Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI:10.21474/IJAR01/24071
DOI URL: http://dx.doi.org/10.21474/IJAR01/24071

ISSN (O): 2320-5407
ISSN (P): 3107-4928

RESEARCH ARTICLE

COMPREHENSIVE NUTRITIONAL , PHYTOCHEMICAL AND GC–MS PROFILING OF FRESH AND DRIED CHICKPEA (*Cicerarietinum L.*) MICROGREENS

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Manuscript Info

Manuscript History
Received: 18 June 2026
Final Accepted: 20 July 2026
Published: August 2026

Key words:-
Chickpea microgreens; drying; nutritional composition; phytochemicals; GC–MS; functional food.

Abstract

Background: Chickpea (*Cicerarietinum L.)* microgreens are nutrient-rich plant foods containing proteins, minerals, pigments and diverse phytochemicals. This study focused to evaluate the nutritional and phytochemical characteristics of fresh and dried chickpea microgreens and profiled the major phytoconstituents of the dried powder by GC–MS.

Methods: Fresh microgreens and samples dried at 65 °C for 3 h 30 min were analysed for proximate composition, chlorophyll, phenolics, sugars, vitamins, minerals and major phytochemical groups using standard methods. Methanolic extracts of the dried powder were further subjected to GC–MS analysis.

Results: Drying reduced moisture from 89.74 ± 0.01% to 2.85 ± 0.01%. On a dry-weight basis, the dried microgreens contained 37.80 g/100 g protein, 24.77 g/100 g crude fibre and 2.20 g/100 g ash**,** together with appreciable chlorophyll (208.96 µg/g)**,** phenolics (98.82 mg/g**)** and sugars (91.89 mg/g). Potassium (1921.77 mg/100 g), phosphorus (801.85 mg/100 g) and calcium (504.37 mg/100 g) were the predominant minerals. GC–MS revealed diverse phytoconstituents, with major compounds including neophytadiene (17.22%), 13-docosenamide (12.00%), phytol (11.58%), 3-cyclopentylpropionic acid, 2-dimethylaminoethyl ester (6.65%) and n-hexadecanoic acid (5.46%)**.**

Conclusion: Chickpea microgreens demonstrated substantial nutritional and phytochemical potential, while drying produced a low-moisture powder with concentrated constituents. The diverse GC–MS profile highlights its promising potential as a phytochemical-rich functional food ingredient**.**

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Introduction

Chickpea (*Cicerarietinum L.*), commonly known as Bengal gram, garbanzo bean or chana, is an important pulse crop belonging to the family Fabaceae and is widely cultivated and consumed, particularly in South Asia. It is nutritionally valued for its protein, carbohydrates, dietary fibre, essential fatty acids, vitamins and minerals and also contains bioactive compounds such as phenolics, flavonoids, carotenoids and phytosterols (Jukanti*et al*., 2012). However, chickpea contains antinutritional factors, including phytic acid, tannins and enzyme inhibitors, which may influence nutrient bioavailability. Processing techniques such as soaking, cooking and germination can modify these compounds and improve the nutritional quality of legumes (DidaBulbula andUrga, 2018; Idate*et al*., 2021). Germination initiates metabolic and biochemical changes in seeds, including activation of enzymes and mobilization of stored nutrients, which can influence protein digestibility, mineral bioavailability, vitamins and bioactive compounds (Atudorei*et al*., 2021; Waliat*et al*., 2023).

Microgreens are young edible seedlings harvested at an early developmental stage, generally within 7–14 days depending on the species and growing conditions, and are commonly harvested when the cotyledons are fully developed and the first true leaves begin to emerge (Turner *et al*., 2020). They have gained considerable attention as nutrient-dense and functional foods because they can contain appreciable amounts of vitamins, minerals, carotenoids, phenolic compounds and other phytochemicals (Kyriacou*et al*., 2016). Although most microgreen research has focused on vegetables and herbs, legumes also represent promising sources of microgreens because their seeds are naturally rich in protein, dietary fibre, minerals and other nutrients. Germination and early seedling development can further modify the nutritional and phytochemical characteristics of legumes, increasing their potential as value-added food ingredients (Waliat*et al*., 2023).

Among legume microgreens, chickpea is of particular interest because it combines the nutritional value of a pulse with the metabolic changes associated with germination and early plant development. Chickpea microgreens can potentially provide protein, dietary fibre, vitamins, minerals, pigments and phytochemicals, including phenolic and flavonoid compounds with potential biological significance. Sreenivasan (2020) demonstrated the feasibility of producing microgreens from chickpea seeds and reported the potential for repeated harvesting of chickpea shoots. However, compared with conventional chickpea seeds and commonly studied vegetable microgreens, comprehensive information on the nutritional and phytochemical composition of chickpea microgreens remains limited. Therefore, characterization of chickpea microgreens is important to establish their nutritional potential and explore their suitability as a functional food ingredient.

Fresh microgreens are highly perishable because of their high moisture content, making drying an important preservation method for improving storage stability and facilitating their conversion into powders for food applications (Turner *et al*., 2020). Drying reduces moisture availability and microbial deterioration; however, thermal processing can also alter nutrients and phytochemicals depending on temperature and processing duration. Heat may enhance the release of certain compounds through disruption of plant tissues, whereas excessive heating may cause degradation of heat-sensitive vitamins and phytochemicals. Hence, the evaluation of fresh and dried chickpea microgreens is necessary to determine the proximate composition, nutrients, vitamins, minerals and phytochemicals. In addition, phytochemicals such as polyphenols, flavonoids, tannins, anthocyanins and carotenoids are of particular interest because of their contribution to the functional and biological properties of plant foods (Jukanti*et al*., 2012; Waliat*et al*., 2023).

Gas chromatography–mass spectrometry (GC–MS) provides a valuable approach for further characterization of volatile and thermally amenable chemical constituents in plant materials. It enables separation and tentative identification of compounds based on their chromatographic and mass spectral characteristics and can complement conventional nutritional and phytochemical analyses. In the present study, GC–MS was specifically used to characterize the methanolic extract of chickpea microgreens dried at 65°C, and the identified compounds were interpreted with respect to their reported biological activities based on available scientific literature. Although chickpea and microgreens have been extensively studied individually, integrated information comparing the proximate, nutrient, vitamin, mineral and phytochemical composition of fresh and dried chickpea microgreens together with GC–MS characterization of the dried material remains limited. Therefore, the present study was undertaken to evaluate the proximate, nutrient, vitamin, mineral and phytochemical composition of fresh and dried chickpea (*Cicerarietinum L.*) microgreens and to characterize the chemical constituents of the 65°C dried microgreen extract using GC–MS, with the reported biological activities of the identified compounds.

Materials and Methods:-

Collection and Selection of Chickpea Seeds

Healthy, mature and uniform chickpea (*Cicerarietinum L.*) seeds were procured from a reliable local agricultural source. The seeds were manually sorted to remove broken, shrivelled, discoloured and insect-damaged seeds and foreign materials, washed thoroughly with clean water and used for germination and microgreen production.

Seed Preparation and Germination

The cleaned seeds were soaked in distilled water for 8 h at room temperature, following the procedure reported by Kaur*et al*., (2022). After soaking, the excess water was drained and the seeds were rinsed with distilled water. The hydrated seeds were uniformly spread on a clean, moist germination medium and maintained under suitable conditions for approximately 36 h. Adequate moisture was maintained while avoiding excess water to minimise fungal contamination. Uniformly germinated seeds with healthy radicle and shoot development were selected for microgreen cultivation.

Cultivation and Harvesting of Chickpea Microgreens

The germinated seeds were transferred to growing trays (40 × 35 × 6 cm) containing a clean growing medium and uniformly distributed. The trays were maintained under suitable light and temperature conditions with regular irrigation to maintain adequate moisture. The microgreens were cultivated until the cotyledons were fully expanded and the shoots attained the desired stage, approximately the tenth day after germination, as described by Kaur*et al*., (2022). The developed chickpea microgreens were manually harvested at 8.4 cm (Figure I),using clean scissors by cutting the stems close to the growing medium, consistent with the stem-base harvesting approach reported by Sreenivasan (2020).

Figure I. Chickpea microgreens

Preparation of Fresh and Dried Microgreens

A portion of the harvested microgreens was retained as the fresh sample, while the remaining portion was dried in a hot-air oven at 65 °C for 3 h 30 min**,** following a drying temperature comparable to that evaluated by Jaureguiet *al*., (2025) for radish microgreens.The cleaned microgreens were spread uniformly as a thin layer on stainless-steel trays and dried until stable moisture content was obtained. The dried samples were cooled in a dessicator, weighed and ground into a fine powder. The powder was sieved, transferred into clean airtight containers and protected from moisture, light and atmospheric contamination until analysis.

Determination of Moisture, Dry Matter and Drying Yield

Moisture content was determined by the standard oven-drying method to constant weight. Dry matter was calculated as:

Dry Matter (%) = 100 − Moisture content (%)

Drying yield and moisture loss were calculated as:

Drying Yield (%) = (Final dry weight / Initial fresh weight) × 100
Moisture Loss (%) = [(Initial fresh weight − Final dry weight) / Initial fresh weight] × 100

Proximate Composition
Moisture, ash, crude protein, crude fat and crude fibre were determined using standard analytical procedures. Moisture was determined by oven drying, ash by incineration, protein by the Kjeldahl method, fat by solvent extraction and crude fibre by the standard gravimetric method. All analyses were performed in triplicate and expressed as mean ± standard deviation (SD). Dried-sample values were additionally converted to a 100% dry-weight basis (DWB) for appropriate comparison with fresh samples.

Estimation of Total Chlorophyll, Phenolics and Sugars
Total chlorophyll was determined by solvent extraction followed by spectrophotometric measurement and expressed as µg/g sample. Total phenolic content (TPC) was determined using the Folin–Ciocalteu method with gallic acid as the standard and expressed as mg GAE/g sample. Total sugar content was estimated by a standard colorimetric method and expressed as mg/g sample. All analyses were conducted in triplicate and reported as mean ± SD.

Vitamin Analysis
Vitamin A, vitamin C, vitamin E and folate were estimated using appropriate validated analytical procedures for plant-based food samples. Results were expressed per 100 g sample. Analyses were conducted in triplicate and expressed as mean ± SD, with dry-weight conversion applied where appropriate.

Mineral Analysis
The mineral composition was determined following acid digestion of the samples. Iron, calcium, sodium, potassium, zinc and phosphorus were quantified using appropriate atomic spectrometric techniques with calibration standards and reagent blanks. Results were expressed as mg/100 g sample and reported as mean ± SD of triplicate determinations.

Quantitative Phytochemical Analysis
Total polyphenols, flavonoids, tannins, anthocyanins and carotenoids were quantitatively estimated using standard spectrophotometric methods. Total phenolics were determined by the Folin–Ciocalteu method using gallic acid as the standard (Singleton *et al*., 1999). Total flavonoids were estimated using the aluminium chloride method with quercetin as the standard (Chang *et al*., 2002). Tannins were determined using the Folin–Denis method with tannic acid as the standard. Total anthocyanins were estimated using the pH differential method (GiustiandWrolstad, 2001), while carotenoids were determined by solvent extraction and spectrophotometry according to Lichtenthaler (1987). Results were expressed in the respective equivalents and all analyses were performed in triplicate.

Preparation of Extract for GC–MS Analysis:-
The dried chickpea microgreen powder was extracted with methanol using an appropriate extraction procedure. Methanol was selected as the extraction solvent because of its suitable polarity and ability to extract a broad range of plant secondary metabolites, including phenolic compounds, flavonoids and other moderately polar phytochemicals (Alara*et al*., 2021; Dai andMumper, 2010). The extract was filtered, concentrated where required and transferred into suitable autosampler vials for GC–MS analysis.

GC–MS Analysis
GC–MS analysis was performed on the methanolic extract of chickpea microgreens dried at 65 °C. Compounds were tentatively identified based on retention time, mass spectral characteristics and comparison with available spectral library databases. The identified constituents were characterised according to their peak area percentage, molecular formula, functional groups and reported biological activities.

Conversion to Dry-Weight Basis
To facilitate valid comparison between fresh and dried samples, analytical values for dried samples were converted to a 100% dry-weight basis using:
DWB = As-is value × 100 / (100 − Moisture content)
For dried chickpea microgreens containing 2.85% moisture, the dry matter was 97.15%. The conversion was applied where appropriate to proximate, chlorophyll, phenolic, sugar, vitamin, mineral and phytochemical results.

Replication and Statistical Expression:-
All laboratory analyses were carried out in triplicate (n = 3). Results were expressed as mean ± standard deviation (SD). The fresh and dried (Dry weight basis) chickpea microgreens were interpreted with consideration of the respective fresh-weight, dried as-is and dry-weight bases.

Results and Discussion:-

Proximate Compositionof chickpea microgreens:-
The proximate composition of fresh and dried chickpea microgreens is presented in Table I.

TABLE-I Proximate composition of fresh and dried chickpea microgreens (mean ± SD, n = 3)

Parameter (per 100 g)	Fresh – FWB	Dried – As-is basis	Dried –DWB
Moisture (%)	89.74 ± 0.01	2.85 ± 0.01	—
Ash (g)	0.803 ± 0.006	2.14 ± 0.01	2.20 ± 0.01
Crude fat (g)	0.17 ± 0.01	1.51 ± 0.01	1.55 ± 0.01
Crude protein (g)	4.57 ± 0.01	36.72 ± 0.02	37.80 ± 0.02
Crude fibre (g)	3.10 ± 0.01	24.06 ± 0.01	24.77 ± 0.01

Note: FWB = fresh-weight basis; DWB = dry-weight basis. DWB values were calculated using 97.15% dry matter in the dried sample.

The results indicated that fresh chickpea microgreens contained 89.74 ± 0.01% moisture, which decreased to 2.85 ± 0.01% following drying at 65 °C for 3 h 30 min, indicating effective dehydration. The dried sample recorded 2.20, 1.55, 37.80 and 24.77 g/100 g DWB of ash, crude fat, crude protein and crude fibre respectively. These values indicate concentration of the major solid components following moisture removal.

The observed proximate composition is comparable with the nutritional characteristics reported for chickpea and other pulse microgreens. Kaur*et al*. (2022) reported appreciable protein, ash and fibre contents in pulse microgreens, including chickpea, while Zhang *et al*. (2021) described microgreens as nutrient-dense plant foods containing substantial amounts of macronutrients and bioactive constituents. Thus, the values recorded in the present study primarily reflect the concentration of non-water components following dehydration rather than nutrient synthesis during drying.

Total Chlorophyll, Phenolic and Sugar content of chickpea microgreens
The total chlorophyll, phenolic and sugar contents of fresh and dried chickpea microgreens are presented in Table II.

TABLE-II Total chlorophyll, phenolic and sugar content of fresh and dried chickpea microgreens (mean ± SD, n = 3)

Parameter	Fresh – FWB	Dried – As-is basis	Dried –DWB
Total chlorophyll (µg/g)	30.00 ± 1.00	203.00 ± 2.00	208.96 ± 2.06
Total phenolic content (mg/g)	14.70 ± 0.10	96.00 ± 0.20	98.82 ± 0.21
Total sugar content (mg/g)	12.13 ± 0.15	89.27 ± 0.21	91.89 ± 0.22

Note: FWB = fresh-weight basis; DWB = dry-weight basis.

From the results, it was observed that the total chlorophyll, phenolic and sugar contents of the dried microgreens were found to be 208.96 µg/g, 98.82 mg/g and 91.89 mg/g DWB, respectively. The corresponding values in the fresh sample were 30.00 µg/g, 14.70 mg/g and 12.13 mg/g, respectively. The differences between the fresh and dried samples are largely attributable to the reduction in moisture and consequent concentration of the remaining constituents.

Kaur*et al*., (2022) reported appreciable chlorophyll and phenolic constituents in chickpea microgreens, while Zhang *et al*., (2021) identified phenolic compounds and pigments as important components of microgreens. Kainikkara*et al*., (2025) further reported that drying and other processing conditions can influence the nutritional and bioactive composition of microgreens. Therefore, the values obtained in the present study represent the combined effects of dehydration, concentration and possible processing-related changes in constituent stability and extractability.

Vitamin Compositionof chickpea microgreens
The vitamin composition of fresh and dried chickpea microgreens is given in Table III.

TABLE-III Vitamin content of fresh and dried chickpea microgreens (mean ± SD, n = 3)

Parameter (per 100 g)	Fresh – FWB	Dried – As-is basis	Dried –DWB
Vitamin A (µg)	621.33 ± 1.53	4502.00 ± 2.00	4634.07 ± 2.06
Vitamin C (mg)	59.70 ± 0.10	381.00 ± 1.00	392.18 ± 1.03
Vitamin E (mg)	0.377 ± 0.006	2.87 ± 0.06	2.95 ± 0.06
Folate (µg)	41.00 ± 1.00	275.00 ± 1.00	283.07 ± 1.03

Note: FWB = fresh-weight basis; DWB = dry-weight basis.

The vitamin analysis indicated values of 4634.07 µg/100 g vitamin A, 392.18 mg/100 g vitamin C, 2.95 mg/100 g vitamin E and 283.07 µg/100 g folate on a DWB for the dried microgreens. The corresponding fresh-sample values were 621.33 µg/100 g, 59.70 mg/100 g, 0.377 mg/100 g and 41.00 µg/100 g, respectively.

The observed differences are predominantly associated with moisture removal and concentration of the remaining solids. However, the stability of individual vitamins during drying may vary. Vitamin C and folate are relatively sensitive to heat and oxidation, whereas fat-soluble vitamins such as vitamin E are comparatively more stable. Zhang *et al*., (2021) reported that the nutritional composition of microgreens can be influenced by post-harvest handling, while Kainikkara*et al*., (2025) emphasized the effect of processing and drying conditions on nutrient retention in microgreens.

Mineral Compositionof chickpea microgreens
The mineral composition of fresh and dried chickpea microgreens is presented in Table IV.

TABLE-IV Mineral content of fresh and dried chickpea microgreens (mean ± SD, n = 3)

Parameter (per 100 g)	Fresh – FWB	Dried – As-is basis	Dried – DWB
Iron (mg)	3.51 ± 0.01	24.80 ± 0.00	25.53 ± 0.00
Calcium (mg)	70.77 ± 0.15	490.00 ± 0.00	504.37 ± 0.00
Sodium (mg)	19.40 ± 0.10	103.00 ± 0.00	106.02 ± 0.00
Potassium (mg)	427.23 ± 0.15	1867.00 ± 0.00	1921.77 ± 0.00
Zinc (mg)	2.613 ± 0.015	11.50 ± 0.00	11.84 ± 0.00
Phosphorus (mg)	183.67 ± 0.58	779.00 ± 0.00	801.85 ± 0.00

Note: FWB = fresh-weight basis; DWB = dry-weight basis.

The mineral analysis recorded 25.53 mg iron, 504.37 mg calcium, 106.02 mg sodium, 1921.77 mg potassium, 11.84 mg zinc and 801.85 mg phosphorus per 100 g DWB in the dried microgreens. The corresponding values in the fresh sample were 3.51, 70.77, 19.40, 427.23, 2.613 and 183.67 mg/100 g, respectively.

The results indicated that potassium, calcium and phosphorus constituted the major minerals in chickpea microgreens. Since minerals are generally stable during moderate-temperature drying, the differences observed between fresh and dried samples are predominantly attributable to moisture removal and concentration of mineral constituents. Similar mineral-rich profiles in chickpea and other pulse microgreens have been reported by Kaur*et al*., (2022) and Kumar *et al*., (2024).

Phytochemical Compositionof chickpea microgreens
The phytochemical composition of fresh and dried chickpea microgreens is presented in Table V.

TABLE-V Phytochemical content of fresh and dried chickpea microgreens (mean ± SD, n = 3)

Parameter	Fresh – FWB	Dried – As-is basis	Dried – DWB
Polyphenols (mg/g)	0.802 ± 0.002	5.23 ± 0.02	5.38 ± 0.02
Flavonoids (mg/g)	0.0365 ± 0.0001	0.32 ± 0.01	0.329 ± 0.010
Tannins (mg/g)	0.0127 ± 0.0002	0.08 ± 0.01	0.082 ± 0.010
Anthocyanins (µg/g)	0.407 ± 0.012	3.10 ± 0.10	3.19 ± 0.10
Carotenoids (µg/g)	5.10 ± 0.10	40.67 ± 0.15	41.86 ± 0.15

Note: FWB = fresh-weight basis; DWB = dry-weight basis.

The phytochemical analysis recorded 5.38 mg/g polyphenols, 0.329 mg/g flavonoids, 0.082 mg/g tannins, 3.19 µg/g anthocyanins and 41.86 µg/g carotenoids on a DWB in the dried microgreens. The corresponding values in the fresh sample were 0.802, 0.0365 and 0.0127 mg/g, and 0.407 and 5.10 µg/g, respectively.

The results indicated the presence of diverse phenolic and pigment constituents in chickpea microgreens. Kaur*et al*., (2022) reported appreciable phenolic and flavonoid constituents in chickpea microgreens, while Zhang *et al*., (2021) identified phenolics, carotenoids and other pigments as important bioactive constituents of microgreens. Kainikkara*et al*., (2025) reported that drying can influence both the concentration and extractability of phytochemicals. Accordingly, the values obtained in the present study may reflect the combined effects of moisture removal, concentration and processing-related changes in phytochemical stability and extractability.

GC–MS Analysis

The GC–MS analysis of the methanolic extract of chickpea microgreens powder dried at 65 °C for 3 h 30 min revealed a diverse profile of volatile and semi-volatile compounds belonging to terpenoids, fatty acids, fatty acid derivatives, alcohols, phenolics, amides and other oxygenated compounds. The GC–MS chromatogram is presented in Figure II, while the identified compounds, retention time, peak area, molecular formula, functional groups and reported biological activities are presented in Table VI**.**

TABLE – VI MASS SPECTRUM AND BIOLOGICAL ACTIVITIES OF PHYTOCOMPONENTS IDENTIFIED BY GC–MS IN METHANOLIC EXTRACT OF CHICKPEA MICROGREENS POWDER DRIED AT 65°C

S.No.	Name of the Compound	Retention time (min)	Peak Area %	Molecular formula	Major Functional Group(s)	Biological Activity*
1	4H-Pyran-4-one, 2,3-dihydro-3,5-dihydroxy-6-methyl-	9.226	2.69	C6H10O4	Hydroxyl (–OH), ketone (C=O), ether	Antioxidant, antimicrobial
2	9-Octadecene, (E)-	16.230	1.41	C18H36	Alkene (C=C)	Antimicrobial, anti-inflammatory
3	2,4-Di-tert-butylphenol	19.200	1.48	C14H22O	Phenolic –OH	Antioxidant, antimicrobial
4	9-Eicosene, (E)-	21.256	1.55	C20H40	Alkene (C=C)	Antimicrobial, anti-inflammatory
5	Hexadecane	21.431	0.59	C16H34	Alkane	Antimicrobial
6	1-Heptadecene	25.751	1.38	C17H34	Alkene (C=C)	Antimicrobial
7	Cycloheptanone, 2-hydroxy-	26.550	1.60	C7H12O2	Hydroxyl (–OH), ketone (C=O)	Antioxidant, antimicrobial
8	Neophytadiene	26.659	12.08	C20H38	Alkene (terpenoid)	Antioxidant, anti-inflammatory, antimicrobial
9	7-Acetyl-6-ethyl-1,1,4,4-tetramethyltetralin	26.793	5.93	C17H24O	Ketone (C=O), aromatic ring	Antimicrobial, antioxidant
10	Neophytadiene	27.163	1.84	C20H38	Alkene (terpenoid)	Antioxidant, anti-inflammatory, antimicrobial
11	Benzaldehyde, 3-	27.402	3.43	C15H13FO3	Aldehyde, ether,	Antimicrobial, antioxidant

S.No.	Name of the Compound	Retention time (min)	Peak Area %	Molecular formula	Major Functional Group(s)	Biological Activity*
	benzyloxy-2-fluoro-4-methoxy-				methoxy, aromatic	
12	Neophytadiene	27.542	3.30	C20H38	Alkene (terpenoid)	Antioxidant, anti-inflammatory, antimicrobial
13	Lidocaine	27.683	2.17	C14H22N2O	Amide, tertiary amine, aromatic	Local anaesthetic activity
14	7,9-Di-tert-butyl-1-oxaspiro[4,5]deca-6,9-diene-2,8-dione	28.017	2.47	C17H24O3	Lactone/ether, ketone, alkene	Antioxidant, antimicrobial
15	n-Hexadecanoic acid	29.165	5.46	C16H32O2	Carboxylic acid (–COOH)	Antioxidant, anti-inflammatory, antimicrobial
16	Dichloroacetic acid, heptadecyl ester	29.811	0.66	C19H36Cl2O2	Ester, halogen	Antimicrobial, cytotoxic potential
17	Phytol	31.983	11.58	C20H40O	Alcohol (–OH), diterpene/terpenoid	Antioxidant, antimicrobial, anti-inflammatory
18	9,12,15-Octadecatrienoic acid, (Z,Z,Z)-	32.473	3.42	C18H30O2	Carboxylic acid, multiple alkene	Anti-inflammatory, antioxidant
19	Octanoic acid, 2-dimethylaminoethyl ester	35.043	2.35	C12H25NO2	Ester, tertiary amine	Antimicrobial
20	13-Docosenamide, (Z)-	36.327	1.86	C22H43NO	Amide, alkene	Anti-inflammatory, antimicrobial
21	3-Cyclopentylpropionic acid, 2-dimethylaminoethyl ester	37.932	6.65	C12H23NO2	Ester, tertiary amine	Antimicrobial
22	9,12,15-Octadecatrienoic acid, 2,3-dihydroxypropyl ester, (Z,Z,Z)-	38.185	2.00	C21H38O4	Ester, hydroxyl, multiple alkene	Anti-inflammatory, antioxidant
23	Benzyltriethyl-[2,6-xylylcarbamoyl]-ammonium benzoate	38.698	2.08	C26H32N2O3	Amide, quaternary ammonium, aromatic	Antimicrobial
24	Hexadecanoic acid, 2-hydroxy-1-(hydroxymethyl)ethyl ester	38.759	2.32	C19H38O4	Ester, hydroxyl	Antimicrobial, anti-inflammatory
25	7-Tetradecanol, (Z)-	41.582	3.87	C14H28O	Alcohol (–OH), alkene	Antimicrobial
26	13-Docosenamide, (Z)-	42.735	10.14	C22H43NO	Amide, alkene	Anti-inflammatory, antimicrobial
27	Squalene	43.222	1.99	C30H50	Multiple alkene (triterpene)	Antioxidant, anti-inflammatory, anticancer potential
28	Vitamin E	48.404	3.69	C29H50O2	Phenolic –OH,	Antioxidant, anti-

S.No.	Name of the Compound	Retention time (min)	Peak Area %	Molecular formula	Major Functional Group(s)	Biological Activity*
					ether (chromanol)	inflammatory

***Source: Duke (1992)**

The GC–MS profile demonstrated considerable phytochemical diversity in the methanolic extract of dried chickpea microgreens. The major individual constituents were neophytadiene (12.08%), phytol (11.58%), 13-docosenamide (10.14%), 3-cyclopentylpropionic acid, 2-dimethylaminoethyl ester (6.65%), 7-acetyl-6-ethyl-1,1,4,4-tetramethyltetralin (5.93%) and n-hexadecanoic acid (5.46%). The occurrence of diverse terpenoids, fatty acids and phenolic compounds is consistent with the reported phytochemical richness of pulse microgreens (Kaur*et al*., 2022; Kumar *et al*., 2024).

Neophytadiene showed the highest individual peak area (12.08%) and was detected at three retention times, with a combined peak area of 17.22%. Neophytadiene has been reported to possess antioxidant, antimicrobial and anti-inflammatory activities. The occurrence of terpenoidconstituents is consistent with the diverse bioactive profile reported for microgreens (Zhang *et al*., 2021).

Phytol (11.58%) was another predominant constituent. Phytol is a diterpene alcohol associated with chlorophyll metabolism and has been reported to exhibit antioxidant, antimicrobial and anti-inflammatory properties (Duke, 1992). Its substantial representation in the extract may therefore contribute to the overall phytochemical profile of the dried chickpea microgreens.

13-Docosenamide (Z)- was detected at two retention times, accounting for peak areas of 1.86% and 10.14%. Although its combined peak area was 12.00%. Long-chain amides and lipid derivatives have been reported among the chemical constituents of plant-derived extracts (Kumar *et al*., 2024).

The lipid-associated fraction included n-hexadecanoic acid (5.46%), 9,12,15-octadecatrienoic acid (3.42%), its glycerol ester (2.00%), 7-tetradecanol (3.87%) and squalene (1.99%). The identification of 9,12,15-octadecatrienoic acid, corresponding to α-linolenic acid, is nutritionally relevant because it is an essential omega-3 fatty acid. Kaur*et al*. (2022) reported appreciable lipid-associated and nutritional constituents in chickpea and other pulse microgreens, supporting the presence of diverse lipid-derived compounds in the present sample.

The phenolic compound 2,4-di-tert-butylphenol (1.48%) and vitamin E (3.69%) were also detected. Phenolic compounds and tocopherols are recognized for their antioxidant properties, and their occurrence may contribute to the antioxidant potential of plant-derived materials (Duke, 1992; Zhang *et al*., 2021). However, the presence of these compounds in the GC–MS profile should be considered as an indication of potential contribution rather than direct evidence of antioxidant activity in the extract.

The detection of squalene (1.99%) further indicates the presence of triterpenoid constituents. Squalene has been associated with antioxidant and anti-inflammatory properties in the literature (Duke, 1992). The combined occurrence of squalene, phytol, neophytadiene, phenolic compounds and vitamin E demonstrates the structural diversity of the identified phytochemicals.

Several other compounds, including 4H-pyran-4-one derivative, 7,9-di-tert-butyl-1-oxaspiro compound, benzaldehyde derivative and long-chain alcohols, were detected at lower concentrations. These compounds contained functional groups such as hydroxyl, carbonyl, ether, ester and alkene groups and have been associated with various biological activities in phytochemical databases (Duke, 1992). Such compounds may contribute to the overall chemical complexity of the extract.The identification of lidocaine (2.17%) requires particular caution because it is primarily a pharmaceutical compound and is not a characteristic endogenous phytochemical of chickpea.

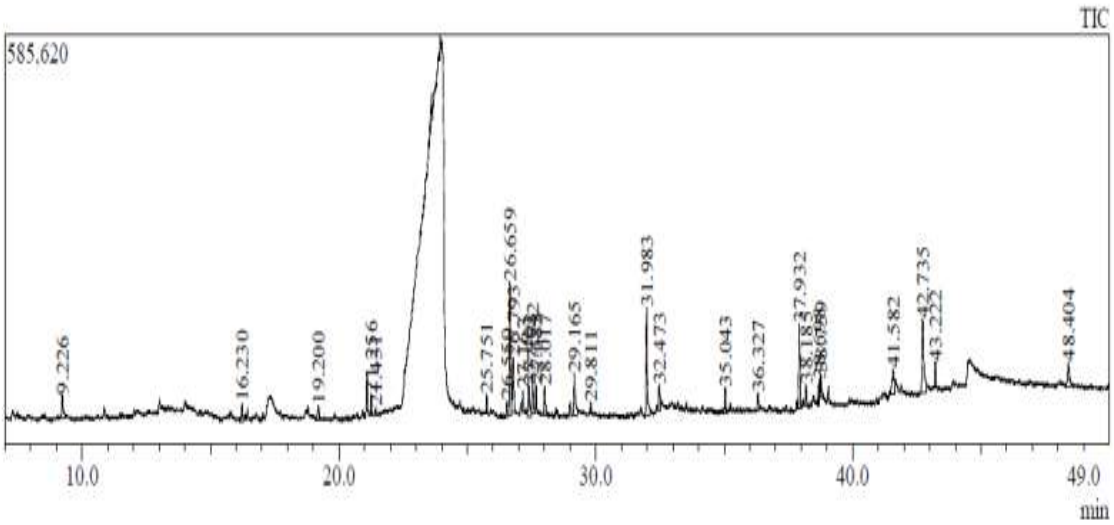

FIGURE – II GC-MS Spectrum of methanolic extract of Chickpea microgreens

Overall, the GC–MS profile of the methanolic extract of chickpea microgreens powder dried at 65 °C demonstrated considerable phytochemical diversity, with constituents belonging mainly to terpenoids, fatty acids, fatty acid derivatives, long-chain alcohols, amides, phenolic compounds and other oxygenated compounds. The major detected constituents included neophytadiene (combined 17.22%), phytol (11.58%), 13-docosenamide (combined 12.00%), 3-cyclopentylpropionic acid, 2-dimethylaminoethyl ester (6.65%), 7-acetyl-6-ethyl-1,1,4,4-tetramethyltetralin (5.93%) and n-hexadecanoic acid (5.46%). The occurrence of terpenoids, phenolic compounds, fatty acids and other bioactive constituents is consistent with the phytochemical diversity reported in chickpea and other pulse microgreens (Kaur*et al*., 2022; Zhang *et al*., 2021; Kumar *et al*., 2024).The identified compounds were predominantly associated with antioxidant, antimicrobial and anti-inflammatory activities**,** while some compounds have been reported to possess additional pharmacological properties (Duke, 1992). The presence of compounds such as phytol, squalene, phenolic derivatives, unsaturated fatty acids and vitamin E further supports the potential functional value of chickpea microgreens **(**Zhang *et al*., 2021). Thus, the GC–MS findings indicate that 65°C dried chickpea microgreens powder contains a chemically diverse array of potentially bioactive constituents, particularly terpenoid, lipid-derived and phenolic compounds, which may contribute to its antioxidant, antimicrobial and anti-inflammatory potential and enhance its suitability as a functional food ingredient.

Conclusion:-

Based on the nutritional, mineral, phytochemical and GC–MS findings, chickpea microgreens powder dried at 65 °C can be strongly recommended as a promising plant-based functional food ingredient for incorporation into value-added food products.The appreciable amounts ofprotein, dietary fibre, vitamins A, C and E and folate and the minerals iron, calcium, sodium, potassium, zinc and phosphorus**,** together withpolyphenols, flavonoids, tannins, anthocyanins and carotenoids**,** demonstrate its potential for nutritional enrichment and functional food development. The diverse phytoconstituents tentatively identified through GC–MS further support its potential as a phytochemical-rich ingredient.The use of dried microgreens in products such as nutrient-dense mixes, snack products, bakery products, extruded foods, beverages and other value-added formulations may provide an effective approach for improving the nutritional and bioactive profile of conventional foods. Recent literature similarly recognizes microgreens as nutrient-dense materials with potential for functional-food and value-added applications, while emphasizing the importance of processing conditions for maintaining their nutritional and phytochemical quality. However, before commercial or therapeutic claims are made, further studies are strongly recommended to validate the antioxidant, antimicrobial and other biological activities through standardized in-vitro assays and evaluate storage stability, bioavailability, safety and sensory acceptability in developed food products.

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