equivalent to 7 mg curcumin/kg body weight. In this group, MDA levels decreased to 3.47 and 6.04 nmol/g in the liver and kidney respectively, while GSH increased to 4.41 and 5.36 µM/mg and SOD to 41.48 and 45.53 U/mg in the respective tissues. These observations are consistent with the established antioxidant role of curcumin and provide biological support for the high antioxidant potential observed in the LTS-2 rhizomes and the formulated product. Importantly, the recent work highlights that curcumin delivery characteristics can be modified through food-compatible technologies such as microfluidisation and nanoprecipitation, with differences in particle characteristics and release profiles influencing its functional utilisation (28). In contrast, the present study focused on a minimally processed, food-based formulation using fresh turmeric and common culinary spices rather than a nano-delivery system. Therefore, the observed antioxidant responses should be interpreted as evidence of the biological potential of the developed formulation under the experimental conditions, while further studies are required to establish curcumin bioavailability, absorption and dose-response relationships.

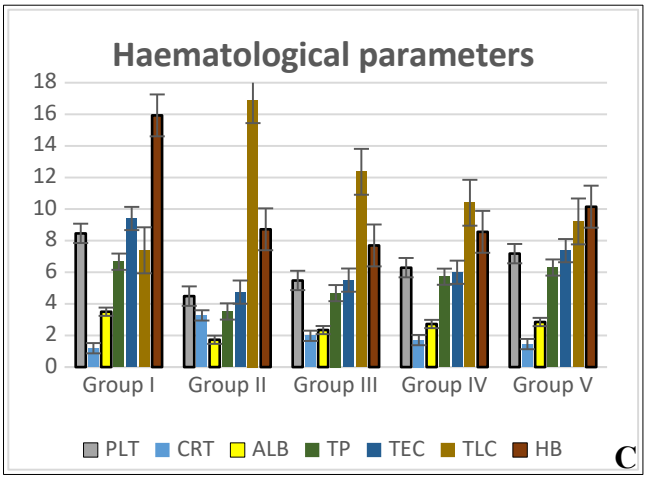
In the present study, administration of folic acid resulted in a significant alteration of the peroxidative status, characterised by increased MDA levels and decreased endogenous antioxidant defences, namely SOD and GSH, in the liver and kidney. Supplementation with the turmeric-based curry powder containing curcumin in Groups 3, 4 and 5 significantly reduced MDA levels and enhanced SOD and GSH concentrations compared with the folic-acid-treated group, indicating an improvement in the antioxidant defence system. The response was more pronounced at the higher curcumin-equivalent dose, suggesting a dose-related protective effect of the turmeric-based formulation. These findings are consistent with the antioxidant activity reported for curcumin, which can attenuate oxidative damage by reducing lipid peroxidation and supporting endogenous antioxidant defences.

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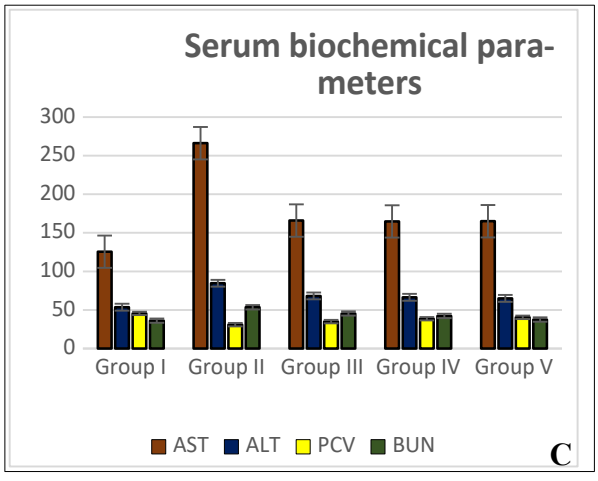


Fig. 4. Dose-dependent effects of curcumin-based product administered to mice. (A) body weight changes over time in various groups; (B) oxidative stress indices (TBARS: thiobarbituric acid-reactive substance, GSH: reduced glutathione, SOD: superoxide dismutase) and total antioxidant activity (%) in liver and kidney on day 28 of the study; (C) haematological parameters and serum biochemical on day 28 of the study. (PLT: platelets (count × 105/ µL); CRT: creatinine (mg/dL); ALB: albumin (g/dL); TP: total proteins (g/dL); TEC: total erythrocyte count (millions/µL); TLC: total leucocyte count (thousands/µL); HB: hemoglobin; AST: aspartate transaminase (IU/L); ALT: alanine transaminase (IU/L), concentration (g %); PCV: packed cell volume (Hematocrit - Hct) (%); BUN: blood urea nitrogen (mg/dL).

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The present findings are further supported by the investigation of the protective effect of curcumin-loaded cockle shell-derived calcium carbonate nanoparticles against lead (Pb)-induced oxidative and tissue damage in rats (31). Their study demonstrated that curcumin treatment attenuated oxidative stress and improved antioxidant defence in the affected tissues, as evidenced by reduced lipid peroxidation and restoration of antioxidant parameters. Although the experimental stressor and curcumin delivery system differed from those used in the present study, both investigations demonstrate a similar response pattern, wherein curcumin supplementation reduced oxidative damage and enhanced endogenous antioxidant defences. The agreement between these findings provides additional support for the potential of curcumin-rich turmeric formulations to modulate oxidative stress. However, the present study evaluated a food-based turmeric curry powder rather than a nanoformulated curcumin preparation, indicating the potential of incorporating naturally curcumin-rich turmeric into a convenient functional food formulation.

Total antioxidant activity (DPPH activity (%))

The antioxidant activity data for the liver and kidney are presented in Fig. 4B. In the liver, activity decreased significantly in Group 2 (34.05 %) compared to the control (63.88 %) but increased in Group 5 (52.02 %), followed by Group 4 (45.94 %) and Group 3 (42.78 %) on day 28. Similarly, in the kidney, activity dropped in Group 2 (30.80 %) from the control (53.46 %) but improved in Group 5 (46.61 %), Group 4 (40.32 %) and Group 3 (34.42 %) compared to Group 2. The decrease in antioxidant activity of the liver and kidney in folic-acid-treated mice (Group 2) might be due to the toxicity of folic acid and oxidative stress in tissues. There was a significant increase in antioxidant activity in the liver and kidney of Groups 3, 4 and 5, which indicates that curcumin and other antioxidant constituents present in the turmeric-based formulation. A significant increase in total antioxidant activity was observed in the liver and kidney of Groups 3, 4 and 5 following supplementation with the turmeric-based curry powder, compared with the folic-acid-treated group. The enhancement of antioxidant activity, together with the observed reduction in MDA and increases in SOD and GSH, indicates an improved endogenous antioxidant defence following administration of the curcumin-rich formulation. The response was more pronounced with increasing levels of curry powder, suggesting that the bioactive constituents of turmeric may contribute to restoration of antioxidant balance under oxidative stress conditions. Curcumin is recognised for its ability to counteract free-radical-mediated oxidative damage and to support cellular antioxidant defence mechanisms.

These findings are supported by a study of the protective effect of curcumin against Pb-induced oxidative stress in rats (31). Their study showed that Pb exposure significantly increased MDA levels and reduced SOD activity in tissues, demonstrating the development of oxidative stress. Treatment with free curcumin attenuated these alterations, while curcumin-loaded cockle shell-derived calcium carbonate nanoparticles produced a greater improvement in oxidative stress parameters than free curcumin, as evidenced by a stronger reduction in MDA and restoration of SOD activity. The authors attributed this protective effect to the antioxidant potential of curcumin and suggested that enhanced delivery of curcumin could further improve its efficacy. The study used a Pb-induced oxidative stress model and a nanoformulated curcumin preparation, whereas the present study evaluated a food-based turmeric curry formulation in a folic-acid-induced model and the comparable improvement in antioxidant status supports the potential contribution of curcumin to attenuation of oxidative stress (31). The increased antioxidant activity observed in the liver and kidney in the present study therefore provides additional evidence for the functional potential of the curcumin-rich turmeric-based formulation.

Serum biochemical parameters

The perusal of data on BUN, creatinine, albumin, TP, AST and ALT on the 28th day of the experiment is given in Fig. 4C.

A significant increase in BUN (53.47 mg/dL), creatinine (3.27 mg/dL), AST (266.20 IU/L) and ALT (84.60 IU/L), along with a decrease in TP (3.52 g/dL) and albumin (1.73 g/dL), was observed in Group 2 compared to the control values (36.08 mg/dL, 1.19 mg/dL, 125.52 IU/L, 53.59 IU/L, 6.67 g/dL and 3.50 g/dL respectively). A progressive decline in BUN, creatinine, AST and ALT, along with an increase in TP and albumin, was noted in Groups 3, 4 and 5. Among these, Group 5 exhibited the most significant improvement, with reduced BUN (37.53 mg/dL), creatinine (1.45 mg/dL), AST (165.03 IU/L) and ALT (64.98 IU/L), as well as increased TP (6.30 g/dL) and albumin (2.85 g/dL), compared to Groups 3 and 4.

In Group 2, liver transaminase enzymes (ALT and AST) increased following folic acid injection in mice compared to Group 1, likely due to liver cell toxicity or damage (32). These changes were also associated with elevated MDA levels and reduced GSH and SOD in liver tissue, aligning with early findings (33). Total protein levels also decreased in Group 2, possibly due to liver damage and impaired protein synthesis. Similar findings were reported, noting reduced TP and albumin levels in cases of liver damage, likely due to impaired protein synthesis (34).

These findings are consistent with previous reports, which demonstrated that exposure to Pb produced marked alterations in biochemical indicators of renal and hepatic function, including increases in circulating renal function markers and alterations in hepatic enzyme activities (35). Their study further

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showed that antioxidant supplementation attenuated these toxicant-induced biochemical changes, indicating improved protection of hepatic and renal tissues. Although the toxicant and protective intervention differed between the two studies, the similar improvement in biochemical indices following antioxidant treatment suggests that antioxidant-rich interventions may help counteract toxicant-associated hepatic and renal disturbances. In the present study, the concurrent improvement in serum biochemical parameters, tissue antioxidant status and histological appearance further supports the protective potential of the curcumin-rich turmeric-based formulation. In Groups 3, 4 and 5, decreased AST and ALT levels, along with increased protein content, suggest the hepatoprotective effect of curcumin. The elevated BUN and creatinine levels in folic acid-treated mice may be attributed to kidney toxicity and damage, leading to protein breakdown and increased BUN and creatinine levels (33). Conversely, the reduction in BUN and creatinine levels in Groups 3, 4 and 5 indicates the nephroprotective and antioxidant properties of curcumin, in agreement with early findings (31).

Hematological parameters

The data on hematological parameters, including total erythrocyte count (TEC), total leucocyte count (TLC), hemoglobin (Hb), PCV and platelets, on the 28th day of the experiment are shown in Fig. 4C.

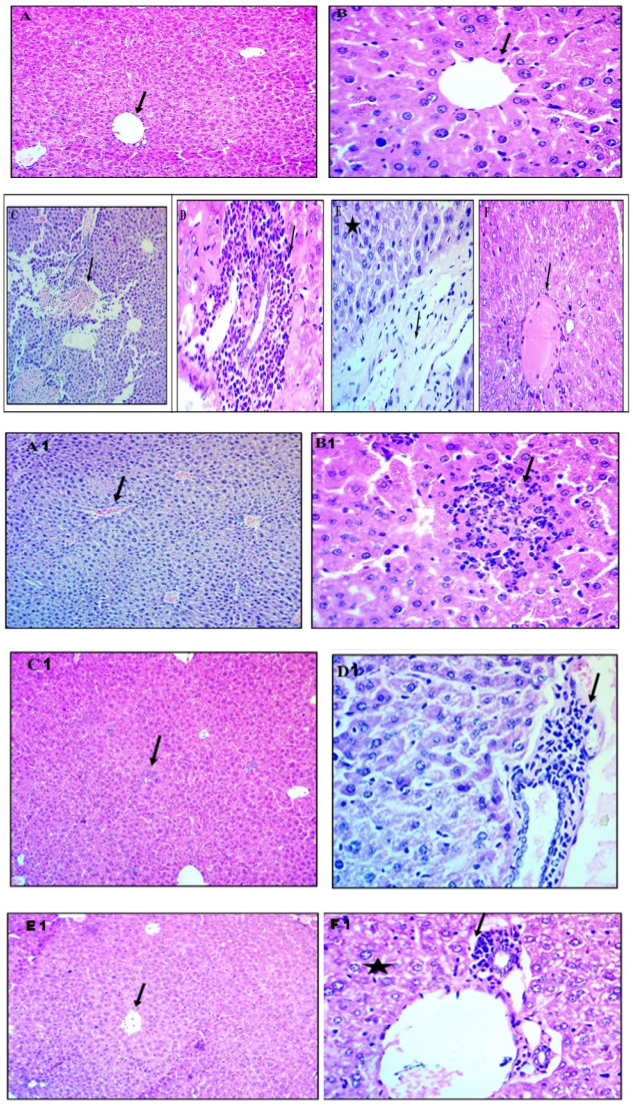
Decreased TEC (4.74 million/µL), Hb (8.72 g %), PCV (30.93 %), platelets (4.49 × 10^5/µL) and increased TLC (16.90 thousands/µL) were recorded in Group 2, compared to control values (9.40 million/µL, 15.93 g %, 45.55 %, 8.46 × 10^5/µL and 7.39 thousands/µL, respectively). A significant progressive increase in TEC, Hb, PCV and platelets, alongside a decrease in TLC relative to the control in Groups 3, 4 and 5 was observed. Among these, Group 5 recorded significantly increased TEC (7.37 million/µL), Hb (10.15 g %), PCV (40.43 %), platelets (7.18 × 10^5/µL) and decreased TLC (9.22 thousands/µL). The improvement was more pronounced at the higher supplementation level, indicating a potential protective effect of the curcumin-rich formulation on blood parameters. The reduction in TEC, Hb, PCV and platelets in folic-acid-treated mice (Group 2) might be associated with folic-acid-induced toxicity and oxidative stress, which can adversely affect erythrocyte integrity and haematological homeostasis. An increase in leukocytes may be an immunological action of mice against folic acid. In Groups 3, 4 and 5, there was a significant increase in TEC, Hb, PCV and platelets and a decrease in leukocytes, which shows the ameliorative effect and antioxidant activity of curcumin (36). These findings are in agreement with the previous study, which investigated the protective effect of turmeric against carbofuran-induced haematological toxicity in rats (37). Carbofuran exposure adversely affected several haematological parameters, whereas co-administration of turmeric significantly increased red blood cells (RBC) and Hb levels and ameliorated the elevation in white blood cells (WBC) and lymphocyte counts. The authors suggested that turmeric supplementation could alleviate toxicant-induced haematological disturbances, partly through its antioxidant activity. The similarity between the present findings and those of previous study, despite differences in the toxicant and experimental model, supports the potential role of turmeric-derived bioactive compounds in maintaining haematological homeostasis under oxidative stress conditions (37). In the present study, the improvement in haematological indices, together with the observed enhancement of tissue antioxidant status, suggests that the curcumin-rich turmeric curry formulation may contribute to protection against folic-acid-associated oxidative and haematological alterations.

Histopathology of organs (liver and kidney)

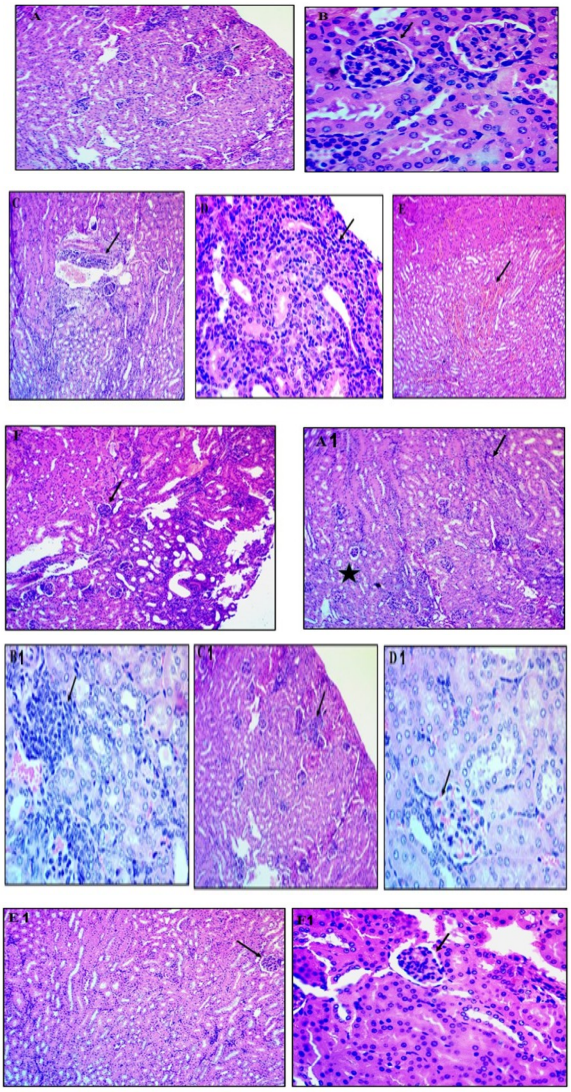
The histopathology of organs viz., liver and kidney were studied in all the groups of mice to know the underlying defence mechanism. Visually, the organs of mice in Group 5 were found to be similar to those in Group 1, with no significant damage observed (Fig. 5). Liver sections of Group 1 showed normal structure (Fig. 5(I) A, B). Group 2 exhibited severe congestion, hepatocyte necrosis, severe infiltration of inflammatory cells and fibroblastic cells, vacuolar degeneration of hepatocytes and Kupffer cell proliferation with marked oedema of central vein (Fig. 5(I) C–F). Group 3 had moderate congestion and inflammation (Fig. 5(I) A1, B1). Group 4 showed mild to moderate hepatocyte degeneration and inflammation (Fig. 5(I) C1, D1). Group 5 displayed mild inflammatory infiltration and vascular changes, with a normal central vein in some sections (Fig. 5(I) E1, F1). Similarly, kidney sections of Group 1 showed normal glomeruli and tubules (Fig. 5(II) A, B). Group 2 exhibited severe congestion, atrophy and inflammation (Fig. 5(II) C–E). Group 3 showed moderate inflammation, glomerular degeneration (Fig. 5(II) F) and atrophied glomeruli with tubular casts (Fig. 5(II) A1). Group 4 had moderate to mild inflammatory infiltration and congestion (Fig. 5(II) B1–D1). Group 5 showed restored tissue architecture with normal glomeruli (Fig. 5(II) E1, F1).

Histopathological examination provided further evidence of the protective effect of the turmeric-based curry powder against folic acid-induced tissue injury. Folic acid intoxication primarily affects the liver due to its role in storage, biotransformation and toxin elimination. Group 5 showed milder degenerative changes compared to Groups 3 and 4, suggesting the ameliorative effect of curcumin. Similarly, kidney sections from Group 2 exhibited severe congestion, atrophy and inflammation, indicating folic acid toxicity. In contrast, Group 5 showed better tissue restoration and normal glomeruli compared to Groups 3 and 4, supporting curcumin's protective role.

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Photomicrograph of liver (I)



Photomicrograph of kidney (II)

Fig. 5. Histopathology of liver and kidney in various groups of mice. Photomicrograph of liver (I): (A) normal radiating hepatic cords with normal central vein (Arrow, Group-1) H & E × 100; (B) normal radiating hepatic cords with normal central vein (Arrow, Group-1) H & E × 400 (Group 1); (C) severe congestion (Arrow), necrosis of hepatocytes, infiltration of inflammatory cells (Arrow, Group-2) H & E × 100; (D) severe infiltration of inflammatory cells (Arrow, Group-2) H & E × 400; (E) infiltration of fibroblastic cells (Arrow), vacuolic degeneration of hepatocytes (star, Group-2) H & E × 400; (F) Kupffer cell proliferation with marked oedema of central vein (Arrow, Group-2) H & E × 400, (Group 2); (A-1) moderate congestion of central vein (Arrow, Group-3) H & E × 100; (B-1) moderate infiltration of inflammatory cells (Arrow, Group-3) H & E × 400, (Group 3); (C-1) moderate to mild degenerative changes in hepatocytes (Arrow, Group-4) H & E × 100; (D-1) moderate to mild infiltration of inflammatory cells (Arrow, Group-4) H & E × 400, (Group 4); (E-1) mild degenerative changes in hepatocytes with normal central vein (Arrow, Group-5) H & E × 100; (F-1) mild infiltration of inflammatory cells (Arrow) near portal triad with mild vacuole changes (Arrow, Group-5) H & E × 400, (Group 5). Photomicrograph of kidney (II): (A) normal architecture of glomeruli and tubules (Group-1) H & E × 100; (B) normal architecture of glomeruli (Arrow, Group-1) H & E × 400, (Group 1); (C) severe congestion, atrophy and infiltration of inflammatory cells (Arrow, Group-2) H & E × 100; (D) severe congestion along with infiltration of inflammatory cells (Arrow, Group-2) H & E × 400, E. Severe congestion (Arrow, Group-2) H & E ×100, (Group 2); (F) moderate infiltration of inflammatory cells with degenerative changes in glomeruli (Arrow, Group-3) H & E × 100; (A-1) Atrophied glomeruli with deposition of cast (star) within tubules (Arrow, Group-3) H & E × 100, (Group 3); (B-1) Moderate infiltration of inflammatory cells (arrow) with intertubular congestion (Group-4) H & E × 400; (C-1) mild infiltration of inflammatory cells (Arrow, Group-4). H & E × 100; (D-1) mild infiltration of inflammatory cells with mild congestion (Arrow, Group-4). H & E × 400, (Group 4); (E-1) restoration of tissue architecture with normal glomeruli (Arrow, Group-5) H & E × 100; (F-1) normal glomeruli (Arrow, Group-5) H & E × 400, (Group 5).

The progressive improvement in hepatic and renal architecture with increasing levels of the turmeric-based curry powder may be associated with the antioxidant and anti-inflammatory properties of turmeric-derived bioactive compounds, particularly curcumin. The histopathological observations also correspond with the biochemical findings of the present study, in which curry-powder supplementation reduced serum AST, ALT, BUN and creatinine levels and improved antioxidant status. Thus, the biochemical and histological responses together suggest attenuation of folic-acid-associated hepatic and renal injury.

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Similar findings were reported by a previous study, which investigated the effects of turmeric and curcumin on T3-induced oxidative stress and renal hyperplasia in rats. T3 treatment produced marked renal histopathological alterations, including tubular dilation and interstitial oedema, which were accompanied by increased oxidative stress (38). Treatment with turmeric restored the T3-induced histopathological changes and reduced lipid peroxidation, supporting a relationship between oxidative stress and tissue injury. Although the experimental model and toxicant differed from those used in the present study, the restoration of renal tissue architecture following turmeric treatment is consistent with the improved hepatic and renal morphology observed in the present investigation. In particular, the near-normal renal architecture observed in Group 5 supports the potential role of turmeric-derived bioactive compounds in mitigating oxidative-stress-associated tissue damage.

Positive outcomes that are observed in the current formulation are attributed to antioxidant effects. It has also been suggested that bioactive compounds from turmeric have anti-inflammatory and anti-cancerous properties and affect cellular defence mechanisms by activating the Nrf2 pathway, which controls antioxidant activity. In this way, positive responses seen might be due to both antioxidants and other types of activity of the formulated product. Compared to other plant-based functional foods available on the market, the current formulation might bring added value to its consumer due to a combination of turmeric bioactive compounds and spices (28, 39 and 40).

In relation to models specific to folic acid, our results are similar to those reported in prior literature in which overdoses of folic acid induced tubular necrosis through lipid peroxidation (41). Folic acid toxin model prompted a cascade of oxidative stress resulting from elevated MDA levels and decreased SOD activity and is highly reminiscent of established toxicant oxidative models (42–44).

4. Conclusion

The raw rhizomes of these 10 genotypes were assessed for various biochemical parameters and one superior genotype, LTS-2, was identified and selected for product design. The curry preparation was standardised using the superior turmeric genotype (LTS-2). The treatment consisting of 25 g of turmeric rhizome and common base (CB: ginger + black pepper seeds + cumin seeds + coriander seeds + curry leaves + tamarind + dry red chillies + salt + water + oil) recorded the highest sensory scores and dried to extend shelf life. Storage studies revealed that the nutrient-rich raw turmeric-based curry had a lower storage life, while tray- and freeze-dried turmeric-based curry powders recorded an extended storage period of 60 days and retained all the nutrients with acceptable sensory evaluation scores. The tray-dried raw turmeric-based curry powder was selected for *in vivo* evaluation to assess antioxidant potential. Swiss albino male mice administered curry powder containing 7 mg of curcumin per kg of body weight registered the highest ameliorative action and could be promoted as an immunity booster. Thus, raw turmeric-based curry powder, a novel product, might provide a new opportunity for the marketing and better utilisation of a high-value commercial crop. Future research should focus on evaluating the bioavailability of the developed product, conducting comprehensive clinical trials to validate its antifungal and anticancer potential, assessing its market potential and commercial feasibility and developing novel value-added products from turmeric rhizomes and leaves.

Acknowledgements

The authors sincerely acknowledge the Associate Dean, Dr. N T R College of Agricultural Engineering, Bapatla, Guntur, for extending the post-harvest equipment required for product drying and enabling the smooth conduct of the experiments. The research was supported by Dr. Y S R Horticultural university and AICRP on Spices.

Authors' contributions

PSPC conducted the biochemical analyses and contributed to data collection and interpretation. TPB conceptualised and designed the study, supervised the research work, performed data analysis and prepared the original manuscript. SV^1 performed experimental work related to turmeric genotypes and assisted in laboratory investigations. GK assisted in statistical analysis and interpretation of the results. SVV contributed to functional food product formulation and standardisation. VKA participated in clinical evaluation and validation of health-related outcomes. SV^2 contributed to manuscript review, editing and final proofreading. All authors have read and approved the final manuscript [SV^1 stands for Sailaja V and SV^2 stands for Sravathi V].

Compliance with ethical standards

Conflict of interest

Authors do not have any conflict of interests to declare.

Ethical issues

Ethics approval (include appropriate approvals or waivers): All experimental procedures, including clinical evaluations, were conducted in accordance with ethical standards and were approved by Institutional Animal Ethics Committee, C V Sc., Rajendranagar, Hyderabad (22/26/C.V.Sc, HYD. IAEC).

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https://doi.org/10.14719/pst.16936

Supplementary Files

Supplementary Table 1. List and details of studied turmeric genotypes

Sl. No.	Code	Genotype	Category	Place of collection	GPS	
					Latitude	Longitude
1	LTS-2	Lam Swarna	Released variety	Lam, Guntur, AP	16.3693° N	80.4271° E
2	LTS-3	Tekurpet white-3	Land race	Kadapa, AP	14.4673° N	78.8242° E
3	LTS-4	Tekuripeta-1	Land race	Kadapa, AP	14.4673° N	78.8242° E
4	LTS-5	Kolluru	Selection	Guntur, AP	16.1826° N	80.7969° E
5	LTS-6	Kolluru	Selection	Guntur, AP	16.1826° N	80.7969° E
6	LTS-7	Nalgonda	Land race	Nalgonda, TG	17.0577° N	79.2684° E
7	LTS-8	V. Puram (W)	Land race	Kollipara, AP	16.2872° N	80.7495° E
8	LTS-9	V. Puram (R)	Land race	Kollipara, AP	16.2872° N	80.7495° E
9	LTS-10	Tadepalle	Selection	Guntur, AP	16.4799° N	80.6174° E
10	LTS-11	Tadepalle	Selection	Guntur, AP	16.4799° N	80.6174° E
11	LTS-12	Bottuguda	Land race	Nalgonda, TG	17.0577° N	79.2684° E
12	LTS-13	Kollipara	Selection	Guntur, AP	16.2872° N	80.7495° E
13	LTS-14	Kollipara	Selection	Guntur, AP	16.2872° N	80.7495° E
14	LTS-16	LTS-19-1	Selection	Vemuru, Guntur, AP	16.1793° N	80.7400° E
15	LTS-17	LTS-19-3	Selection	Vemuru, Guntur, AP	16.1793° N	80.7400° E
16	LTS-18	LTS-19-4	Selection	Vemuru, Guntur, AP	16.1793° N	80.7400° E
17	LTS-20	LTS-19-5	Selection	Vemuru, Guntur, AP	16.1793° N	80.7400° E
18	LTS-21	LTS-19-6	Selection	Vemuru, Guntur, AP	16.1793° N	80.7400° E
19	LTS-22	Vellaturu	Selection	Bapatla, AP	16.1160° N	80.8141° E
20	LTS-23	Pedalanka	Selection	Bapatla, AP	16.2082° N	80.8127° E
21	LTS-24	Vellaturu	Selection	Bapatla, AP	16.1160° N	80.8141° E
22	LTS-25	LTS-19-2	Selection	Vemuru, Guntur, AP	16.1793° N	80.7400° E
23	LTS-27	Epuru	Selection	Bapatla, AP	16.6387° N	80.9735° E
24	LTS-29	Pedalanka	Selection	Bapatla, AP	16.2082° N	80.8127° E
25	LTS-30	Epuru	Selection	Bapatla, AP	16.3693° N	80.4271° E
26	LTS-31	Veerampalli (R)	Landrace	Nellore, AP	14.4426° N	79.9865° E
27	LTS-33	BS	Landrace	Nutakki, AP	16.4158° N	80.6507° E
28	LTS-35	Duggirala	Selection	Guntur, AP	16.3273° N	80.6272° E
29	LTS-47	Duggirala	Selection	Guntur, AP	16.3273° N	80.6272° E
30	LTS-73	JTS-314	Selection	Mallial, TG	18.7042° N	78.9504° E
31	LTS-74	JTS-321	Selection	Korutla, TG	18.8254° N	78.7148° E
32	LTS-75	JTS-386	Selection	Pegadapalli, TG	18.5069° N	79.4670° E
33	LTS-76	JTS-38	Selection	Kodimial, TG	18.6303° N	78.9033° E
34	LTS-77	JTS-313	Selection	Pegadapalli, TG	18.5069° N	79.4670° E
35	LTS-78	JTS-308	Selection	Mallial, TG	18.7042° N	78.9504° E
36	LTS-79	JTS-1	Selection	Raikal, TG	18.9105° N	78.8092° E
37	LTS-80	JTS-317	Selection	Velgatur, TG	18.8458° N	79.1719° E
38	LTS-81	JTS-603	Selection	Velgatur, TG	18.8458° N	79.1719° E
39	LTS-82	JTS-314 Sln	Selection	Pegadapalli, TG	18.5069° N	79.4670° E
40	LTS-83	E-17-Y-1	Selection	Lam, Guntur, AP	16.3693° N	80.4271° E
41	LTS-84	T_3-17-3	Selection	Lam, Guntur, AP	16.3693° N	80.4271° E
42	LTS-85	E-17- 2	Selection	Lam, Guntur, AP	16.3693° N	80.4271° E
43	LTS-86	T_6-17-2	Selection	Lam, Guntur, AP	16.3693° N	80.4271° E
44	LTS-87	E-Y-4	Selection	Lam, Guntur, AP	16.3693° N	80.4271° E
45	LTS-88	T_4-17-3	Selection	Lam, Guntur, AP	16.3693° N	80.4271° E
46	LTS-89	T_7-17-5	Selection	Lam, Guntur, AP	16.3693° N	80.4271° E
47	LTS-90	IR-17-W-2	Selection	Lam, Guntur, AP	16.3693° N	80.4271° E
48	LTS-91	T_3-17-6	Selection	Lam, Guntur, AP	16.3693° N	80.4271° E
49	LTS-92	T_3-17-5	Selection	Lam, Guntur, AP	16.3693° N	80.4271° E

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50	LTS-93	T_4-17-2	Selection	Lam, Guntur, AP	16.3693° N	80.4271° E
51	LTS-94	IR-17-W-1	Selection	Lam, Guntur, AP	16.3693° N	80.4271° E
52	LTS-95	T_3-17-4	Selection	Lam, Guntur, AP	16.3693° N	80.4271° E
53	LTS-96	T_6-17-6	Selection	Lam, Guntur, AP	16.3693° N	80.4271° E
54	LTS-97	T_8-17-3	Selection	Lam, Guntur, AP	16.3693° N	80.4271° E
55	LTS-98	T_6-17-1-2	Selection	Lam, Guntur, AP	16.3693° N	80.4271° E
56	LTS-99	Paderu local	Land race	Vizag, AP	17.6868° N	83.2185° E
57	LTS-100	Vontimitta	Land race	Kadapa, AP	14.4673° N	78.8242° E
58	LTS-101	Chinthapalli local	Land race	Chintapalli, AP	17.8710° N	82.3499° E
59	LTS-102	JTS-608	Selection	Korutla. TG	18.8254° N	78.7148° E
60	LTS-103	LTS-334	Selection	Lam, Guntur, AP	16.3693° N	80.4271° E
61	C1	BSR-2	Released Variety	Tamila Nadu	11.1271° N	78.6569° E
62	C2	Tekurpeta	Local cultivar	Kadapa	15.0010° N	79.0355° E
63	C3	Duggirala Red	Released Variety	Telangana	16.3273° N	80.6272° E
64	C4	Salem	Released Variety	Tamil Nadu	11.6643° N	78.1460° E
65	C5	IISR Pragathi	Released Variety	Kerala	11.2985° N	75.8403° E
66	C6	IISR Prathibha	Released Variety	Kerala	11.2985° N	75.8403° E
67	C7	Myd. Sel (Guntur)	Land race	Guntur, AP	16.3067° N	80.4365° E
68	C8	Myd Sel (Kadapa)	Land race	Kadapa, AP	14.7265° N	78.7321° E
69	C9	Lakadong	Land race	Meghalaya	25.4670° N	91.3662° E
70	C10	Rajendra Sonia	Released Variety	Bihar	25.6126° N	85.1588° E
71	C11	Rajendra sonali	Released Variety	Bihar	25.6126° N	85.1588° E
72	C12	Megha turmeric	Released Variety	Meghalaya	25.4670° N	91.3662° E
73	C13	Rajapuri	Released Variety	Maharashtra	19.7515° N	75.7139° E
74	C14	Roma	Released Variety	Orissa	20.2376° N	84.2700° E
75	C15	Kasturi	Land race	Paderu, AP	18.0459° N	82.4012° E

GPS: global positioning system; AP: Andra Pradesh.

Supplementary Table 2. Analysis of variance for 16 biochemical traits in dry rhizomes of 75 turmeric genotypes

Sl. No.	Source	Mean sum of squares (MSS)		
		Replication	Treatment	Error
	Degrees of freedom	2	74	148
1.	Carbohydrates (%)	18.397	104.27**	18.24
2.	Crude Protein (%)	0.298	1.432**	0.209
3.	Crude fibre (%)	0.001	3.072**	0.048
4.	Ash (%)	0.009	0.846**	0.008
5.	Nitrogen (%)	0.002	0.037**	0.007
6.	Phosphorus (%)	0.001	0.022**	0.001
7.	Potassium (%)	0.021	0.955**	0.055
8.	Calcium (%)	0.001	0.021**	0.001
9.	Magnesium (%)	0.001	0.014**	0.001
10.	Sulphur (%)	0.001	0.039**	0.001
11.	Zinc mg/100 g	0.069	2.256**	0.03
12.	Iron mg/100 g	7.117	343.236**	3.618
13.	Manganese mg/100 g	0.004	5.023**	0.031
14.	Copper mg/100 g	0.007	0.416**	0.004
15.	Curcumin (%)	0.017	3.393**	0.021
16.	Antioxidant (%)	8.436	557.214**	16.716

*Significant at 5 % level of significance; **Significant at 1 % level of significance.

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Supplementary Table 3. Descriptive statistics of 16 biochemical traits in dry rhizomes of 75 turmeric genotypes

Sl. No.	Parameters	Mean	Minimum	Maximum	Standard error	Standard deviation	CV (%)
1.	Carbohydrates (%)	52.93	40.13	67.20	2.47	0.05	8.07
2.	Crude protein (%)	8.30	6.13	9.33	0.26	0.21	5.51
3.	Crude fibre (%)	3.57	2.03	5.13	0.13	0.02	6.13
4.	Ash (%)	5.40	4.20	9.21	0.05	0.02	6.18
5.	Nitrogen (%)	1.33	0.98	1.49	0.05	0.03	6.21
6.	Phosphorous (%)	0.40	0.21	0.56	0.02	0.01	6.49
7.	Potassium (%)	3.00	1.17	3.85	0.14	0.09	7.86
8.	Calcium (%)	0.31	0.16	0.48	0.01	0.01	5.80
9.	Magnesium (%)	0.24	0.10	0.38	0.01	0.01	5.80
10.	Sulphur (%)	0.24	0.01	0.49	0.01	0.01	6.50
11.	Zinc (mg/100 g)	2.62	0.72	3.98	0.10	0.02	6.66
12.	Iron (mg/100 g)	26.68	9.93	55.33	1.10	0.37	7.13
13.	Manganese (mg/100 g)	2.74	1.14	7.36	0.10	0.04	6.47
14.	Copper (mg/100 g)	1.00	0.09	1.48	0.03	0.02	5.99
15.	Curcumin (%)	2.18	0.58	5.24	0.08	0.02	6.67
16.	Antioxidant activity (%)	70.64	40.16	87.71	2.36	0.27	5.79

Supplementary Table 4. Principal component analysis (PCA) analysis of 16 biochemical traits for 75 turmeric genotypes

Sl. No.	Principal component	Eigenvalue	Variability (%)	Cumulative (%)
1	PC1	3.18	19.88	19.88
2	PC2	2.07	12.91	32.79
3	PC3	1.76	10.98	43.77
4	PC4	1.37	8.55	52.32
5	PC5	1.25	7.80	60.12
6	PC6	1.14	7.10	67.22
7	PC7	0.99	6.21	73.43
8	PC8	0.85	5.31	78.74
9	PC9	0.83	5.18	83.92
10	PC10	0.61	3.80	87.72
11	PC11	0.53	3.31	91.03
12	PC12	0.41	2.58	93.61
13	PC13	0.39	2.46	96.07
14	PC14	0.32	1.97	98.04
15	PC15	0.31	1.95	99.99
16	PC16	0.00	0.01	100

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Supplementary Table 5. Factor loadings of various principal components (PC)

Traits	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Potassium (%)	0.44	0.06	0.21	-0.48	0.32	0.21	0.28
Phosphorous (%)	0.77	0.10	0.20	0.26	0.08	0.02	-0.06
Calcium (%)	0.07	0.29	0.47	-0.33	-0.26	0.01	-0.01
Magnesium (%)	0.35	0.40	-0.18	0.43	-0.02	0.46	0.15
Nitrogen (%)	0.75	-0.47	-0.25	-0.18	-0.14	-0.11	0.24
Sulphur (%)	-0.29	0.17	0.29	0.04	0.20	0.48	0.46
Antioxidant activity (%)	0.09	-0.47	0.65	0.25	0.20	0.01	-0.06
Curcumin (%)	0.13	-0.50	0.58	0.33	0.20	-0.19	-0.12
Carbohydrates (%)	-0.36	0.14	-0.18	0.39	0.35	-0.43	0.35
Crude protein (%)	0.75	-0.47	-0.24	-0.17	-0.14	-0.11	0.23
Crude fibre (%)	0.29	0.09	-0.27	-0.24	0.58	0.19	-0.45
Ash (%)	-0.21	-0.44	-0.17	0.24	-0.45	0.43	-0.30
Zinc (mg/100 g)	0.37	0.52	-0.01	0.01	0.12	-0.27	-0.34
Iron (mg/100 g)	0.50	0.38	0.46	0.04	-0.21	0.11	-0.10
Manganese (mg/100 g)	0.62	0.26	-0.23	0.52	-0.07	-0.05	0.08
Copper (mg/100 g)	-0.02	0.41	0.24	-0.11	-0.43	-0.31	0.11

Supplementary Table 6. Carbohydrates and crude protein content-CP (%) in various turmeric genotypes

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Sl. No.	Genotype	Carbohydrates (%)	CP (%)	Sl. No.	Genotype	Carbohydrates (%)	CP (%)	Sl. No.	Genotype	Carbohydrates (%)	CP (%)
1	LTS-2	59.04	8.60	27	LTS-33	55.92	8.46	53	LTS-96	58.26	8.60
2	LTS-3	61.18	7.00	28	LTS-35	65.26	8.02	54	LTS-97	58.92	8.17
3	LTS-4	49.90	8.60	29	LTS-47	44.68	8.75	55	LTS-98	60.61	8.31
4	LTS-5	54.79	8.31	30	LTS-73	49.83	8.90	56	LTS-99	49.98	7.44
5	LTS-6	52.74	8.75	31	LTS-74	52.46	8.75	57	LTS-100	53.74	8.31
6	LTS-7	47.10	9.04	32	LTS-75	40.13	8.90	58	LTS-101	54.38	6.13
7	LTS-8	54.70	8.46	33	LTS-76	56.64	9.04	59	LTS-102	42.91	8.90
8	LTS-9	52.36	8.60	34	LTS-77	56.19	8.46	60	LTS-103	54.04	9.04
9	LTS-10	51.03	9.04	35	LTS-78	53.41	7.88	61	C1	62.07	7.88
10	LTS-11	56.41	8.46	36	LTS-79	58.67	9.04	62	C2	52.40	8.75
11	LTS-12	50.07	8.75	37	LTS-80	47.92	8.75	63	C3	47.28	8.31
12	LTS-13	46.72	9.04	38	LTS-81	48.53	8.46	64	C4	64.30	8.17
13	LTS-14	54.00	8.02	39	LTS-82	50.10	8.17	65	C5	67.20	8.17
14	LTS-16	66.50	9.19	40	LTS-83	56.44	8.02	66	C6	50.07	8.60
15	LTS-17	56.21	9.04	41	LTS-84	48.03	8.02	67	C7	54.58	6.13
16	LTS-18	44.96	9.33	42	LTS-85	53.99	8.60	68	C8	63.14	6.27
17	LTS-20	45.04	8.31	43	LTS-86	51.27	8.02	69	C9	44.47	8.90
18	LTS-21	53.60	8.46	44	LTS-87	58.01	7.00	70	C10	42.49	7.73
19	LTS-22	55.38	8.17	45	LTS-88	60.31	8.46	71	C11	50.48	8.90
20	LTS-23	54.08	8.90	46	LTS-89	53.51	8.02	72	C12	42.88	8.02
21	LTS-24	53.89	8.02	47	LTS-90	55.00	8.46	73	C13	43.89	8.90
22	LTS-25	51.84	9.19	48	LTS-91	44.98	8.31	74	C14	57.89	7.88
23	LTS-27	47.53	8.46	49	LTS-92	49.69	8.46	75	C15	50.71	8.02
24	LTS-29	52.46	8.46	50	LTS-93	45.84	8.17		SEM±	0.045	0.214
25	LTS-30	55.42	7.00	51	LTS-94	48.97	7.88		C.D. at 5 %	0.125	0.597
26	LTS-31	55.84	8.46	52	LTS-95	54.22	6.56				

C1*: BSR-2; C2*: Tekurpeta; C3*: Duggirala Red; C4*: Salem; C5*: Pragathi; C6*: Prathibha; C7*: Myd. Sel (Guntur); C8*: Myd Sel (Kadapa); C9*: Lakadong; C10*: Rajendra Sonia; C11*: Rajendra sonali; C12*: Megha turmeric; C13*: Rajapuri; C14*: Roma; C15: Kasturi.

Supplementary Table 7. Crude fibre and ash content (%) in various turmeric genotypes

Sl. No.	Genotype	Crude fibre (%)	Ash (%)	Sl. No.	Genotype	Crude fibre (%)	Ash (%)	Sl. No.	Genotype	Crude fibre (%)	Ash (%)
1	LTS-2	4.34	4.20	27	LTS-33	4.46	4.45	53	LTS-96	2.85	4.88
2	LTS-3	4.13	4.31	28	LTS-35	4.39	4.68	54	LTS-97	4.51	5.40
3	LTS-4	2.90	9.20	29	LTS-47	3.77	4.40	55	LTS-98	2.67	4.80
4	LTS-5	5.12	4.26	30	LTS-73	5.07	5.05	56	LTS-99	2.87	4.78
5	LTS-6	3.13	4.93	31	LTS-74	4.37	4.62	57	LTS-100	4.41	4.28
6	LTS-7	2.27	4.85	32	LTS-75	3.00	4.50	58	LTS-101	5.00	4.43
7	LTS-8	2.27	6.70	33	LTS-76	4.32	4.35	59	LTS-102	2.78	9.20
8	LTS-9	4.71	5.75	34	LTS-77	2.40	6.53	60	LTS-103	2.61	7.83
9	LTS-10	2.59	4.57	35	LTS-78	4.77	4.53	61	C1	2.82	6.48

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10	LTS-11	3.66	4.45	36	LTS-79	2.76	4.70	62	C2	3.38	7.85
11	LTS-12	2.92	5.45	37	LTS-80	2.23	4.75	63	C3	2.39	6.33
12	LTS-13	5.12	6.42	38	LTS-81	3.15	4.23	64	C4	3.25	4.42
13	LTS-14	4.21	4.83	39	LTS-82	5.10	4.65	65	C5	2.03	5.43
14	LTS-16	2.19	5.35	40	LTS-83	4.69	4.45	66	C6	2.70	4.70
15	LTS-17	4.42	5.58	41	LTS-84	2.83	4.90	67	C7	2.51	6.58
16	LTS-18	3.82	4.48	42	LTS-85	4.62	9.21	68	C8	2.20	5.95
17	LTS-20	4.89	6.45	43	LTS-86	4.81	5.25	69	C9	2.80	4.32
18	LTS-21	4.57	4.40	44	LTS-87	2.30	5.82	70	C10	2.36	6.65
19	LTS-22	2.55	4.55	45	LTS-88	5.13	5.00	71	C11	4.24	5.57
20	LTS-23	3.67	4.20	46	LTS-89	4.44	9.12	72	C12	4.04	6.40
21	LTS-24	2.09	4.48	47	LTS-90	2.68	4.80	73	C13	5.05	4.63
22	LTS-25	4.73	4.75	48	LTS-91	3.89	9.20	74	C14	5.06	4.45
23	LTS-27	4.15	4.60	49	LTS-92	3.09	4.38	75	C15	4.24	5.13
24	LTS-29	2.45	4.70	50	LTS-93	4.28	6.13		SEM±	0.017	0.022
25	LTS-30	2.15	5.68	51	LTS-94	4.40	4.48		C.D. at 5 %	0.047	0.060
26	LTS-31	2.91	6.70	52	LTS-95	2.41	4.80				

C1*: BSR-2; C2*: Tekurpeta; C3*: Duggirala Red; C4*: Salem; C5*: Pragathi; C6*: Prathibha; C7*: Myd. Sel (Guntur); C8*: Myd Sel (Kadapa); C9*: Lakadong; C10*: Rajendra Sonia; C11*: Rajendra sonali; C12*: Megha turmeric; C13*: Rajapuri; C14*: Roma; C15: Kasturi

Supplementary Table 8. Primary macronutrients (nitrogen, phosphorus and potassium) assessment in turmeric genotypes

Sl. No.	Genotype	N (%)	P (%)	K (%)	Sl. No.	Genotype	N (%)	P (%)	K (%)	Sl. No.	Genotype	N (%)	P (%)	K (%)
1	LTS-2	1.38	0.52	3.35	27	LTS-33	1.35	0.52	3.75	53	LTS-96	1.38	0.29	3.35
2	LTS-3	1.12	0.38	2.93	28	LTS-35	1.28	0.35	2.95	54	LTS-97	1.31	0.29	2.85
3	LTS-4	1.38	0.41	3.05	29	LTS-47	1.40	0.49	3.15	55	LTS-98	1.33	0.31	2.12
4	LTS-5	1.33	0.32	2.95	30	LTS-73	1.42	0.36	3.40	56	LTS-99	1.19	0.51	2.95
5	LTS-6	1.40	0.50	3.50	31	LTS-74	1.40	0.50	3.85	57	LTS-100	1.33	0.41	2.30
6	LTS-7	1.45	0.48	3.10	32	LTS-75	1.42	0.35	2.88	58	LTS-101	0.98	0.42	3.55
7	LTS-8	1.35	0.39	2.25	33	LTS-76	1.45	0.38	3.05	59	LTS-102	1.42	0.40	3.20
8	LTS-9	1.38	0.37	1.28	34	LTS-77	1.35	0.41	2.90	60	LTS-103	1.45	0.26	2.13
9	LTS-10	1.45	0.42	3.72	35	LTS-78	1.26	0.47	3.25	61	C1	1.26	0.45	3.15
10	LTS-11	1.35	0.46	3.15	36	LTS-79	1.45	0.44	3.40	62	C2	1.40	0.41	3.80
11	LTS-12	1.40	0.53	2.50	37	LTS-80	1.40	0.31	2.72	63	C3	1.33	0.26	2.75
12	LTS-13	1.45	0.55	3.05	38	LTS-81	1.33	0.51	2.80	64	C4	1.31	0.37	3.85
13	LTS-14	1.28	0.38	3.15	39	LTS-82	1.31	0.54	3.45	65	C5	1.31	0.41	2.55
14	LTS-16	1.47	0.56	2.25	40	LTS-83	1.28	0.26	3.80	66	C6	1.38	0.40	3.20
15	LTS-17	1.45	0.56	2.65	41	LTS-84	1.28	0.37	3.50	67	C7	0.98	0.21	1.17

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16	LTS-18	1.49	0.56	3.35	42	LTS-85	1.38	0.30	3.35	68	C8	1.00	0.31	1.27
17	LTS-20	1.33	0.46	3.35	43	LTS-86	1.28	0.45	3.10	69	C9	1.42	0.41	3.35
18	LTS-21	1.35	0.29	3.40	44	LTS-87	1.12	0.26	3.60	70	C10	1.24	0.42	3.35
19	LTS-22	1.31	0.35	2.95	45	LTS-88	1.35	0.40	3.05	71	C11	1.42	0.51	3.13
20	LTS-23	1.42	0.43	3.10	46	LTS-89	1.28	0.34	1.55	72	C12	1.28	0.47	2.85
21	LTS-24	1.28	0.35	3.20	47	LTS-90	1.35	0.34	3.05	73	C13	1.42	0.53	3.15
22	LTS-25	1.47	0.47	3.15	48	LTS-91	1.33	0.35	3.07	74	C14	1.28	0.22	3.05
23	LTS-27	1.35	0.41	3.20	49	LTS-92	1.35	0.34	3.30	75	C15	1.28	0.41	3.25
24	LTS-29	1.35	0.45	3.20	50	LTS-93	1.31	0.45	3.25		SEM±	0.034	0.007	0.088
25	LTS-30	1.12	0.33	2.60	51	LTS-94	1.26	0.39	3.15		C.D. at 5 %	0.095	0.020	0.246
26	LTS-31	1.35	0.32	2.20	52	LTS-95	1.05	0.39	2.60					

N*: Nitrogen; P*: Phosphorous; K*: Potassium; C1*: BSR-2; C2*: Tekurpeta; C3*: Duggirala Red; C4*: Salem; C5*: Pragathi; C6*: Prathibha; C7*: Myd. Sel (Guntur); C8*: Myd Sel (Kadapa); C9*: Lakadong; C10*: Rajendra Sonia; C11*: Rajendra sonali; C12*: Megha turmeric; C13*: Rajapuri; C14*: Roma; C15: Kasturi.

Supplementary Table 9. Secondary macronutrients (calcium, magnesium, sulphur) assessment in turmeric genotypes

Sl. No.	Genotype	Calcium (%)	Magnesium (%)	Sulphur (%)	Sl. No.	Genotype	Calcium (%)	Magnesium (%)	Sulphur (%)	Sl. No.	Genotype	Calcium (%)	Magnesium (%)	Sulphur (%)
1	LTS-2	0.32	0.38	0.42	27	LTS-33	0.32	0.29	0.33	53	LTS-96	0.24	0.19	0.28
2	LTS-3	0.24	0.14	0.25	28	LTS-35	0.24	0.19	0.25	54	LTS-97	0.48	0.34	0.27
3	LTS-4	0.24	0.34	0.23	29	LTS-47	0.24	0.24	0.23	55	LTS-98	0.27	0.24	0.23
4	LTS-5	0.16	0.24	0.15	30	LTS-73	0.32	0.19	0.13	56	LTS-99	0.24	0.19	0.44
5	LTS-6	0.40	0.14	0.48	31	LTS-74	0.40	0.34	0.21	57	LTS-100	0.32	0.24	0.13
6	LTS-7	0.32	0.22	0.33	32	LTS-75	0.32	0.19	0.11	58	LTS-101	0.40	0.24	0.20
7	LTS-8	0.32	0.19	0.12	33	LTS-76	0.40	0.18	0.27	59	LTS-102	0.40	0.19	0.38
8	LTS-9	0.32	0.14	0.07	34	LTS-77	0.40	0.19	0.22	60	LTS-103	0.32	0.14	0.11
9	LTS-10	0.32	0.19	0.28	35	LTS-78	0.48	0.29	0.20	61	C1	0.32	0.34	0.02
10	LTS-11	0.24	0.29	0.26	36	LTS-79	0.40	0.29	0.33	62	C2	0.40	0.19	0.11
11	LTS-12	0.16	0.38	0.16	37	LTS-80	0.40	0.24	0.15	63	C3	0.32	0.19	0.16
12	LTS-13	0.32	0.29	0.01	38	LTS-81	0.40	0.24	0.11	64	C4	0.16	0.29	0.36
13	LTS-14	0.32	0.19	0.26	39	LTS-82	0.32	0.29	0.12	65	C5	0.32	0.24	0.16
14	LTS-16	0.16	0.38	0.20	40	LTS-83	0.32	0.21	0.37	66	C6	0.32	0.19	0.23
15	LTS-17	0.32	0.38	0.02	41	LTS-84	0.43	0.27	0.19	67	C7	0.32	0.29	0.48
16	LTS-18	0.24	0.19	0.21	42	LTS-85	0.16	0.29	0.15	68	C8	0.32	0.19	0.49
17	LTS-20	0.32	0.38	0.23	43	LTS-86	0.21	0.19	0.21	69	C9	0.48	0.38	0.30
18	LTS-21	0.24	0.19	0.48	44	LTS-87	0.48	0.26	0.22	70	C10	0.24	0.19	0.23
19	LTS-22	0.24	0.24	0.15	45	LTS-88	0.24	0.29	0.27	71	C11	0.32	0.19	0.17
20	LTS-23	0.32	0.14	0.06	46	LTS-89	0.24	0.19	0.22	72	C12	0.43	0.38	0.48
21	LTS-24	0.24	0.24	0.35	47	LTS-90	0.40	0.24	0.29	73	C13	0.24	0.29	0.18
22	LTS-25	0.40	0.26	0.31	48	LTS-91	0.16	0.29	0.35	74	C14	0.40	0.24	0.11

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23	LTS-27	0.24	0.19	0.31	49	LTS-92	0.24	0.29	0.29	75	C15	0.24	0.24	0.07
24	LTS-29	0.40	0.10	0.17	50	LTS-93	0.32	0.19	0.30		SEM±	0.006	0.005	0.005
25	LTS-30	0.24	0.19	0.20	51	LTS-94	0.32	0.29	0.31		C.D. at 5 %	0.017	0.013	0.014
26	LTS-31	0.24	0.19	0.26	52	LTS-95	0.40	0.29	0.34					

C1*: BSR-2; C2*: Tekurpeta; C3*: Duggirala Red; C4*: Salem; C5*: Pragathi; C6*: Prathibha; C7*: Myd. Sel (Guntur); C8*: Myd Sel (Kadapa); C9*: Lakadong; C10*: Rajendra Sonia; C11*: Rajendra sonali; C12*: Megha turmeric; C13*: Rajapuri; C14*: Roma; C15: Kasturi.

Supplementary Table 10. Zinc and iron content (mg/100 g) in various turmeric genotypes

Sl. No.	Genotype	Zinc (mg/100 g)	Iron (mg/100 g)	Sl. No.	Genotype	Zinc (mg/100 g)	Iron (mg/100 g)	Sl. No.	Genotype	Zinc (mg/100 g)	Iron (mg/100 mg)
1	LTS-2	3.95	34.48	27	LTS-33	2.89	36.02	53	LTS-96	2.37	11.59
2	LTS-3	3.73	14.29	28	LTS-35	2.57	14.57	54	LTS-97	3.46	9.93
3	LTS-4	2.41	35.28	29	LTS-47	2.56	15.32	55	LTS-98	2.39	16.17
4	LTS-5	3.95	20.92	30	LTS-73	0.95	22.76	56	LTS-99	3.33	25.31
5	LTS-6	3.98	45.44	31	LTS-74	3.08	53.61	57	LTS-100	3.11	18.87
6	LTS-7	3.97	25.27	32	LTS-75	2.35	33.81	58	LTS-101	2.29	35.96
7	LTS-8	3.91	32.54	33	LTS-76	2.29	25.03	59	LTS-102	0.89	25.17
8	LTS-9	3.00	22.25	34	LTS-77	1.23	30.32	60	LTS-103	1.96	18.15
9	LTS-10	2.02	22.49	35	LTS-78	2.36	38.06	61	C1	2.54	26.31
10	LTS-11	3.96	43.93	36	LTS-79	1.43	47.16	62	C2	2.34	12.88
11	LTS-12	3.10	28.58	37	LTS-80	2.87	39.38	63	C3	2.36	28.55
12	LTS-13	2.96	34.73	38	LTS-81	3.58	55.33	64	C4	1.73	23.21
13	LTS-14	2.95	23.58	39	LTS-82	3.18	37.56	65	C5	1.49	28.40
14	LTS-16	1.08	20.48	40	LTS-83	1.35	12.75	66	C6	2.27	20.77
15	LTS-17	3.89	19.55	41	LTS-84	3.17	35.94	67	C7	2.21	17.13
16	LTS-18	3.90	19.31	42	LTS-85	3.25	16.27	68	C8	2.18	18.71
17	LTS-20	3.94	31.05	43	LTS-86	1.79	14.94	69	C9	1.56	28.50
18	LTS-21	3.93	34.13	44	LTS-87	3.06	17.15	70	C10	2.31	40.50
19	LTS-22	2.41	20.28	45	LTS-88	2.43	14.41	71	C11	2.88	32.16
20	LTS-23	3.92	45.15	46	LTS-89	2.18	13.45	72	C12	3.31	46.71
21	LTS-24	2.39	24.82	47	LTS-90	3.80	22.18	73	C13	2.54	37.91
22	LTS-25	2.75	23.55	48	LTS-91	0.72	16.23	74	C14	2.25	17.97
23	LTS-27	1.70	28.30	49	LTS-92	2.01	14.28	75	C15	2.54	31.44
24	LTS-29	2.80	22.38	50	LTS-93	1.68	15.89		SEM±	0.023	0.370
25	LTS-30	1.40	19.43	51	LTS-94	2.99	25.65		C.D. at 5 %	0.063	1.035
26	LTS-31	1.31	22.26	52	LTS-95	3.10	46.25				

C1*: BSR-2; C2*: Tekurpeta; C3*: Duggirala Red; C4*: Salem; C5*: Pragathi; C6*: Prathibha; C7*: Myd. Sel (Guntur); C8*: Myd Sel

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Supplementary Table 11. Manganese and copper content (mg/100 g) in various turmeric genotypes

Sl. No.	Genotype	Manganese (mg/100 g)	Copper (mg/100 g)	Sl. No.	Genotype	Manganese (mg/100 g)	Copper (mg/100 g)	Sl. No.	Genotype	Manganese (mg/100 g)	Copper (mg/100)
1	LTS-2	6.31	1.32	27	LTS-33	2.03	1.33	53	LTS-96	1.37	0.68
2	LTS-3	2.03	0.09	28	LTS-35	1.58	0.60	54	LTS-97	2.26	1.14
3	LTS-4	3.62	0.77	29	LTS-47	1.75	0.47	55	LTS-98	1.61	0.80
4	LTS-5	2.57	1.26	30	LTS-73	1.58	1.37	56	LTS-99	1.90	1.43
5	LTS-6	3.36	1.47	31	LTS-74	2.39	1.19	57	LTS-100	2.17	1.21
6	LTS-7	3.43	0.74	32	LTS-75	2.42	0.89	58	LTS-101	3.45	1.41
7	LTS-8	3.71	1.45	33	LTS-76	2.08	0.97	59	LTS-102	1.97	0.78
8	LTS-9	2.68	1.14	34	LTS-77	2.40	1.40	60	LTS-103	1.39	0.59
9	LTS-10	2.04	1.21	35	LTS-78	2.67	0.69	61	C1	1.68	1.27
10	LTS-11	3.42	1.06	36	LTS-79	2.55	0.28	62	C2	2.34	1.24
11	LTS-12	6.69	1.06	37	LTS-80	3.70	1.32	63	C3	1.86	1.20
12	LTS-13	5.65	0.86	38	LTS-81	3.26	0.16	64	C4	2.24	0.84
13	LTS-14	4.22	0.76	39	LTS-82	2.45	1.05	65	C5	4.13	0.94
14	LTS-16	7.36	0.85	40	LTS-83	1.54	0.37	66	C6	2.30	1.31
15	LTS-17	5.11	1.19	41	LTS-84	2.01	1.30	67	C7	1.14	1.34
16	LTS-18	3.09	0.76	42	LTS-85	3.05	0.24	68	C8	1.82	1.22
17	LTS-20	4.95	0.43	43	LTS-86	2.26	1.08	69	C9	3.92	1.42
18	LTS-21	4.60	0.85	44	LTS-87	1.92	1.44	70	C10	2.16	1.25
19	LTS-22	4.51	0.82	45	LTS-88	1.63	1.25	71	C11	3.38	1.23
20	LTS-23	3.13	1.35	46	LTS-89	1.54	0.69	72	C12	2.18	0.49
21	LTS-24	1.78	1.08	47	LTS-90	1.76	1.48	73	C13	3.24	1.36
22	LTS-25	4.25	0.53	48	LTS-91	1.60	1.04	74	C14	2.34	0.38
23	LTS-27	1.75	0.73	49	LTS-92	1.76	1.38	75	C15	2.14	1.29
24	LTS-29	2.23	1.31	50	LTS-93	1.74	0.58		SEM±	0.044	0.016
25	LTS-30	1.40	1.01	51	LTS-94	2.52	1.39		C.D. at 5 %	0.122	0.045
26	LTS-31	1.58	0.31	52	LTS-95	2.87	1.46				

C1*: BSR-2; C2*: Tekurpeta; C3*: Duggirala Red; C4*: Salem; C5*: Pragathi; C6*: Prathibha; C7*: Myd. Sel (Guntur); C8*: Myd Sel (Kadapa); C9*: Lakadong; C10*: Rajendra Sonia; C11*: Rajendra sonali; C12*: Megha turmeric; C13*: Rajapuri; C14*: Roma; C15: Kasturi.

Supplementary Table 12. Powder colour of various turmeric genotypes based on Hunter lab colorimeter

Sl. No	Genotype	Hue values			Sl. No	Genotype	Hue values			Sl. No	Genotype	Hue values		
		L	a	b			L	a	b			L	a	b
1	LTS-2	54.6	17	40.4	27	LTS-33	55.8	16.4	39.2	53	LTS-96	59.9	17.3	45.8
2	LTS-3	60	21.1	50.1	28	LTS-35	58.2	23	51.6	54	LTS-97	61.6	21.6	42.2
3	LTS-4	58.4	19.1	45.7	29	LTS-47	56.7	19.1	42.2	55	LTS-98	59.3	19.9	48.8

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4	LTS-5	48	12.7	23.5	30	LTS-73	56.4	20.1	46.1	56	LTS-99	55.4	19.7	42.1
5	LTS-6	48.6	16.7	33.3	31	LTS-74	59.2	14.9	47.1	57	LTS-100	61.7	15.6	50.2
6	LTS-7	58.1	19.2	45.5	32	LTS-75	53	15.4	42.3	58	LTS-101	54.4	17.4	34.7
7	LTS-8	53	16.8	36.3	33	LTS-76	48.7	13	32.1	59	LTS-102	49.9	14.5	35.1
8	LTS-9	60.7	15.3	49	34	LTS-77	55.5	16.1	41.8	60	LTS-103	53.4	16.5	38.9
9	LTS-10	56.5	16.1	41.8	35	LTS-78	59.2	17.8	46.5	61	C1	55.7	15.5	44.6
10	LTS-11	52.2	17.6	18.1	36	LTS-79	54.2	18.2	36.8	62	C2	56	15.8	34.1
11	LTS-12	57	14	42.5	37	LTS-80	57.1	15.3	43.4	63	C3	56.3	13.6	34.2
12	LTS-13	53.5	17.8	47.7	38	LTS-81	55.4	18.2	42.5	64	C4	56.8	15.8	38
13	LTS-14	59.3	18	49.1	39	LTS-82	55.8	17.7	37	65	C5	57	18.2	39
14	LTS-16	63.2	20.8	52.3	40	LTS-83	61.8	21.3	43.1	66	C6	57.6	16.6	40.2
15	LTS-17	60.2	16.4	47.5	41	LTS-84	58.3	17.1	47.8	67	C7	57.9	14.9	38
16	LTS-18	55.9	20.4	32.4	42	LTS-85	57.4	19.4	37.4	68	C8	59.2	17.2	40.4
17	LTS-20	58.7	20.1	43.1	43	LTS-86	62.2	20.8	54.5	69	C9	56.1	17.7	55.1
18	LTS-21	56.1	14	41.8	44	LTS-87	56.1	18.7	47.2	70	C10	56.2	19.2	40.6
19	LTS-22	54.8	16.9	41.8	45	LTS-88	19	12.8	18.1	71	C11	54	18	44.4
20	LTS-23	51	16	34.4	46	LTS-89	59.6	22.5	55	72	C12	62.2	21.6	49.1
21	LTS-24	56.9	20.2	48.3	47	LTS-90	57.7	21.5	46.6	73	C13	57.3	17.8	38.2
22	LTS-25	59.7	17.9	41.5	48	LTS-91	59	20.6	48.4	74	C14	61.5	23.3	50
23	LTS-27	63.4	18.9	55.7	49	LTS-92	58	18.4	47.1	75	C15	56.3	17.7	42.7
24	LTS-29	54.7	17.5	43.4	50	LTS-93	59.8	19.4	54.7		SEM±	0.884	0.452	0.467
25	LTS-30	56.7	20.6	43.1	51	LTS-94	60.3	20.6	41.8		C.D. at 5 %	2.473	1.265	1.305
26	LTS-31	53.5	16.1	37.1	52	LTS-95	57.7	19.4	54.7					

C1*: BSR-2; C2*: Tekurpeta; C3*: Duggirala Red; C4*: Salem; C5*: Pragathi; C6*: Prathibha; C7*: Myd. Sel (Guntur); C8*: Myd Sel (Kadapa); C9*: Lakadong; C10*: Rajendra Sonia; C11*: Rajendra sonali; C12*: Megha turmeric; C13*: Rajapuri; C14*: Roma; C15: Kasturi.

Supplementary Table 13. Estimation of curcumin (%) and antioxidant activity (DPPH activity (%)) of various turmeric genotypes

Sl. No.	Genotype	Curcumin (%)	Antioxidant activity (%)	Sl. No.	Genotype	Curcumin (%)	Antioxidant activity (%)	Sl. No.	Genotype	Curcumin	Antioxidant activity (%)
1	LTS-2	2.27	79.29	27	LTS-33	3.76	74.35	53	LTS-96	1.89	81.12
2	LTS-3	2.66	83.58	28	LTS-35	3.13	79.03	54	LTS-97	1.21	59.35
3	LTS-4	2.01	78.64	29	LTS-47	1.33	57.27	55	LTS-98	1.41	80.69
4	LTS-5	0.59	41.46	30	LTS-73	1.53	74.64	56	LTS-99	2.35	72.06
5	LTS-6	1.69	71.29	31	LTS-74	2.36	82.05	57	LTS-100	1.61	83.43
6	LTS-7	2.61	70.29	32	LTS-75	1.22	68.54	58	LTS-101	2.38	74.99
7	LTS-8	3.65	72.04	33	LTS-76	1.61	71.25	59	LTS-102	2.54	73.90
8	LTS-9	4.63	85.68	34	LTS-77	1.41	81.05	60	LTS-103	2.68	77.49
9	LTS-10	4.09	84.78	35	LTS-78	1.47	83.71	61	C1	3.01	76.38
10	LTS-11	0.71	43.27	36	LTS-79	2.71	76.05	62	C2	1.94	40.16

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11	LTS-12	1.13	49.56	37	LTS-80	1.08	45.37	63	C3	1.11	46.68
12	LTS-13	4.69	86.41	38	LTS-81	2.99	69.59	64	C4	2.07	69.40
13	LTS-14	0.85	44.38	39	LTS-82	3.11	73.68	65	C5	2.57	68.32
14	LTS-16	3.04	71.25	40	LTS-83	3.02	74.18	66	C6	1.76	82.70
15	LTS-17	1.00	45.24	41	LTS-84	1.30	65.39	67	C7	0.63	42.61
16	LTS-18	3.76	74.56	42	LTS-85	1.50	79.74	68	C8	2.83	69.11
17	LTS-20	2.05	74.17	43	LTS-86	1.27	59.46	69	C9	1.59	77.59
18	LTS-21	1.12	48.44	44	LTS-87	3.37	73.30	70	C10	3.97	75.43
19	LTS-22	1.99	76.37	45	LTS-88	0.58	40.63	71	C11	3.85	81.73
20	LTS-23	2.10	75.78	46	LTS-89	1.37	82.26	72	C12	1.50	73.86
21	LTS-24	2.90	74.56	47	LTS-90	3.71	81.26	73	C13	1.53	83.56
22	LTS-25	2.28	82.64	48	LTS-91	2.69	78.74	74	C14	0.70	41.84
23	LTS-27	5.24	87.71	49	LTS-92	1.69	80.51	75	C15	0.71	43.59
24	LTS-29	1.45	77.83	50	LTS-93	2.30	70.54		SEM±	0.020	0.265
25	LTS-30	2.31	76.48	51	LTS-94	1.90	81.18		C.D. at 5 %	0.056	0.742
26	LTS-31	3.20	79.55	52	LTS-95	1.31	82.75				

C1*: BSR-2; C2*: Tekurpeta; C3*: Duggirala Red; C4*: Salem; C5*: Pragathi; C6*: Prathibha; C7*: Myd. Sel (Guntur); C8*: Myd Sel (Kadapa); C9*: Lakadong; C10*: Rajendra Sonia; C11*: Rajendra sonali; C12*: Megha turmeric; C13*: Rajapuri; C14*: Roma; C15: Kasturi

Supplementary Table 14. Economics of different treatments of nutrient rich raw turmeric-based curry for commercialisation

Treatments	Cost of common base (₹)	Turmeric cost (108 ₹/250 g)	Product cost (₹)	Product cost (₹/kg)	Selling price (₹/kg)	Total product cost (₹/100 kg)	Gross income (₹)	Net income (₹)	Returns per rupee
T_1: 0 g of turmeric rhizome + CB	42	-	42/283.1 g	148.4	155	14835.7	15500	664.3	1.04
T_2: 25 g of turmeric rhizome + CB	42	10.8	52.8/308.1 g	171.4	185	17137.3	18500	1362.7	1.08
T_3: 50 g of turmeric rhizome + CB	42	21.6	63.6/333.1 g	190.9	210	19093.4	21000	1906.6	1.10
T_4: 75 g of turmeric rhizome + CB	42	32.4	74.4/358.1 g	207.8	230	20776.3	23000	2223.7	1.11
T_5: 100 g of turmeric rhizome + CB	42	43.2	85.2/383.1 g	222.4	250	22239.6	25000	2760.4	1.12
T_6: 125 g of turmeric rhizome + CB	42	54	96/408.1 g	235.2	270	23523.6	27000	3476.4	1.15

Particulars	Quantity	Amount (₹)	Cost (₹)
Ginger	27.3 g	12.3	45/100 g
Black pepper seeds	0.5 g	0.6	60/50 g
Cumin seeds	2.4 g	2.9	120/100 g
Coriander seeds	2.7 g	1.4	50/100 g

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Curry leaves	1.1 g	0.2	15/100 g
Tamarind	19.3 g	5.2	135/500 g
Dry chillies	3.7 g	2.6	70/100 g
Salt	7.7 g	0.2	25/kg
Water	200 mL (d = g/mL)	0.2	10/20 L
Oil	20 mL (d = 0.92 g/mL)	3	150/L
Packaging material		2	
Cooking, cleaning Packaging and labelling		6.4	
Miscellaneous		5	
Total cost		42	

CB: common base.

Supplementary Table 15. Organoleptic evaluation of raw turmeric-based nutrient rich curry, tray and freeze-dried curry powders for consumer acceptability at ambient temperature (based on hedonic scale)

Treatments	Colour	Flavour	Taste	Texture	Mouth feel	Overall acceptability
T_1 (Raw turmeric-based curry)	7.2	7.4	7.1	7.5	6.9	7.6
T_2 (Tray dried curry powder)	8.4	8.5	8.8	8	8.3	8.7
T_3 (Freeze-dried curry powder)	8.6	8.3	8.6	8.4	7.9	8.6
SEM±	0.069	0.073	0.048	0.049	0.051	0.053
C.D. at 5 %	0.207	0.219	0.143	0.146	0.152	0.159

Supplementary Table 16. Effect of storage on proximate and mineral composition of raw turmeric-based nutrient rich curry, tray and freeze-dried curry powders

Nutrients	Initial			3rd day			Means for treatments			Nutrients	Initial			3rd day			Means for treatments		
	T_1	T_2	T_3	Mean for days	T_1	T_2	T_3	Mean for days	T_1	T_2	T_3		T_1	T_2	T_3	Mean for days	T_1	T_2	T_3	Mean for days	T_1	T_2	T_3
N (%)	0.28	0.77	1.26	0.77	0.21	0.77	1.26	0.75	0.25	0.77	1.26	CP (%)	1.75	4.81	7.88	4.81	1.32	4.81	7.88	4.67	1.53	4.81	7.88
P (%)	1.03	0.21	0.23	0.49	0.83	0.20	0.23	0.42	0.93	0.21	0.23	CF (%)	1.42	2.09	2.26	1.92	1.22	2.07	2.25	1.84	1.32	2.08	2.25
K (%)	0.25	0.97	1.40	0.87	0.14	0.94	1.40	0.83	0.20	0.96	1.40	Ash (%)	0.73	1.09	1.26	1.02	0.65	1.07	1.25	0.99	0.69	1.08	1.25
Ca (%)	0.24	0.32	0.24	0.27	0.16	0.32	0.24	0.24	0.20	0.32	0.24	Zn	0.02	0.10	0.12	0.08	0.01	0.10	0.12	0.07	0.01	0.10	0.12
Mg (%)	0.14	0.19	0.24	0.19	0.10	0.19	0.24	0.18	0.12	0.19	0.24	Fe	6.32	8.40	8.52	7.74	6.07	8.36	8.49	7.64	6.19	8.38	8.50
S (%)	0.03	0.41	0.47	0.30	0.02	0.41	0.47	0.30	0.02	0.41	0.47	Mn	1.93	3.42	3.65	3.00	1.84	3.40	3.65	2.96	1.89	3.41	3.65
Carbs (%)	58.23	61.97	66.67	62.29	61.89	66.62	59.95	63.76	61.93	66.64		Cu	0.29	1.18	1.25	0.90	0.16	1.17	1.25	0.86	0.22	1.17	1.25

Nutrients	Days	Treatments	Days ×	Nutrients	Days	Treatments	Days × Treatments

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	Treatments											
	SEM±	C.D. at 5 %	SEM±	C.D. at 5 %	SEM±	C.D. at 5 %		SEM±	C.D. at 5 %	SEM±	C.D. at 5 %	SEM±	C.D. at 5 %
N (%)	0.018	NS	0.022	0.065	0.031	NS	CP (%)	0.111	NS	0.136	0.407	0.192	NS
P (%)	0.004	0.012	0.005	0.015	0.007	0.021	CF (%)	0.008	0.024	0.010	0.029	0.014	0.041
K (%)	0.022	NS	0.027	0.080	0.038	NS	Ash (%)	0.005	0.014	0.006	0.018	0.008	0.025
Ca (%)	0.011	NS	0.013	0.040	0.019	NS	Zn	0.001	0.004	0.002	0.005	0.002	NS
Mg (%)	0.008	NS	0.010	0.030	0.014	NS	Fe	0.009	0.026	0.011	0.032	0.015	0.045
S (%)	0.007	NS	0.009	0.026	0.012	NS	Mn	0.006	0.017	0.007	0.021	0.010	0.029
Carbs (%)	0.017	0.050	0.021	0.062	0.029	0.087	Cu	0.005	0.016	0.007	0.020	0.009	0.028

T1: nutrient rich raw turmeric curry; T2: tray dried curry powder; T3: freeze-dried curry powder; Zn: zinc; Fe: iron; Mn: manganese; Cu: copper: N: nitrogen; P: potassium; K: potassium; Ca: calcium; Mg; magnesium; S: sulphur (mg/100 g).

Supplementary Table 17. Effect of storage on secondary metabolites, water activity and microbial count of raw turmeric-based nutrient rich curry, tray and freeze-dried curry powders

Attributes	Initial				3rd day				Means for treatments		
	T_1	T_2	T_3	Mean for days	T_1	T_2	T_3	Mean for days	T_1	T_2	T_3
Curcumin (%)	0.15	1.00	0.99	0.72	0.09	0.98	0.98	0.68	0.12	0.99	0.99
Antioxidant activity (%)	75.79	82.43	82.79	80.34	72.75	82.37	82.76	79.29	74.27	82.40	82.78
Water activity	0.82	0.25	0.13	0.40	0.87	0.26	0.14	0.42	0.84	0.26	0.14
Microbial count (Bacteria) (cfu/g)	ND	ND	ND	ND	2.64	ND	ND	0.88	1.32	ND	ND
Microbial count (Mould) (cfu/g)	ND	ND	ND	ND	1.32	ND	ND	0.44	0.66	ND	ND

Attributes	Days		Treatments		Days × Treatments	
	SEM±	C.D. at 5 %	SEM±	C.D. at 5 %	SEM±	C.D. at 5 %
Curcumin	0.002	0.007	0.003	0.008	0.004	0.012
Antioxidant activity	0.118	0.353	0.144	0.432	0.204	0.611
Water activity	0.004	0.012	0.005	0.015	0.007	0.021
Microbial count (Bacteria)	0.003	0.009	0.004	0.011	0.005	0.015
Microbial count (Mould)	0.003	0.009	0.004	0.011	0.005	0.015

T1: nutrient rich raw turmeric curry, T2: tray dried curry powder and T3: freeze-dried curry powder.

Supplementary Table 18. Effect of storage on sensory attributes of raw turmeric-based nutrient rich curry, tray and freeze-dried curry powders for consumer acceptability at ambient

Attributes	Initial				3rd day				Means for treatments		
	T_1	T_2	T_3	Mean for days	T_1	T_2	T_3	Mean for days	T_1	T_2	T_3
Colour	7.91	8.24	8.53	8.23	7.13	8.09	8.32	7.85	7.52	8.16	8.43
Flavour	6.83	7.81	7.57	7.41	5.57	7.64	7.32	6.84	6.20	7.72	7.45
Taste	7.22	8.57	8.36	8.05	6.54	8.29	8.35	7.72	6.88	8.43	8.35

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Texture	7.64	8.46	8.76	8.29	6.93	8.33	8.57	7.94	7.28	8.39	8.67
Mouth feel	7.56	8.53	8.15	8.08	7.17	8.39	7.97	7.84	7.36	8.46	8.06
Overall acceptability	7.76	8.86	8.67	8.43	6.92	8.59	8.32	7.94	7.34	8.72	8.49

Attributes	Days		Treatments		Days × Treatments	
	SEM±	C.D. at 5 %	SEM±	C.D. at 5 %	SEM±	C.D. at 5 %
Colour	0.03	0.10	0.04	0.12	0.06	0.17
Flavour	0.02	0.05	0.03	0.06	0.03	0.09
Taste	0.01	0.04	0.01	0.04	0.02	0.06
Texture	0.01	0.04	0.02	0.04	0.02	0.06
Mouth feel	0.01	0.03	0.01	0.03	0.02	0.04
Overall acceptability	0.02	0.05	0.02	0.06	0.03	0.08

T1: nutrient rich raw turmeric curry, T2: tray dried curry powder and T3: freeze-dried curry powder.

Supplementary Table 19. Effect of storage on proximate and mineral composition of tray and freeze-dried curry powders

Nutrients	Initial			60th day			Means for treatments		Nutrients	Initial			60th day			Means for treatments	
	T_1	T_2	Mean for days	T_1	T_2	Mean for days	T_1	T_2		T_1	T_2	Mean for days	T_1	T_2	Mean for days	T_1	T_2
N (%)	0.77	1.26	1.02	0.35	0.91	0.63	0.56	1.09	CP (%)	4.81	7.88	6.35	2.19	5.69	3.94	3.50	6.78
P (%)	0.20	0.23	0.22	0.07	0.14	0.10	0.14	0.19	CF (%)	2.11	2.24	2.18	1.99	2.15	2.07	2.05	2.20
K (%)	0.96	1.40	1.18	0.65	1.20	0.93	0.81	1.30	Ash (%)	1.12	1.27	1.19	0.87	1.07	0.97	0.99	1.17
Ca (%)	0.32	0.24	0.28	0.24	0.24	0.24	0.28	0.24	Zn	0.11	0.12	0.11	0.07	0.09	0.08	0.09	0.10
Mg (%)	0.14	0.24	0.19	0.10	0.19	0.14	0.12	0.22	Fe	8.42	8.53	8.47	8.12	8.32	8.22	8.27	8.42
S (%)	0.43	0.48	0.45	0.22	0.29	0.26	0.33	0.38	Mn	3.39	3.67	3.53	3.09	3.38	3.23	3.24	3.52
Carbs (%)	62.09	66.73	64.41	61.89	66.63	64.26	61.99	66.68	Cu	1.18	1.28	1.23	0.94	1.14	1.04	1.06	1.21

Nutrients	Days		Treatments		Days × Treatments		Nutrients	Days		Treatments		Days × Treatments	
	SEM±	C.D. at 5 %	SEM±	C.D. at 5 %	SEM±	C.D. at 5 %		SEM±	C.D. at 5 %	SEM±	C.D. at 5 %	SEM±	C.D. at 5 %
N (%)	0.033	0.100	0.033	0.100	0.047	NS	CP (%)	0.207	0.627	0.207	0.627	0.293	NS
P (%)	0.002	0.006	0.002	0.006	0.003	0.009	CF (%)	0.007	0.021	0.007	0.021	0.010	NS
K (%)	0.017	0.050	0.017	0.050	0.023	0.071	Ash (%)	0.011	0.032	0.011	0.032	0.015	NS
Ca (%)	0.015	NS	0.015	NS	0.022	NS	Zn	0.001	0.004	0.001	0.004	0.002	NS
Mg (%)	0.009	0.028	0.009	0.028	0.013	NS	Fe	0.007	0.020	0.007	0.020	0.009	0.029
S (%)	0.007	0.022	0.007	0.022	0.010	NS	Mn	0.007	0.022	0.007	0.022	0.010	NS
Carbs (%)	0.013	0.040	0.013	0.040	0.019	0.057	Cu	0.008	0.023	0.008	0.023	0.011	0.033

T1: nutrient rich raw turmeric curry; T2: tray dried curry powder; T3: freeze-dried curry powder; Zn: zinc; Fe: iron; Mn: manganese; Cu: copper: N: nitrogen; P: potassium; K: potassium; Ca: calcium; Mg; magnesium; S: sulphur (mg/100 g).

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https://doi.org/10.14719/pst.16936

Supplementary Table 20. Effect of storage on secondary metabolites, water activity and microbial count of tray and freeze-dried curry powders

Attributes	Initial			15th day			30th day			45th day			60th day			Means for treatments	
	T_1	T_2	Mean for days	T_1	T_2	Mean for days	T_1	T_2	Mean for days	T_1	T_2	Mean for days	T_1	T_2	Mean for days	T_1	T_2
Curcumin (%)	1.00	1.02	1.01	0.92	0.96	0.94	0.88	0.95	0.91	0.84	0.89	0.87	0.79	0.86	0.82	0.89	0.94
Antioxidant activity (%)	82.12	82.43	82.28	80.76	81.95	81.35	79.79	81.55	80.67	78.07	80.54	79.31	77.14	79.39	78.27	79.58	81.17
Water activity	0.24	0.10	0.17	0.28	0.19	0.24	0.31	0.25	0.28	0.37	0.34	0.35	0.48	0.39	0.44	0.33	0.25
Microbial count (Bacteria)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.27	0.63	0.95	0.25	0.13
Microbial count (Mould)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.74	0.46	0.60	0.15	0.09

Attributes	Days		Treatments		Days × Treatments	
	SEM±	C.D. at 5 %	SEM±	C.D. at 5 %	SEM±	C.D. at 5 %
Curcumin	0.005	0.016	0.003	0.010	0.008	0.023
Antioxidant activity	0.151	0.449	0.096	0.284	0.214	0.636
Water activity	0.007	0.021	0.005	0.014	0.010	0.030
Microbial count (Bacteria)	0.005	0.015	0.003	0.009	0.007	0.021
Microbial count (Mould)	0.004	0.011	0.002	0.007	0.005	0.016

T1: tray dried curry powder; T2: freeze-dried curry powder; microbial count (cfu/g).

Supplementary Table 21. Effect of storage on sensory attributes of tray and freeze-dried curry powders for consumer acceptability at ambient temperature (based on hedonic scale)

Attributes	Initial			15th day			30th day			45th day			60th day			Means for treatments	
	T_1	T_2	Mean for days	T_1	T_2	Mean for days	T_1	T_2	Mean for days	T_1	T_2	Mean for days	T_1	T_2	Mean for days	T_1	T_2
Colour	8.27	8.61	8.44	8.22	8.52	8.37	8.15	8.44	8.30	8.09	8.25	8.17	7.82	8.06	7.94	8.11	8.38
Flavour	8.55	8.25	8.40	8.29	8.16	8.23	8.12	8.06	8.09	7.89	7.65	7.77	7.73	7.42	7.58	8.12	7.91
Taste	8.75	8.48	8.62	8.54	8.32	8.43	8.26	8.21	8.24	8.19	7.68	7.93	7.33	7.16	7.25	8.21	7.97
Texture	8.63	8.23	8.43	8.47	8.17	8.32	8.35	8.04	8.20	8.27	7.32	7.80	7.28	7.25	7.26	8.20	7.80
Mouth feel	8.79	8.63	8.71	8.45	8.51	8.48	8.32	8.30	8.31	8.15	7.85	8.00	7.78	7.62	7.70	8.30	8.18
Overall acceptability	8.84	8.72	8.78	8.68	8.63	8.66	8.23	8.49	8.36	7.45	7.34	7.40	7.27	7.18	7.22	8.10	8.07

Attributes	Days		Treatments		Days × Treatments	
	SEM±	C.D. at 5 %	SEM±	C.D. at 5 %	SEM±	C.D. at 5 %
Colour	0.013	0.038	0.008	0.024	0.018	0.054
Flavour	0.013	0.037	0.008	0.024	0.018	0.053
Taste	0.011	0.032	0.007	0.020	0.015	0.045
Texture	0.010	0.028	0.006	0.018	0.013	0.040

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Mouth feel	0.010	0.031	0.007	0.020	0.015	0.044
Overall acceptability	0.011	0.033	0.007	0.021	0.016	0.047

Treatments	Cost of curry powder (₹/308.1 g)	Drier rent (₹)	Product cost (₹/308.1 g)	Product cost (₹/kg)	Selling price (₹/kg)	Total product cost (₹/100 kg)	Gross income (₹)	Net income (₹)	Returns per rupee
T_1: Tray dried curry powder	52.8	80	132.8	431	600	43100	60000	16900	1.39
T_2: Freeze-dried curry powder	52.8	200	252.8	820	1000	82000	100000	18000	1.22

Particulars	Quantity	Amount (₹)	Cost (₹)
Ginger	27.3 g	12.3	45/100 g
Black pepper seeds	0.5 g	0.6	60/50 g
Cumin seeds	2.4 g	2.9	120/100 g
Coriander seeds	2.7 g	1.4	50/100 g
Curry leaves	1.1 g	0.2	15/100g leaves
Turmeric	10.8 g	10.8	108/250 g
Tamarind	19.3 g	5.2	135/500 g
Dry chillies	3.7 g	2.6	70/100 g
Salt	7.7 g	0.2	25/ kg
Water	200 mL (d = g/mL)	0.2	10/20 L
Oil	20 mL (d = 0.92 g/mL)	3	150/L
Packaging material		2	
Cooking, cleaning Packaging and labelling		6.4	
Miscellaneous		5	
Total cost		52.8	

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