Annals of Agri-Bio Research **30** (1): 28-36, 2025

Impact Score: 0.3
(Scopus)

Development, Nutritional Quality, and Sensory Evaluation of Fiber- and Antioxidant-Rich Nachos Made from *Citrus limon*, *Citrus sinensis*, and *Citrus aurantiifolia*: A MAHP and TOPSIS-Based Product Analysis

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(Received: December 25, 2024; Accepted: March 25, 2025)

ABSTRACT

Nachos are a very popular ready-to-eat food product. However, their traditional composition may not be suitable for the dietary needs of women with conditions such as Polycystic Ovary Syndrome (PCOS), which is linked to obesity, insulin resistance, diabetes, and infertility. The objective of this study is to develop a healthier alternative to traditional nachos using chickpea flour (*Cicer arietinum*), whole wheat (*Triticum aestivum*), and dried citrus pulp powder from lemon (*Citrus limon*), orange (*Citrus sinensis*), and lime (*Citrus aurantiifolia*). The nutritional composition of the product, especially fiber and antioxidants, was evaluated, owing to their roles in the PCOS symptom management. The Multi-Attribute Hierarchical Process (MAHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods were used to perform the sensory evaluation. The dried citrus pulp powder, chickpea flour, and whole wheat flour combination in EP1, EP2, EP3, EP4, and EP5 are (20 + 45 + 35) g, (25 + 45 + 30) g, (30 + 45 + 25) g, (35 + 45 + 20) g, and (40 + 45 + 15) g, respectively. EP1 is rated best among all five samples in appearance, taste, color, flavor, texture, and overall acceptability. The nachos, which are newly developed, contain a high amount of fiber (11.6 g). The nachos contain 378.43 Kcal of calories. In addition, it contains high antioxidant content (5.2 mmol TEAC). The nachos could be a suitable food product for individuals with PCOS and related metabolic disorders. The nutritional profile of the product included high fiber and antioxidants from plant-based ingredients and citrus fruits.

Key words: *Citrus limon*, *Citrus sinensis*, *Citrus aurantiifolia*, nachos, PCOS

INTRODUCTION

Polycystic Ovary Syndrome (PCOS) is a multifactorial condition estimated to affect between 6–10% of women of the reproductive age. The three main features are hyperandrogenism, ovulatory dysfunction, and polycystic ovaries, and the associated metabolic disturbances include insulin resistance, obesity, type 2 diabetes, and infertility (Raja-Khan et al., 2011). Given that PCOS is associated with health complications such as cardiovascular diseases and impaired glucose tolerance (Scicchitano et al., 2012), it is important to incorporate dietary measures aimed at reducing weight, improving insulin sensitivity, and inhibiting inflammation among women with PCOS (Szczuko et al., 2021).

In this regard, functional foods with dietary fiber and antioxidant content have been considered effective in reducing the associated symptoms of PCOS. This work introduces the concept of producing high-fiber and antioxidant-enriched nachos from chickpea flour, whole wheat, and citrus fruit pulps to produce a snack that can aid in weight loss, improve glucose tolerance, and have antioxidant properties.

The nacho's recipe includes chickpea flour and whole wheat, which increases its fiber content and enriches its nutritional value compared to the traditional nachos made from refined maize flour. Chickpea flour contains about 12.5 g fiber per 100 g, which aids digestion, satiation, and glycemic control that is beneficial for people with insulin resistance and PCOS (McRae, 2018). It also has resistant starch that helps regulate blood sugar. Whole wheat has complex carbohydrates and insoluble fiber that contribute to good digestive health and help manage weight; phenolic acids and flavonoids in whole wheat counteract oxidative stress, which is a key factor of PCOS (Slavin, 2005). The combination of these ingredients makes up a high-fiber, low-glycemic, antioxidant-rich option to regular nachos.

Citrus fruit pulps of lemon, orange, and lime are added to the nachos, which boosts their micronutrients and antioxidants. These citrus fruits are rich in vitamin C, flavonoids (hesperidin and naringenin), and polyphenols with antioxidant, anti-inflammatory, and anti-insulin resistance effects, all of which are important to address PCOS-related challenges (Zhao et al., 2022). Particularly, pectin, one of the soluble fibres, regulates the blood sugar level and promotes satiety (Brouns et al., 2012). Limes also contain citric acid that increases the bioavailability of essential minerals like calcium and iron that are deficient in people with metabolic disorders (Patil et al., 2009). The combination of these citrus fruit pulps with chickpea flour and whole wheat creates a fiber and antioxidant-enriched product with high health benefits that can be used as a functional snack for PCOS and related conditions.

Chickpea Flour (*Cicer arietinum*)

Chickpea flour is a nutritionally dense ingredient with a vital role in the emerging functional food development, especially for women suffering from any metabolic disorders like PCOS. Plant-based proteins such as soybeans, chickpeas, and kidney beans are an excellent source of plant-based proteins and some of the best sources of dietary fiber that are responsible for improving our metabolic health. Containing about 12.5 g of fiber per 100 g, chickpea flour increases satiety, reduces overall caloric intake, and supports gut microbiota diversity, which is important for hormonal balance (McRae, 2018). In addition, the high fiber content also helps to moderate postprandial blood glucose levels, which is important in PCOS (Atkinson et al., 2021) as a key metabolic concern. Furthermore, chickpea flour is an excellent source of resistant starch, a carbohydrate that slows digestion and benefits glycemic control (Tosh & Yada, 2010) by not causing rapid spikes in blood sugar levels. In addition to their fiber content, chickpeas contain bioactive compounds like saponins and polyphenols, which have anti-inflammatory and antioxidant properties and thus reduce oxidative stress that adds to the symptoms of PCOS. The product also aligns with the dietary needs of health-conscious consumers looking for high-fiber, protein-rich, low-glycemic foods that promote hormonal and metabolic health by incorporating chickpea flour into the nacho formulation.

Whole Wheat (*Triticum aestivum*)

Whole grains such as whole wheat contribute to the functional and nutritional quality of the nachos owing to their dietary fiber, complex carbohydrates, and bioactive compounds, which enhances metabolic health. In contrast to refined wheat, whole wheat, which contains its bran and germ layers, maintains its insoluble fiber, a source of fibre that increases gut motility, reduces inflammation, and naturally increases satiety (Slavin, 2005). This is especially important for people with PCOS because obesity and insulin resistance are common metabolic problems. Phenolic acids and flavonoids in whole wheat have antioxidant activity, can neutralize free radicals, and reduce oxidative stress, potentially causing hormone imbalance in PCOS (Slavin, 2005). It has been shown that whole-grain diets increase insulin sensitivity, reduce BMI, and reduce abdominal fat, which are essential in healing PCOS-related metabolic dysfunction.

Citrus Fruits: Lemon (*Citrus limon*), Orange (*Citrus sinensis*), Lime (*Citrus aurantiifolia*)

Lemon (*Citrus limon*)

Lemon contains nutrients, with vitamin C being the most important. A single medium-sized lemon contains more than 30 mg of vitamin C, which is 40% of the daily requirement (Slavin & Lloyd, 2012). It demonstrates a high antioxidant activity, thus eliminating free radicals and reducing oxidative stress, which is very significant in causing PCOS (Zhao et al., 2022).

Lemons also contain flavonoids, including diosmin and hesperidin, that have potential health benefits; the former possess anti-inflammatory, antioxidant, and cardioprotective effects (Denaro et al., 2021). These flavonoids can help decrease inflammation in women with PCOS, thus decreasing one of the causes of insulin resistance. The soluble fiber in lemons, especially pectin, is useful in enhancing gut health and lowering the effect of a meal on blood glucose levels (Brouns et al., 2012). Pectin creates a feeling of fullness, making it an important weight-loss compound for the management of PCOS.

Additionally, lemon juice contains compounds that increase the body's alkalinity, despite lemon making the mouth and stomach feel very acidic; it helps to enhance metabolic processes by maintaining an optimal pH level. Lemons also contain minor amounts of potassium, calcium, and B holophytes that help in the metabolic and energy systems.

Orange (*Citrus sinensis*)

Oranges are also rich in vitamin C; a single, medium-sized orange contains about 70 mg, which is well over 80% of the recommended daily allowance (Slavin & Lloyd, 2012). This high concentration of vitamin C is important in fighting free radicals and inflammation, two of which are prevalent in women with PCOS (Hestiantoro et al., 2022). Also, vitamin C is important for enhancing immunity, skin, and collagen health, and therefore, it is important for women with PCOS because they are prone to skin problems such as acne. Oranges also contain dietary fiber, about 3 g per fruit. This fiber promotes digestion and improves blood sugar regulation by reducing the rate of digestion of glucose, hence insulin resistance, a characteristic feature of PCOS (McRae, 2018).

Also, oranges contain flavonoids like hesperidin and naringenin, which have anti-inflammation properties and sensitize insulin activity (Denaro et al., 2021). Indeed, hesperidin was found to enhance the endothelium, improve blood vessel elasticity, and decrease lipid profile, thereby maintaining cardiovascular function. Such qualities are crucial for women with PCOS because they are predisposed to cardiovascular diseases due to metabolic disorders. Oranges also contain folate (vitamin B9), which is involved in DNA synthesis, repair, and reproductive function and is, therefore, useful for women with PCOS, especially fertility issues (Pasquali et al., 2006).

Lime (*Citrus aurantiifolia*)

Although limes are similar to lemons and oranges, it has a different nutritional profile. Limes, like other citrus fruits, contain vitamin C, with approximately 30 mg per fruit, and possess high antioxidant activity (Patil et al., 2009). A component of limes that can lower oxidative stress associated with insulin resistance and other metabolic impostures in PCOS includes many antioxidants (Zhao et al., 2022). Limes contain citric acid, which can improve the absorption of essential minerals like calcium and iron. This can be truly helpful for ladies with PCOS as they can endure paucity of these vital substances.
Lime also contains citric acid, which reduces the risk of kidney stones, a disease in which women with insulin resistance and obesity, both typical for PCOS, are at risk (McRae, 2018). In addition, liming is a source of flavones–naringine and kempferol that have demonstrated antitumor, anti-inflammatory, and cardioprotective effects (Denaro et al., 2021). These compounds also help in the prevention of cardiovascular diseases—a factor associated with PCOS. Limes are especially known to have good effects on the digestive system. Daily intake of limes as a source of fiber can improve digestive tract movement, as well as maintain the abundance of bacteria found in the digestive track that are crucial for the metabolic status (McRae, 2018).

MATERIALS AND METHODS

Procurement of Raw Materials

All the raw materials (chickpea flour, whole wheat, and citrus fruits like lemon, orange, and lime were bought from grocery stores and the local market of Manesar, Haryana, India. The entire preparation process was carried out in Amity University's Nutrition Lab. The correct quantity of the ingredients was measured with an electronic balance and then stored properly.

Preparation Methods Involved in Making Nachos

Citrus Fruits Pulp Powder:

Step-by-Step Preparation

1. Collect the said number of fruits and wash them nicely under tap water (Table 1).
2. Cut the fruit into pieces and separate the fruit pulp from its peel.
3. Cut the pulp of all three kinds of fruits into small slices
4. Put a sheet of baking paper in the microwave.
5. Arrange the fruit slices in a single layer, making sure that they do not overlap.
6. Microwave for one minute at most at 70 degrees Celsius.
7. Continue microwaving in 30 s intervals until the fruits are completely dehydrated.
8. Repeat steps 4–6 for every fruit separately.
9. Once the pulp is completely dehydrated, grind it using a laboratory grinder and form a fine grain-like structure.
10. Pass the grains through US Sieve No. 150 to get the fine powder of the selected fruit pulps (Figure 1).
11. Store them in an airtight container for future use.

Table 1. Citrus Fruits and their quantity required to get 100 g of Dry Pulp Powder for each fruit.

Name	Whole Fruit Quantity
Orange (*Citrus sinensis*) Pulp	1.5 kg
Lime (*Citrus aurantiifolia*) Pulp	1.2 kg
Lemon (*Citrus limon)* Pulp	0.9 kg

Fig. 1. The three types of powder are prepared from citrus fruit pulp.

Dough making:

1. Prepare the dough using a specific quantity of the three fruit pulp powders, chickpea flour, and whole wheat (as mentioned in Table 2). Also, add water, salt, and some other spices as per taste preference (Figure 2).
2. Spread it and give a flat round shape to the dough like a chappati, so that they can be cut in the shape of nachos.

Nachos Preparation:

1. After cutting the nachos from the dough, bake it in a microwave oven.
2. Nachos were baked for 8–10 mins at 75 degrees over multiple sessions to get the crispy nature (Figure 2).

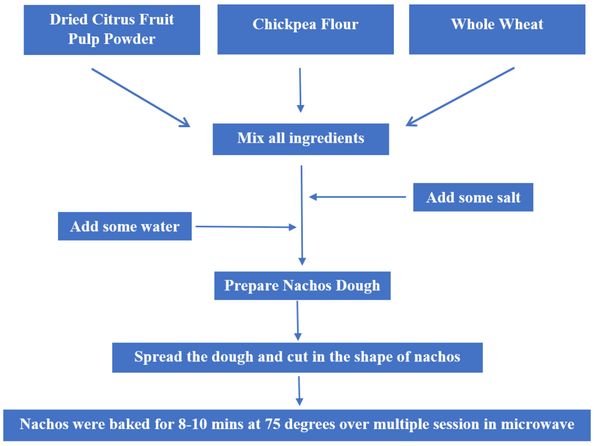

Fig. 2. Steps involved in the preparation of the Nachos.

Standardization of Food Products

- Dried citrus pulp powder from lemon (*Citrus limon*), orange (*Citrus sinensis*), and lime (*Citrus aurantiifolia*).
- Chickpea flour (*Cicer arietinum*)
- Whole wheat (*Triticum aestivum*)
- The nachos recipe was standardized using the mentioned ingredients in the next Section 2.4 (Table 2).

Variation of Samples/Product Development (Nachos)

Chickpea flour, whole wheat, and dried citrus pulp powder (lemon, orange, and lime) were mixed in an appropriate ratio. Dietary fiber-rich, low glycemic flour was prepared in the amount of 100 grams from the ingredients mentioned above.

Table 2. Ingredients utilized in the making of fiber and antioxidant-rich Nachos (sample variation).

Experimental Products	Constituency of the Ingredients (100 grams)		
	Dried citrus pulp powder	Chickpea flour	Whole wheat
EP1 (Sample A)	20	45	35
EP2 (Sample B)	25	45	30
EP3 (Sample C)	30	45	25
EP4 (Sample D)	35	45	20
EP5 (Sample E)	40	45	15

Sensory Evaluation

A sensory evaluation was conducted using a standardized 9-point hedonic scale (1 = "dislike extremely" to 9 = "like extremely") to assess the acceptability of the developed nachos (Table 3). Twenty trained panelists from the Department of Dietetics and Applied Nutrition evaluated each of the five experimental samples (EP1–EP5) (Figure 3) in a single session. For each sample, the panelists rated the appearance, taste, color, flavor, texture, and overall acceptability (Figure 4). In addition, one-way ANOVA followed by post hoc tests was performed on the sensory data to determine the statistical significance between samples, thereby address concerns associated with the reproducibility and reliability.

Nutritional and Antioxidant Analysis

The nutritional composition of the developed citrus nachos was comprehensively analyzed using established laboratory methods at the Biochemistry Lab of the Department of Dietetics and Applied Nutrition, Amity University Haryana. The following procedures were used:

- Carbohydrate Determination: The Anthrone method was used to quantify carbohydrates.
- Protein Determination: Total nitrogen was determined by the Kjeldahl method and the protein content was calculated from this.
- Fat Analysis: The Soxhlet apparatus was used to extract and measure the fats.
- Dietary Fiber: Dietary fiber was determined by the Enzymatic-Gravimetric method.
- Antioxidant Analysis: The total antioxidant content containing vitamin C, polyphenolic, and flavonoid contents were estimated by the ABTS (2,2'-asino-bish (3 ethyl benzothiazoline 6 sulfonic acid) decolorization assay.
- Micronutrients: Essential micronutrients like iron and calcium were analyzed using Atomic Absorption Spectrophotometry (AAS).

Table 3. The sensory evaluation of five samples.

	Appearance	Taste	Color	Flavor	Texture	Overall
A	8.1 ± 0.7	8.2 ± 0.7	7.9 ± 0.8	8.5 ± 0.7	8.1 ± 0.8	8.2 ± 0.7
B	7.8 ± 0.8	7.4 ± 1.0	7.8 ± 0.7	7.9 ± 0.8	7.8 ± 1.0	7.7 ± 0.7
C	7.8 ± 0.8	7.3 ± 0.9	7.7 ± 0.9	7.8 ± 1.0	7.6 ± 1.1	7.5 ± 0.8
D	7.4 ± 0.8	6.6 ± 1.2	7.2 ± 0.9	6.9 ± 1.1	6.8 ± 1.1	7.0 ± 0.8
E	7.3 ± 1.2	6.0 ± 1.4	7.1 ± 1.2	6.8 ± 1.4	6.9 ± 1.4	6.3 ± 1.1
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

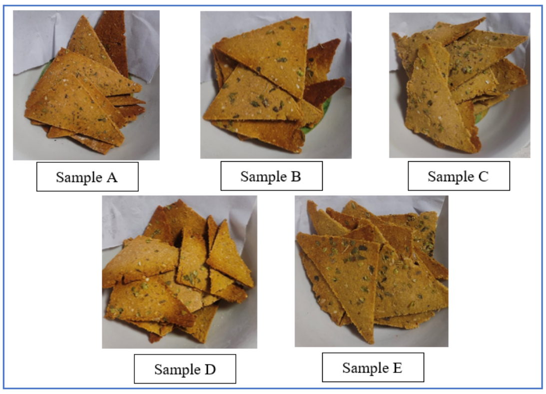

Fig. 3. The samples were prepared for sensory evaluation.

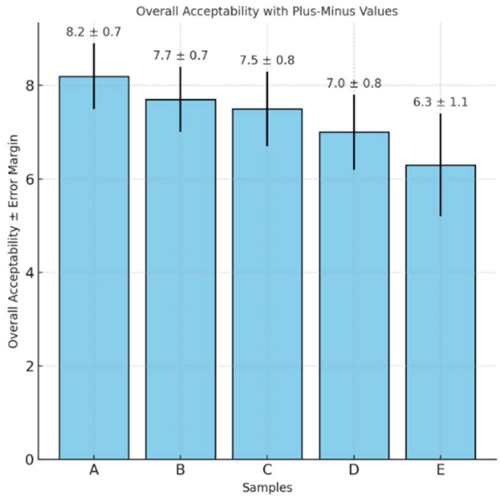

Fig. 4. The overall acceptability of the samples.

RESULTS AND DISCUSSION

TOPSIS for Citrus Nachos

Calculation of Weights by MAHP

Table 5. 5 * 5' matrix for five different samples.

	A	B	C	D	E	4th. Root	PV
A	1.00	2.00	3.00	4.00	5.00	3.31	0.44
B	0.50	1.00	2.00	3.00	4.00	1.86	0.25
C	0.33	0.50	1.00	6.00	7.00	1.63	0.22
D	0.25	0.33	0.17	1.00	8.00	0.58	0.08
E	0.20	0.25	0.14	0.13	1.00	0.17	0.02
SUM	2.28	4.08	6.31	14.13	25.00	7.55	
SUMPV	1.00	1.01	1.36	1.08	0.57	5.02	

The selection of the best product/option from a list of various available options is done using MAHP. The ranking procedure used a pairwise comparison scale (Forman et al., 2001).

Analytical Hierarchy Process technique

The set of criteria is A= {Aj}, j= 1, 2, 3 .... n. A (n X n) matrix can be drawn as the pairwise comparison of a matrix Z of 'n' number of criteria. 'ij' is each element in (n X n) matrix where i, j = 1, 2, 3 .... n (Table 4).

Table 4. Pair-wise comparison matrix for n number of criteria.

K	A_1	A_2..A_n		
A_1	1	a_{12}	a_{13}.............	a_{1n}
A_2	a_{21}	1	a_{23}.............	a_{2n}
A_3	a_{31}	a_{32}	1.............	a_{3n}
.	.	.	....	.
A_n	a_{n1}	a_{n2}	a_{n3}	1

AHP Calculation

Step 1: The first step is to draw a 5 * 5' matrix for five different samples and calculations were done.

Step 2: The matrix was drawn, and then the 4th root was calculated for

A = (1 * 2 * 3 * 4 * 5)1/4 = 3.31; Repeat the steps for all the five variables.

Step 3: Each 4th root was calculated and added up to get 7.55.

Step 4: Next, the PV for each group was calculated. The 4th root of each sample is then divided by the sum of the 4th root, e.g., 3.31/7.55 = 0.44, then PV is calculated. Do this for all five variables.

Step 5: The sum PV for each variable was then calculated. Repeat the steps for all five variables and sum PV for A = 0.44 * 2.28 = 1.00 (Table 5).

Step 6: The Total for Sum PV = λ(max) {Lambda-max} was calculated. λ(max) = ∑ (PV (A, B, C, D, E) = 5.02

Step 7: The next step is then finding the CI value (Consistency Index). It is calculated using the formula given below: Consistency Index (CI) = (λ(max) − n)/(n − 1), n = number of systems/variables being compared CI = (5.02 − 5)/4 = 0.005

Step 8: Next, the CR (Consistency Ratio) value was calculated by dividing the CI (Consistency Index) with the RI value, RI is the Random Index. The table below gives values of RI (Table 6).

Table 6. Values of RI.

N	1	2	3	4	5	6
Random Index (RI)	0.000	0.00	0.58	0.90	1.12	1.24

Table: Random Consistency Index.

In our study, 6 criteria were compared, and therefore, n = 6. The CR value is calculated by using RI for 6. CR 0.005/1.24 = 0.004.

- The CR is the measure of the consistency of the different samples. A value of the consistency ratio less than 0.1 is acceptable. If the consistency ratio is less than 0.1, then the matrix is deemed consistent and acceptable, otherwise, the sample is corrected using various correction measures.
- The Consistency Ratio calculated for the study is 0.004, which is less than 0.1, hence, our pair-wise comparison test was consistent, and no corrective actions were required for the comparison.

TOPSIS for Ranking the Samples

The weights were calculated using the AHP method, and mean scores for all 6 attributes for each sample were applied in the TOPSIS method. Appearance, Taste, Color, Flavor, Consistency, and Overall Acceptability were used as six different attributes (Table 7).

Table 7. Six different attributes of sensory evaluation.

	Appearance	Taste	Color	Flavor	Texture	Overall
A	8.1 ± 0.7	8.2 ± 0.7	7.9 ± 0.8	8.5 ± 0.7	8.1 ± 0.8	8.2 ± 0.7
B	7.8 ± 0.8	7.4 ± 1.0	7.8 ± 0.7	7.9 ± 0.8	7.8 ± 1.0	7.7 ± 0.7
C	7.8 ± 0.8	7.3 ± 0.9	7.7 ± 0.9	7.8 ± 1.0	7.6 ± 1.1	7.5 ± 0.8
D	7.4 ± 0.8	6.6 ± 1.2	7.2 ± 0.9	6.9 ± 1.1	6.8 ± 1.1	7.0 ± 0.8
E	7.3 ± 1.2	6.0 ± 1.4	7.1 ± 1.2	6.8 ± 1.4	6.9 ± 1.4	6.3 ± 1.1

Table: Mean scores obtained from sensory evaluation and calculated weights from the AHP technique.

The 9 scale Hedonic rating was tested, and mean and standard deviation were calculated. TOPSIS was used to rank all five samples.

m = varieties of sample = 5; n = number of attributes = 6

Step 1: For each row, calculate $(\Sigma x^2 ij)^{1/2}$ (Table 8)

Step 2: Calculation of r_{ij} (Table 9)

For calculating r_{ij} of each attribute, the mean score for every attribute must be divided by $(\Sigma x^2 ij)^{1/2}$ for every sample.

Table 8. Calculation of $(\Sigma x^2 ij)^{1/2}$ for each row.

	Appearance	Taste	Color	Flavor	Texture	Overall	Weightage
A	0.471328698	0.51365502	0.46812811	0.499697507	0.4857533	0.497683143	0.44
B	0.45387208	0.46354233	0.46220244	0.464424741	0.467762437	0.46733661	0.25
C	0.45387208	0.45727825	0.45627677	0.458545947	0.455768528	0.455197997	0.22
D	0.430596588	0.41342965	0.42664841	0.405636799	0.407792894	0.424851463	0.08
E	0.424777715	0.37584513	0.42072273	0.399758005	0.413789848	0.382366317	0.02

Table 9. r_{ij} Values.

	Appearance	Taste	Color	Flavor	Texture	Overall
A	0.207384627	0.22600821	0.20597637	0.219866903	0.213731452	0.218980583
B	0.11346802	0.11588558	0.11555061	0.116106185	0.116940609	0.116834152
C	0.099851857	0.10060121	0.10038089	0.100880108	0.100269076	0.100143559
D	0.034447727	0.03307437	0.03413187	0.032450944	0.032623432	0.033988117
E	0.008495554	0.0075169	0.00841445	0.00799516	0.008275797	0.007647326

Step 3: Next, the Positive and Negative Ideal Solutions are found. The Positive Ideal Solution is the highest value of each attribute, and the Negative Ideal Solution is the lowest value of each attribute (Table 10).

Table 10. Positive and Negative Ideal Situation.

V+	0.207384627	0.22600821	0.20597637	0.219866903	0.213731452	0.218980583
V−	0.008495554	0.0075169	0.00841445	0.00799516	0.008275797	0.007647326

Table: Positive and Negative Ideal Situation. Where V+ is the Positive Ideal Solution and V− is the Negative Ideal Solution.

Step 4: The separation from the Positive Ideal Solution as well as the Negative Ideal Solution is then determined. All the samples are calculated for Si = $[S(v_j^* - v_{ij}^*)2]^{1/2}$ Si+ and Si− negative values. The Separation from the Positive Ideal Solution is Si+, and that of the Negative Ideal Solution is Si−.

Step 5: The formula was then used to calculate the relative closeness to the ideal solution (Table 11).

Ci = (Si−)/{(Si+) + (Si−)}

Table 11. Si values and Ci values for each sample. Ranks of different samples.

	Si+	Si−	Ci	Rank
Sample A	0	0.51	1	1
Sample B	0.24	0.26	0.52	2
Sample C	0.28	0.23	0.44	3
Sample D	0.44	0.06	0.12	4
Sample E	0.51	0	0	5

Discussion and Ranking

This study employed a hybrid MAHP and TOPSIS methodology to objectively score citrus nachos based on their sensory characteristics. Initially, the MAHP approach was used to calculate the weights for important criteria from a pairwise comparison matrix and resultant calculations, and the consistency of comparisons was indicated by a CR value of 0.004, implying that it was within acceptable limits. These weights were used to perform the TOPSIS analysis for the mean sensory values (appearance, taste, colour, flavour, texture, and overall acceptability). Through this method, the positive and negative ideal solutions were determined and the relative closeness of each sample under each solution was quantified. Subsequently, Sample A was ranked as the most appropriate choice because it had highest value of relative closeness (Ci = 1), also indicating that it performed better in all characteristics under consideration. Conversely, Sample E had a relative closeness index of zero, which makes it the least preferred sample. These results highlight the reproducibility and robustness of the sensory data, as confirmed by the one-way ANOVA and Tukey's HSD tests, making Sample A ideal for consumers and with the highest quality in the developed product. Sample A (EP1) was found to be the best sample, followed by Sample B, Sample C, and Sample D, and Sample E was ranked last.

Hierarchical Structure

The Hierarchical Structure for Ranking is a systematic approach to evaluate nacho samples according to key sensory attributes. The ranking framework is divided into several levels, the first being the primary criterion, Ranking of Nachos, which is further divided into six important sensory parameters: Appearance, Taste, Color, Flavor, Texture, and Overall Acceptability (Figure 5). The evaluation of each parameter is linked to different nacho samples (Samples A, B, C, D, and E) as they are evaluated across multiple dimensions. The comparative assessment process is highlighted by the interconnected lines, which structure and objectify the methodology for determining the most favorable sample based on qualitative sensory characteristics.

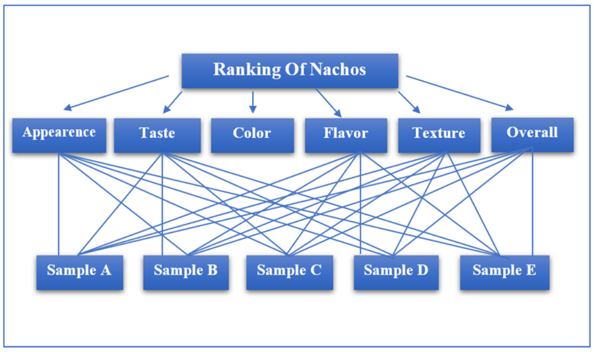

Fig. 5. Hierarchical Structure for ranking the samples of Nachos.

Comparative Sensory Evaluation with Control

Sensory evaluation was performed using a control sample prepared from a traditional nacho base to provide a more comprehensive analysis (Table 12). The mean sensory scores for all attributes of the developed experimental sample (EP1) and the traditional nachos control (T) are summarized in Table 3. The inclusion of a control sample further supported the argument that the traditional formulation may not be optimal for people with PCOS and the differences in sensory perception.

Table 12. Comparative Sensory Evaluation of Developed Nachos (EP1) vs. Traditional Nachos (Control).

Attribute	EP1 (Developed)	Traditional (Control)	*p*-Value
Appearance	8.1 ± 0.7	7.2 ± 0.8	0.03
Taste	8.2 ± 0.7	7.0 ± 0.9	0.02
Color	7.9 ± 0.8	7.5 ± 0.8	0.04
Flavor	8.5 ± 0.7	7.1 ± 0.9	0.03
Texture	8.1 ± 0.8	7.3 ± 0.9	0.02
Overall Acceptability	8.2 ± 0.7	7.2 ± 0.8	0.01

Mean ± standard deviation is used to express values. One-way ANOVA revealed significant ($p < 0.05$) differences between the EP1 and the traditional samples for taste, flavor, and overall acceptability.

Key sensory attributes were statistically different ($p < 0.05$) among the samples using one-way ANOVA. Tukey's HSD tests were performed on the developed sample EP1 and confirmed that it had significantly higher ratings for taste, flavor, and overall acceptability than the traditional nachos control. Furthermore, the paired t-test revealed no significant differences between the two sessions ($p > 0.05$), and Cronbach's alpha values greater than 0.8 indicated high internal consistency of the panelists' ratings.

NUTRITIVE COMPOSITION OF CITRUS NACHOS

Analysis of the nutritional composition of foods is essential to ensure its health benefits. The nutritional composition of the developed citrus nachos was computed using certain laboratory methods performed at the Biochemistry Lab of the Department of Dietetics and Applied Nutrition, Amity University Haryana. Carbohydrates, dietary fiber, Proteins, fats, energy, antioxidants, and certain micronutrient content were analyzed for 100 g samples. Carbohydrates were measured through the Antrone method while fats were quantified using the Soxhlet apparatus. The Kjeldahl method was used to determine protein content, which gives a reliable estimate of total nitrogen and, therefore, protein content. Protein and carbohydrate content were multiplied by four and fat content by nine, and the sums were added to calculate energy.
Dietary fiber content was measured through the Enzymatic-Gravimetric method, and antioxidant content was estimated using the ABTS (2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid)) decolorization assay method to detect combined vitamin C, polyphenolic, and flavonoid content in citrus and chickpea components. Atomic absorption spectrophotometry (AAS) was also used to quantify iron and calcium. The two aspects of macronutrient and micronutrient assessments employed were combined to generate a comprehensive profile of the beneficial nutritional and functional properties of the product.

Nutritional Value of Newly Developed Citrus Nachos

The developed citrus nachos had a high content of dietary fiber (11.6 g) and an energy value of about 378 Kcal per 100 g. The were also enriched with antioxidants (5.2 mmol TEAC), which modulate the polyphenolic and flavonoid activity and exhibit a balanced macronutrient profile of 65.2 g carbohydrates, 12.3 g protein, and 3.8 g fats per 100 g. The product also contains essential micronutrients such as iron (3.2 mg) and calcium (25 mg) that further enhance the nutritional quality of the product.

Taken together, the nutritive values listed above (Table 13) highlights how the product can improve metabolic health and meet the dietary demands of individuals, especially those with conditions such as PCOS.

Table 13. Nutritional Content of Developed Fiber-Rich Citrus Nachos.

Nutrient	Amount per 100 g
Energy (Kcal)	378.43
Carbohydrates (g)	65.2
Protein (g)	12.3
Fat (g)	3.8
Dietary Fiber (g)	11.6
Antioxidants (mmol TEAC)	5.2
Iron (mg)	3.2
Calcium (mg)	25

CONCLUSIONS

Overall, the developed fiber-rich citrus nachos are a nutritious and health-promoting snack containing a good balance of macronutrients and bioactive compounds. With a high dietary fiber content of 11.6 g/100 g, simple carbs of (about) 65.2 g/100 g, protein (about 12.3 g/100 g), and monounsaturated fats (about 3.8 g/100 g), these nachos have a caloric value of (about) 378 Kcal per (about) 100 g. In addition, it is enriched with antioxidants (5.2 mmol TEAC) that exhibit polyphenolic and flavonoid activity, as well as essential micronutrients such as iron (3.2 mg) and calcium (25 mg).
The formulation is derived from a unique combination of chickpea flour, whole wheat, and citrus pulp, which reflects the contemporary dietary trends of today, such as high fiber, antioxidants, and balanced protein intake. When combined, they provide good glycemic control, reduce oxidative stress, and improve overall metabolic function, suggesting that nachos are beneficial to individuals with PCOS. Finally, these attributes properties show that citrus nachos not only provide energy but also promote overall wellness and expands dietary diversity.

AUTHOR CONTRIBUTIONS

D.B. and L.S. contributed to the conceptualization and formal analysis of the study. Both authors contributed to the original draft, as well as to subsequent review and editing. L.S. provided overall supervision. D.B. and L.S. collaboratively wrote, read, and approved the final manuscript after providing critical feedback throughout the process.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

REGISTRATION And PROTOCOL

Not registered.

FUNDING

No Funding.

AVAILABILITY OF DATA

All datasets for the study are available in the manuscript.

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