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Evaluation of The Quality Characteristics of Tortilla Chips Fortified With Defatted Corn Germ Flour

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ABSTRACT

This study investigated the effects of using defatted corn germ flour (DCGF) in preparing tortilla chips on the physicochemical, texture, microstructure, antioxidant, and sensory properties of the final product. Defatted corn germ flour was added to tortilla chip formulations at 0%, 5%, 10%, and 15%. The results showed that fortification with DCGF increased the protein and ash contents and decreased the carbohydrate content of tortilla chips compared to the control samples (100% corn flour), while the fat content was not significantly affected even with the addition of 10% DCGF. Additionally, fortification with DCGF increased tortilla chips' essential amino acid content, total phenolic, total flavonoids, and antioxidant activity. Fortification at 5% and 10% DCGF reduced the water-holding capacity of tortilla chips compared to the control sample, while their oil-holding capacity was not significantly affected. The hardness of tortilla chips decreased after fortification with 5% and 10% DCGF and increased with 15% DCGF. Higher cohesiveness, springiness, gumminess, chewiness, and fracturability values were observed in the 15% DCGF samples. According to the sensory evaluation of tortilla chips, fortification with 15% DCGF was found to be acceptable by participants, but the highest sensory acceptance rates were observed in the 5% and 10% DCGF samples. Therefore, this study recommends the use of DCGF as a nutritional and functional ingredient at 5% and 10% in the preparation of tortilla chips.

1. Introduction

Convenience food that is typically consumed between meals is known as snack food. While people of all ages consume snacks, children are the ones who enjoy them the most. During the growth stage of children, they need a diet that contains a higher percentage of protein and energy. To meet their nutritional needs, snacks should be healthy (Ochoa-Martínez et al., 2016; Chhabra et al., 2017 and Buzgau et al., 2023). Snack products have become a significant part of the human diet in the majority of nations worldwide due to their steadily rising consumption. As a result, the nutritional and energy content of snacks should adhere to strict guidelines. These products are frequently enhanced with healthy or functional ingredients (Pęksa et al., 2010 and Njike et al., 2016). One important way to ensure that consumers have healthy food choices is to incorporate nutrients directly into snacks. Grains are an important source of protein and energy for human nutrition, but a diet based solely on grains is deficient in essential amino acids such as lysine (Shewry 2007). Cereals and grains are the main ingredients in the most popular extruded snacks because of their excellent expansion properties; however,

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they are typically low in protein and many other nutrients (Gimenez et al., 2013). Given its dual use as human food and animal feed, corn is one of the most extensively grown and consumed cereals, with production taking place across vast regions of the world (Gwirtz and Garcia-Casal, 2014; Erenstein et al., 2022; Madhu, 2022). Corn is increasingly being used as an ingredient in ready-to-eat (RTE) breakfast cereals, snacks, and mixes as consumers look for quick and convenient foods that satisfy their nutritional and health needs. This grain has received recent recognition for being a viable choice for making gluten-free products, which can help individuals suffering from celiac disease avoid its symptoms. Food processors and the dry-milling industry are searching for corn with higher yields and improved quality to enhance the quality of their finished products (Serna-Saldivar and Pérez-Carrillo, 2019). According to Anderson and Almeida (2019), the endosperm, germ, and bran make up 80%, 13%, and 7% of the total weight of corn kernels, respectively. Through either wet or dry grinding, the starch in the corn kernel is separated, leaving primarily the corn germ. The final composition of corn germ contains 18%–41% fat and 12%–21% protein, though these values vary depending on the extraction method (Navarro et al., 2016). Corn germ's high content of vitamin E and unsaturated fatty acids makes it a popular ingredient for cosmetics and for managing chronic illnesses (Shende and Sidhu, 2015). Defatted corn germ flour (DCGF), sometimes referred to as maize germ cake (MGC), is a byproduct of the corn oil production process and is a relatively inexpensive product. The finely ground powder that constitutes DCGF has a high content of protein, starch, and dietary fiber. Along with a significant amount of minerals such as calcium, magnesium, phosphorus, and iron, it also contains varying levels of vitamins E and B1 (Oliinyk et al., 2015). It has been demonstrated that corn germ flour (CGF) possesses excellent functional properties, including bulk density, water and oil absorption capacity, and dough texture. Without compromising consumer acceptance, the addition of DCGF to various food systems can significantly enhance the nutritional profile, particularly the protein and crude fiber content (Nasir et al., 2010). Furthermore, DCGF has been shown to be rich in a variety of nutrients, particularly lysine, a key limiting amino acid in wheat. Therefore, incorporating DCGF into food products offers the dual benefit of improving their nutritional quality and enhancing their functional properties (Siddiq et al., 2009). The food industry has extensively utilized corn germ protein due to its high nutritional value and excellent functional qualities (Alrosan et al., 2021). Corn germ protein can serve as a beneficial nutritional supplement in baked goods and can compensate for the lack of threonine and lysine in wheat protein. As living standards improve, there is increasing attention on achieving balanced nutrition in diets. Due to its superior emulsifying ability, corn germ protein eliminates the need for additional emulsifiers in formulations, making it a high-quality vegetable protein that can replace milk to meet the needs of lactose-intolerant individuals (Sun et al., 2017; Musa et al., 2020). Defatted corn germ flour has great potential for use as an ingredient in a wide range of food products, including bread, cookies, muffins, cakes, and processed cheese (Han et al., 2010; Arora and Saini, 2016; El-Sayed et al., 2023). Due to their color and texture, certain corn varieties are more commonly used to make tortillas (Gunasekaran et al., 2020). The tortilla manufacturing industry consumes millions of tons of corn annually, making it a staple food for many people (Sinaki et al., 2022). Since tortilla chips are made from nixtamalized corn grains, they have a distinct flavor, taste, and aroma. However, the absence of essential amino acids in maize makes it an unbalanced food source (Chhabra et al., 2017). Therefore, this study aimed to enhance the nutritional value and quality characteristics of tortilla chips by incorporating 5%, 10%, and 15% defatted corn germ flour (DCGF).

2. Materials and Methods

Materials

Defatted corn germ flour (DCGF) was obtained from the National Company of Maize Products (NCMP), Egypt. Yellow corn flour was procured from Al Mashreq Gardens for Import and Trading, Albagour, Menofia, Egypt. Sugar, salt, baking powder, mixed spices (onion, garlic, ginger, and paprika powders), and sunflower oil were purchased from the local market in Alexandria, Egypt. All chemicals and reagents used in this study were of analytical grade.

Production of Tortilla Chips

Tortilla chips were prepared according to the method described by Adedeji et al. (2022). Defatted corn germ flour was added to yellow corn flour at 5%, 10%, and 15% ratios to create the matrix formulation, as shown in Table 1. The dry ingredients were thoroughly mixed by hand for the first two minutes. Subsequently, half of the required water at 15°C was added, and mixing continued for two minutes. The remaining water at 90°C was then added, followed by another two minutes of mixing. The final mixture (dough) was left to rest in plastic film for one hour. The dough was then sheeted and cut into discs, maintaining a consistent weight of 50 g. The masa disks were placed on plastic trays and manually cut in both transverse directions using a circular pizza cutter. The tortilla triangles were first cooked on a metal hot plate at 280±10°C for 30 seconds on one side and 25 seconds on the other side. After cooking, they were left to cool for one hour before being deep-fried in a stainless steel fryer with sunflower oil at 180°C (±2°C) for 45 seconds (Gaytan et al., 2000).

The fried product was then left to cool at room temperature for 8 to 10 minutes to allow the surface oil to drain. Finally, the chips were placed in a desiccator for further analysis (Dueik et al., 2014).

Table 1. Different formulations of tortilla chips fortified with defatted corn germ flour (DCGF)

Ingredients (g/100g)	Control	5% DCGF	10% DCGF	15% DCGF
Corn flour	100	95	90	85
Defatted corn germ flour	-	5	10	15
Oil	10	10	10	10
Sugar	1	1	1	1
Salt	1.5	1.5	1.5	1.5
Baking powder	2.5	2.5	2.5	2.5
Specie	2	2	2	2
Water	150	150	150	150

Chemical composition and total caloric Values

The moisture, protein, fat, and ash content of the ingredients and final products were determined using the AOAC procedures (AOAC, 2023). The carbohydrate content was calculated by difference. The total caloric values (K.cal) of the ingredients and finished products were determined using the following formula, as per the AOAC method (AOAC, 2023):

Energy content (K.cal) = 4 × [protein (g) + carbohydrate (g)] + [9 × fat (g)]

Additionally, the energy values contributed by protein, carbohydrate, fat, and the utilizable energy due to protein (UEDP) were estimated using the methods described by Adeyeye (2013) and Sudik (2016) as follows:

Energy attributed to protein [%] = %protein × 4×100/ energy (1)

Energy attributed to fat [%] = %fat×9×100/energy (2)

Energy attributed to protein carbohydrate [%] = % carbohydrate × 4 × 100/energy (3)

Utilizable energy attributed to protein = % protein x 0.60 (4)

Determination of minerals

The mineral content (zinc (Zn), calcium (Ca), magnesium (Mg), iron (Fe), and potassium (K)) of corn flour (CF) and defatted corn germ flour (DCGF) was measured in ash solutions using an ICP-OES Agilent 5100 VDV instrument, following the AOAC method (AOAC, 2023).

Amino acid content and protein quality evaluation

The amino acid content of CF, DCGF, and the final products was determined using a High-Performance Amino Acid Analyzer, as per the AOAC method (AOAC, 2012).

Protein efficiency ratio (PER)

The Protein Efficiency Ratio (PER) was calculated using the formula provided by Alsmeyer et al. (1974):

PER=-0.684+0.456(Leucine)- 0.047(Proline) (g/100g protein) (7)

Biological Value (BV)

The biological value of protein was determined using Oser (1959) equation:

BV=49.09+1053 (PER) (8)

Water holding capacity (WHC) and oil holding capacity (OHC)

The water holding capacity (WHC) and oil holding capacity (OHC) of tortilla chips were estimated using the method described by Heywood et al. (2002).

Antioxidant activity of ingredients and final products

Preparation of ingredients and final product extracts

Extracts of corn flour (CF), defatted corn germ flour (DCGF), and tortilla chips were prepared using a slight modification of the method described by Öztürk et al. (2018). Briefly, 5 grams of each sample were mixed with 25 mL of 75% ethanol solution. The mixture was stirred for 2 hours at 500rpm at room temperature and then filtered using Whatman No.1 filter paper. The resulting extracts were stored at -20°C until further use.

Determination of total phenolic content (TPC)

The total phenolic content (TPC) of the extracts of corn flour (CF), defatted corn germ flour (DCGF), and tortilla chips was determined in triplicate using the method described by Abirami et al. (2014). The TPC was expressed as milligrams of gallic acid equivalents (mg GAE) per 100 grams of sample, calculated using a standard curve.

Determination of total flavonoids (TF)

The total flavonoid (TF) content of the extracts of corn flour (CF), defatted corn germ flour (DCGF), and tortilla chips was estimated using the method described by Barros et al. (2011). The TF content was calculated using a standard curve and expressed as milligrams of rutin equivalents (mg RE) per 100 grams of sample. The assay was performed in triplicate to ensure accuracy.

DPPH assay

The DPPH (2,2-diphenyl-1-picrylhydrazyl) assay was conducted in triplicate following the procedure outlined by Lim and Quah (2007). The DPPH inhibition activity (%) was calculated using the following formula:

DPPH scavenging activity%=$(1-Abs_{sample}/Abs_{control}) \times 100$

FRAP assay

The ferric reducing antioxidant power (FRAP) was measured in triplicate following the methodology described by Oyaizu (1986). The FRAP value was calculated using a standard curve and expressed as milligrams of gallic acid equivalents (mg GAE) per 100g of sample. This assay evaluates the reducing power of the extracts, indicating their antioxidant capacity.

Texture profile analysis (TPA)

The texture properties of the tortilla chips, including hardness (g), cohesiveness, Springiness (mm) Springiness (mm), gumminess (g), chewiness (mJ), resilience, and fracturability (g), were analyzed using a Texture Analyzer (TA-XT, Pro CT3 V1.2, Brookfield, Middleboro, USA) according to the method described by Yuan and Chang (2007). Force-time deformation curves were obtained at a crosshead speed of 1mm/s using a 5kg load cell.

Microstructure

The microstructure of the tortilla chips samples was assessed using scanning electron microscopy (SEM) based on the method outlined by Tahmasebi et al. (2015).

Color measurement

The color parameters of the tortilla chip samples, including *L** (lightness), *a** (red intensity), and *b** (yellow intensity), were measured using a Hunter Lab Ultra Scan (VIS model colorimeter, USA). For each Hunter scale color index (*L*, a**, and *b**), the mean of five measurements was calculated, as described by Santipanichwing and Suphantharika (2007). A standardized instrument with the following reference values was used for each sample measurement: (L* = 94.1, a* = 1.12, and b* = 1.26).

Sensory evaluation

The sensory attributes of the tortilla chip sample, including taste, color, texture, odor and overall acceptability, were evaluated based on the method described by Banach et al. (2014).

A panel of 15 participants (10 females and 5 males, aged 35–55 years) from Food Technology Research Institute, Alexandria, Egypt, assessed the samples using a standard 9-point hedonic scale, where 9 = very like, and 1 = very dislike.

Statistical Analysis

The data obtained in this study were statistically analyzed using one-way analysis of variance (ANOVA) in the SAS statistical analysis software (2004). Means were compared using Duncan's test at a significance level of $P < 0.05$. This analysis helps determine the significance of differences between samples and ensures the reliability of the results.

3. Results and Discussions

Chemical composition and antioxidant activity of CF and DCGF

Table 2 presents the chemical composition of corn flour (CF) and defatted corn germ flour (DCGF). The protein, fat, ash, and energy contents of DCGF (20.19%, 6.72%, 2.84%, and 383.52 Kcal, respectively) were higher than those of CF (6.64%, 2.20%, 0.71%, and 365.57 Kcal, respectively). In contrast, the moisture and carbohydrate contents of CF (10.64% and 79.81%, respectively) were higher than those of DCGF. The results also indicated that DCGF had higher levels of magnesium (Mg), calcium (Ca), zinc (Zn), iron (Fe), and potassium (K) compared to CF. The differences in the chemical composition of CF and DCGF in this study compared to previous studies may be attributed to variations in corn varieties. Shah et al. (2016) reported that maize flour contains 10.23% moisture, 8.84% protein 71.88% carbohydrate, 4.57% fat, 2.15% fiber, and 2.33% ash. Fenta and Kumar (2019) found that corn contains 7.88% crude protein. According to the USDA (2020), the protein content in corn ranges from 10–15%. Shah et al. (2016) also observed that maize flour contains 1.5% minerals, including magnesium, sodium, sulfur, phosphorus, calcium, iron, potassium, and copper. The protein and fat contents of DCGF in this study differed from those reported by Farahat et al. (2020), who found 23.6% protein and 1.2% fat in DCGF. Similarly, El-Sayed et al. (2023) reported that DCGF contains 27.57% protein, 11% fat, and 28.28% starch. According to Păucean and Man (2013), the protein content of DCGF is three times higher than that of CF. These variations in protein content may be due to differences in corn varieties and extraction rates (Brites et al., 2010; Farahat et al., 2020). Additionally, the data in Table 2 also revealed that DCGF has higher total phenolic (TP) and total flavonoid (TF) contents compared to CF. This increase in TP and TF enhances the DPPH scavenging activity and FRAP value in DCGF, which are key indicators of antioxidant activity in food products. Higher antioxidant activity improves the quality and health benefits of the food. These findings align with those of El-Sayed et al. (2023), who reported that DCGF has high levels of TP and TF, contributing to its enhanced antioxidant potential.

Amino Acids content of CF and DCGF

The results obtained in Table 3 show the amino acid content in CF and DCGF, where the results showed that DCGF contains the highest content of essential and non-essential amino acids (7.24 and 11.86% respectively) compared to 2.17 and 3.26% respectively, in CF. Therefore, the TAAA and TSAA of DCGF were higher than that of CF. The leucine: isoleucine ratio in CF was found to be 3.3:1 compared to 1.77:1 in DCGF. Corn germ protein is recognized as one of the best sources of plant-based protein among common grains. Its amino acid composition closely aligns with the human protein standards recommended by the Food and Agriculture Organization (FAO) and the World Health Organization (WHO) (Karimi et al., 2020). According to Shi et al. (2015), corn germ protein exhibits a high biological value (BV) of 64–72%, and protein efficiency ratio (PER) of 2.04–2.56. All the essential amino acids required by the human body. The proteins in DCGF are primarily composed of albumin and globulin, which are well-balanced in most essential amino acids. Notably, lysine, a major limiting amino acid in wheat, constitutes 5–6% of the total proteins in DCGF, which is more than twice the amount found in wheat flour (Parris et al., 2006). Additionally, the lysine content in corn germ is approximately 50% higher than that in whole corn (Naves et al., 2011).

Table 2. Chemical composition and antioxidant activity of corn flour (CF) and defatted corn germ flour (DCGF)

Parameters	CF	DCGF
Moisture	10.64±0.39[a]	9.14±0.29[b]
Protein	6.64±0.45[b]	20.19±0.28[a]
Fat	2.20±0.02[b]	6.72±0.16[a]
Ash	0.71±0.03[b]	2.84±0.11[a]
Total Carbohydrate	79.81±0.63[a]	60.57±1.33[b]
Energy content (K.cal/100g)	365.57±1.50[b]	383.52±1.80[a]
Minerals content (mg/100g)		
Mg	39.02±0.16[b]	88.03±0.25[a]
Ca	7.44±0.06[b]	20.03±0.16[a]
Zn	1.16±0.05[b]	5.36±0.10[a]
Fe	8.29±0.05[b]	13.00±0.06[a]
K	220.03±0.15[b]	230.03±0.95[a]
Antioxidant activity		
Total Phenolic (mg GAE/100g)	981.80±21.30[b]	2172.0±10.23[a]
Total Flavonoids (µg RTE/100g)	4826.64±22.89[b]	16765.17±27.53[a]
DPPH Scavenging Activity (%)	54.75±3.50[b]	68.09±2.86[a]
FRAP Values (mg GAE /100g)	271.48±2.67[b]	284.47±0.51[a]

Mean values (± SD) with different letters within ingredients are significantly different at ($P < 0.05$). CF: corn flour; DCGF: defatted corn germ flour

Table 3. Amino Acids content of corn flour (CF) and defatted corn germ flour (DCGF)

Amino Acid (%)	CF	DCGF
Essential Amino Acids		
Therionine (THR)	0.22	0.73
Phenylalanine (PHE)	0.34	0.97
Methionine	-	0.49
Leucine (LEU)	0.66	1.63
Isoleucine (Iso)	0.2	0.74
Valine (VAL)	0.38	1.08
Lysine (LYS)	0.19	0.92
Hisitidine (HIS)	0.18	0.68
Total essential amino acids	2.17	7.24
Non-Essential Amino Acids		
Aspartic (ASP)	0.4	1.48
Serine (SER)	0.25	0.69
Glutamic (GLU)	1.08	3.17
Glycine (GLY)	0.22	1.1
Alanine (ALA)	0.34	1.26
Tyrosine (TYR)	0.36	0.76
Argnine (ARG)	0.23	1.31
Proline (PRO)	0.38	1.32
Cystine (CYS)	-	0.77
Total non-essential amino acids	3.26	11.86
TAAA	0.7	1.73
TSAA	-	0.49
Leucine: Isoleucine ratio	3.3:1	1.77:1
PER (g/100g protein)	3.58	2.69
BV	86.78	77.42

Mean values (± SD, n=3); CF: corn flour; DCGF: defatted corn germ flour. BV: Biological Value; PER: Protein Efficiency Ratio. TAAA: Total Aromatic Amino Acids = Tyrosine + Phenylalanine; TSAA: Total sulfur-containing Amino Acid= Cystein + Methionine.

Chemical composition of tortilla chips fortified with DCGF

The data presented in Table 4 show the chemical composition and energy content of tortilla chips fortified with DCGF at a ratio of 5, 10, and 15%. The moisture content was significantly decreased after fortification with 5% DCGF compared to the control (100% CF) and then increased with 10% and 15% DCGF. The tortilla chips fortified with DCGF have the higher protein content compared to the control samples, and the highest value was observed with the 15% DCGF samples. The fat and ash contents did not change even with the addition of 10% DCGF but increased significantly (P<0.05) with the addition of 15% DCGF compared to the control group. On the other hand, the carbohydrate content of tortilla chips decreased significantly (P < 0.05) with increasing DCGF addition, and the lowest carbohydrate content was observed with the 15% DCGF samples. Because samples with higher levels of DCGF have higher protein content, they are also more capable of holding onto water, which explains the increase in moisture content (Kumar et al., 2010; Barnwal et al., 2013).

According to Arora and Saini (2016), as the amount of DCGF increased, the protein content of the fortified bun also progressively increased. This was because DCGF has a higher protein content than wheat flour. Additionally, it was discovered that when the amount of DCGF in the wheat flour increased, the carbohydrate content decreased, which occurred because DCGF's carbohydrate content was lower than that of wheat flour (Arora and Saini, 2016). Barnwal et al. (2013) observed that biscuits prepared by replacing wheat flour with 10% DCGF had 2.62% moisture, 8.16% protein, 17.74% fat, 1.09% ash, 1.76% crude fiber, and 68.64% carbohydrate. Meanwhile, Stepankova et al. (2017) reported that when preparing bread with the addition of 15% DCGF, the bread's protein and fat content increased insignificantly, and the carbohydrate content decreased by 13.6%. Additionally, its content of dietary fiber, vitamins B1, E, magnesium, and iron was 1.7, 1.4, 3.0, 2.2, and 2.3 times higher, respectively, compared to the control group. These results agree with Adedeji et al. (2022), who found that moisture, fat, and crude fiber of gluten-free fried products prepared from defatted peanut flour and starches ranged from 3.52% to 5.89%, 11.22% to 13.84%, and 5.54% to 7.50%, respectively. According to Kamel et al. (2020), biscuits made with 20% defatted soybean flour had a protein content that was up to 1.5 times higher than that of chickpea flour at the same substitution ratio.

Table 4. Effect of fortified with defatted corn germ flour (DCGF) on the chemical composition of tortilla chips

Components	Control	5% DCGF	10% DCGF	15% DCGF
Moisture (%)	3.52±0.10[a]	3.37±0.04[b]	3.47±0.05[ab]	3.52±0.02[a]
Protein (%)	5.73±0.15[d]	6.74±0.06[c]	7.82±0.53[b]	9.12±0.61[a]
Fat (%)	10.38±0.15[b]	10.40±0.12[b]	10.45±0.05[b]	11.14±0.13[a]
Ash (%)	1.44±0.09[b]	1.62±0.09[ab]	1.89±0.45[ab]	1.97±0.07[a]
Carbohydrate (%)	78.93±0.08[a]	77.86±0.10[b]	76.37±0.32[c]	74.25±0.65[d]
Energy content (K. cal/100g)	432.10±0.68[ab]	432.03±1.06[ab]	430.82±2.20[b]	433.74±0.61[a]
Proportion of energy due to				
Protein (%)	5.31±0.15[d]	6.24±0.04[c]	7.26±0.47[b]	8.41±0.56[a]
Fat (%)	21.63±0.27[b]	21.67±0.21[b]	21.84±0.05[b]	23.11±0.24[a]
Carbohydrate (%)	73.07±0.16[a]	72.09±0.24[b]	70.91±0.42[c]	68.48±0.59[d]
Utilizable energy due to protein	3.44±0.09[d]	4.04±0.03[c]	4.69±0.32[b]	5.47±0.36[a]

Mean values (± SD) with different letters within treatments are significantly different at (P < 0.05).

Amino acid content in tortilla chips

The amino acid contents of tortilla chips in Table 5 show that the essential amino acid content increased significantly (P<0.05) after fortification with DCGF compared to the control sample (100% CF). The TAAA and TSAA content also increased with the increase in DCGF levels in tortilla chips. On the other hand, the leucine-to-isoleucine ratio significantly decreased (P<0.05) after DCGF supplementation, and the lowest value was observed with the 15% DCGF samples. According to Ijarotimi et al. (2015), BV is the amount of protein that is absorbed from food and integrated into the body's proteins. PER, which has been widely used as a metric in the assessment of protein quality, is the weight gain of a test subject divided by the unit intake of a specific food protein (FAO/WHO, 2011). Regarding BV and PER in this study, the results showed higher BV and PER with the 5% DCGF samples compared to all other treatments. This increase is due to the high content of essential and non-essential amino acids in DCGF. These findings concur with those of Stepankova et al. (2017), who discovered that bread made using 15% DCGF had higher levels of unsubstituted amino acids such as lysine, cystine, methionine, and threonine. The biological value of bread made with DCGF increased, according to an analysis of the protein's amino acid score. The amount of lysine that is lacking in wheat bread must rise by 20.8%, followed by cystine and methionine by 8.0% and threonine by 11.5%. It is recommended that the developed products be used for conventional, health-promoting, preventative, and therapeutic nutrition (Stepankova et al., 2017). Masoumikhah and Zargari (2013) found that when low-fat corn germ flour was added to macaroni, the protein content and essential amino acids such as histidine, arginine, tyrosine, lysine, and phenylalanine increased significantly in comparison to the control. Hojilla-Evangelista (2013) reported that corn germ contains crude protein, methionine, and lysine levels that are 2 to 3, 1.4, and 3.2 times higher than those of corn, respectively.

Table 5. Effect of fortified with defatted corn germ flour (DCGF) on the amino acid content in tortilla chips

Amino Acid (%)	Control	5% DCGF	10% DCGF	15% DCGF
Essential Amino Acids				
Therionine (THR)	0.26	0.27	0.30	0.32
Phenylalanine (PHE)	0.26	0.28	0.29	0.33
Methionine	0.11	0.12	0.15	0.17
Leucine (LEU)	0.57	0.6	0.62	0.63
Isoleucine (Iso)	0.18	0.21	0.22	0.25
Valine (VAL)	0.27	0.29	0.33	0.36
Lysine (LYS)	0.13	0.17	0.18	0.21
Hisitidine (HIS)	0.16	0.19	0.2	0.22
Total essential amino acids	1.94	2.13	2.29	2.49
Non-Essential Amino Acids				
Aspartic (ASP)	0.35	0.4	0.43	0.49
Serine (SER)	0.24	0.25	0.27	0.29
Glutamic (GLU)	0.99	1.08	1.13	1.25
Glycine (GLY)	0.26	0.26	0.29	0.32
Alanine (ALA)	0.35	0.37	0.4	0.44
Tyrosine (TYR)	0.2	0.21	0.23	0.25
Argnine (ARG)	0.22	0.28	0.32	0.38
Proline (PRO)	0.54	0.55	0.57	0.58
Cystine (CYS)	0.11	0.13	0.15	0.18
Total non-essential amino acids	3.26	3.53	3.79	4.18
TAAA	0.46	0.49	0.52	0.58
TSAA	0.11	0.12	0.15	0.17
Leucine: Isoleucine ratio	3.17:1	2.86:1	2.82:1	2.52:1
PER (g/100g protein)	3.71	3.82	3.62	3.51
BV	88.14	89.32	87.18	86.05

BV: Biological Value; PER: Protein Efficiency Ratio. TAAA: Total Aromatic Amino Acids = Tyrosine + Phenylalanine; TSAA: Total sulfur-containing Amino Acid= Cystine + Methionine.

Antioxidant activity of tortilla chips

The effect of fortification with DCGF on the antioxidant activities of tortilla chips is illustrated in Figure 1. Fortification with DCGF caused a significant increase in the total phenolic content (TPC) of the tortilla chip samples. The total phenolic content increased from 381.15mg/100g in the control samples to 475mg/100g in the 15% DCGF samples. Additionally, the total flavonoid (TF) content significantly increased with the addition of DCGF to tortilla chips, and the highest TF was observed in the 15% DCGF samples. The results of DPPH and FRAP assays showed that supplementation with DCGF improved DPPH scavenging activity and the ferric-reducing antioxidant power of tortilla chips. The higher the DCGF content, the greater the antioxidant activity. The TPC in this study ranged from 381mg GAE/100g (in the control sample) to 475mg GAE/100g (in the 15% DCGF sample), which was higher than that reported by Sánchez-Madrigal et al. (2014), who found that TPC in tortilla chips ranged from 60–90mg GAE/100g. The antioxidant activity of corn flours has been linked to the presence of polyphenolics such as catechin and free forms of ferulic acid (De la Parra et al., 2007; López-Martínez et al., 2009; El-Sayed et al., 2023). When compared to corn flour and DCGF, the antioxidant activity of tortilla chips is noticeably lower. This is because bioactive substances such as polyphenols and anthocyanins are degraded during baking and frying, which reduces their antioxidant activity (Lapidot et al., 1999 and Sánchez-Madrigal et al., 2014).

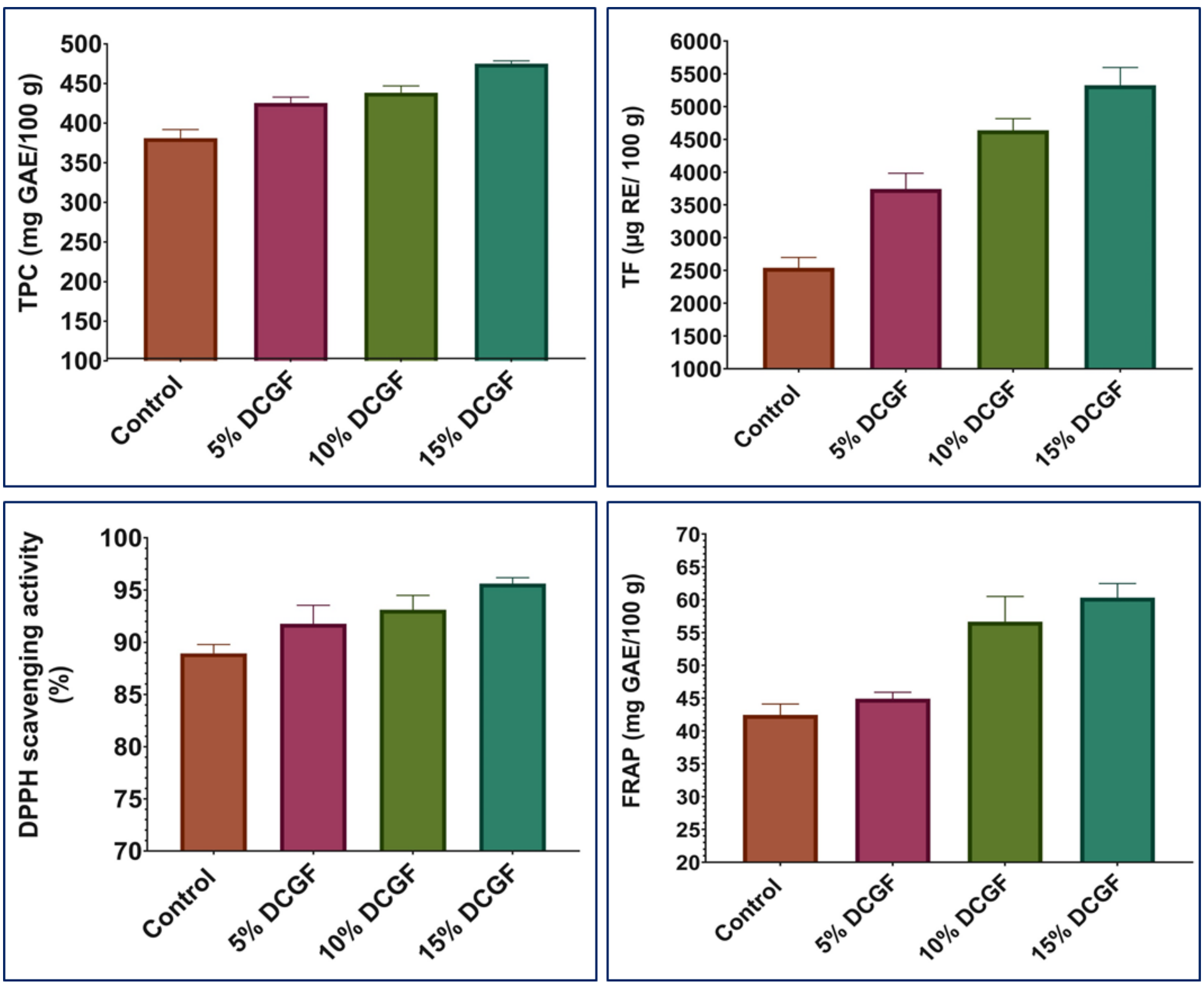

Figure 1. Antioxidant activity of tortilla chips fortified with defatted corn germ flour (DCGF)

Water holding capacity and oil holding capacity of tortilla chips

In addition to nutritional considerations, the final quality of a processed food product is greatly influenced by the functional properties of flour, such as its ability to emulsify, foam capacity and stability, absorb water and oil, and solubility (Siddiq et al., 2009). Data presented in Figure (2) shows the effect of DCGF on the water-holding capacity (WHC) and oil-holding capacity (OHC) of tortilla chips. Fortification with 5% and 10% DCGF caused a significant decrease in the WHC of tortilla chips compared to the control sample, while there was no difference between the samples containing 15% DCGF and the control. Concerning OHC, no significant differences were observed among all treatments. This result clarifies that fortification with DCGF had no effect on the OHC of tortilla chips. The water absorption of corn germ protein is also superior to that of soybean protein. Additionally, corn germ protein has a higher oil-holding capacity, comparable to that of soybean concentrate (Sun et al., 2015). Furthermore, corn germ protein is a great functional food raw material or food additive with good emulsification, foaming, and gelling qualities (Musa et al., 2019). It was found that adding corn germ protein to meat products can improve their water and oil retention qualities, decrease fat separation, boost yield, and significantly enhance their nutritional value because it has good water and oil absorption properties and excellent gel properties (Musa et al., 2020 and Sun et al., 2017). Siddiq et al. (2009) found that after blending wheat flour with more than 10% DCGF, the flour's ability to absorb water and oil as well as form emulsions increased dramatically. Due to its higher protein content, DCGF has a higher water absorption rate (363.3%) than wheat flour, which is 85% (Zayas and Lin, 1989; Siddiq et al., 2009). Păucean and Man (2013) observed that the water absorption of blends made with DCGF was higher than that of blends made with maize and wheat flour. High water absorption may be a result of DCGF's high protein and fiber content.

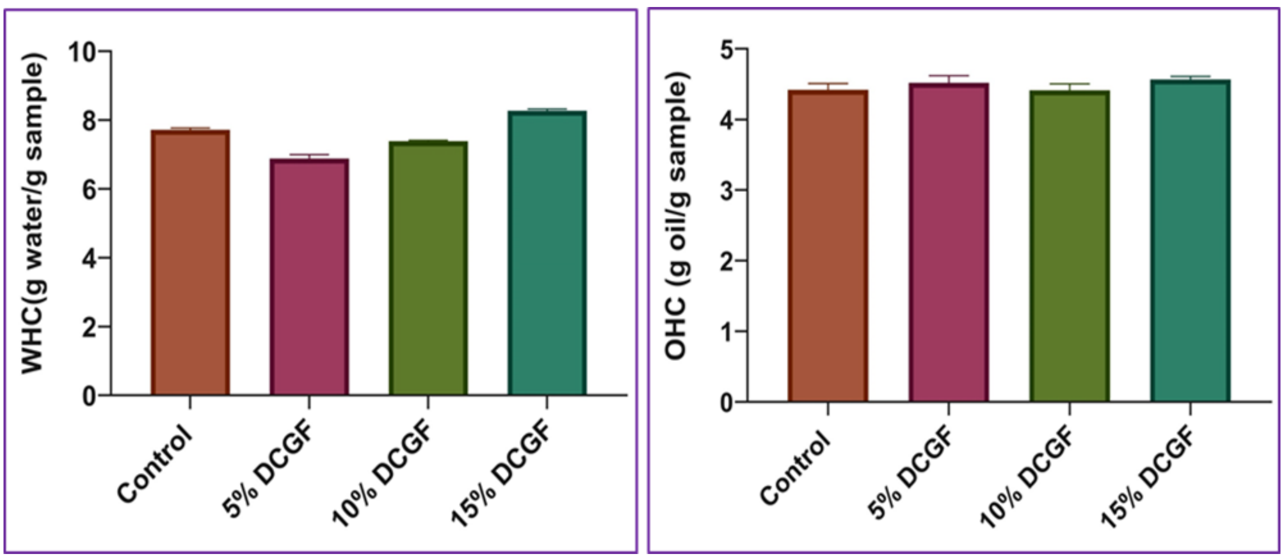

Figure 2. Water holding capacity (WHC) and oil holding capacity (OHC) of tortilla chips fortification with defatted corn germ flour (DCGF).

Texture profile analysis of tortilla chips

Texture is one of the main factors that consumers consider when evaluating the quality of foods. Textural parameters are among the most important quality characteristics influencing the overall quality and demand of food products. The results of the texture parameters of tortilla chips in Table 6 show that the hardness values significantly decreased after fortification with 5% and 10% DCGF, while the highest hardness value was observed in 15% DCGF samples compared to the control samples. On the other hand, fortification with 5% DCGF resulted in the lowest values of cohesiveness, springiness, gumminess, chewiness, and fracturability compared to the control samples.

In contrast, the 15% DCGF samples had the highest values in all parameters, except for springiness, which was lower than the control. These results are consistent with those of Arora and Saini (2016), who found that increasing the percentage of wheat flour replacement with DCGF resulted in increased hardness, resilience, and gumminess values in bun samples. This may be due to DCGF's high protein and fiber content. Additionally, they discovered that springiness values significantly decreased as DCGF addition increased. Similarly, Barnwal et al. (2013) found that biscuit hardness increased when DCGF was incorporated up to 30%. However, Zahroh et al. (2023) reported that increasing the amount of margarine or defatted coconut flour reduced the hardness of crackers.

Table 6. Texture profile analysis of tortilla chips fortified with defatted corn germ flour (DCGF)

Parameters	Control	5% DCGF	10% DCGF	15% DCGF
Hardness (g)	3991±20.5^{b}	1885±9.5^{d}	2237±11.5^{c}	5665±12.5^{a}
Cohesiveness	0.28±0.01^{c}	0.23±0.02^{d}	0.35±0.03^{b}	0.48±0.01^{a}
Springiness (mm)	0.98±0.01^{a}	0.65±0.02^{c}	0.95±0.01^{b}	0.93±0.02^{b}
Gumminess (g)	1199±12.50^{b}	592±9.50^{d}	895±8.51^{c}	2883±10.90^{a}
Chewiness (mJ)	11.5±0.20^{b}	3.8±0.20^{d}	8.3±0.20^{c}	26.3±0.20^{a}
Resilience	0.15±0.01^{c}	0.15±0.01^{c}	0.27±0.02^{b}	0.35±0.02^{a}
Fracturability (g)	4243±21.5^{b}	2539±18.50^{c}	2554±11.5^{c}	6017±16.5^{a}

Mean values (± SD) with different letters within treatments are significantly different at ($P < 0.05$)

Microstructure of tortilla chips

Figure 3 shows the microstructure of tortilla chip samples and illustrates that the main components of the tortilla chip are starch granules, fat globules, and corn protein matrix, which combine to form the protein network. Figure 3A (control) shows larger air spaces between the protein-fat network compared to the other treatments. This composition is likely due to the different composition and protein behavior in the sample containing only corn flour compared to the corn flour-DCGF mixture (Chhabra et al., 2017). In Figures 3B and 3C (samples containing 5% and 10% DCGF, respectively), the texture became more homogeneous and cohesive compared to the control, which is attributed to the addition of DCGF to the tortilla formula. Since DCGF contains a high amount of starch and fiber, its presence led to the absorption of a significant amount of water during the dough stage, resulting in homogeneous swelling in the tortilla network after the drying process. Additionally, it helped increase the retention of water and oil within the protein-fat-starch network, and this effect is more pronounced in Figure 3C (10% DCGF). As for the 15% DCGF treatment, the microscopic image showed the presence of larger air spaces than the 5% and 10% treatments. The reason may be the significant increase in protein content due to the higher DCGF percentage in the tortilla mixture, which led to an increase in the hardness and cohesion of the tortilla chip samples. According to earlier studies, corn flour dough has a cohesive structure that resembles glue and seems to hold the tortilla pieces together. This glue-like matrix is likely composed of free and emulsified lipids, a hydrated and dehydrated protein matrix, or gelatinized and dispersed starch (Gomez et al., 1992; Chhabra et al., 2017).

Color measurements of tortilla chips

The addition of DCGF to tortilla chips caused significant changes in its color parameters (Table 7). Fortification with 5%, 10%, and 15% DCGF significantly increased ($P<0.05$) the *L** values of tortilla chips compared to the control samples, and the highest *L** value was observed in the 15% DCGF samples. Meanwhile, *a** and *b** values significantly increased ($P<0.05$) with 5% and 10% DCGF but decreased with 15% DCGF. Arora and Saini (2016) discovered that fortification with DCGF had a significant impact on the bun's *L**, *a**, and *b** values. The higher *L** values indicated that the bun prepared with 5% substitution was lighter than all other treatments; these values then decreased with further DCGF augmentation. A 5–25% DCGF flour addition to the bun produced a more yellow tint (higher *b** values in the positive range) than a wheat flour bun.

According to Barnwal et al. (2013), the degree of DCGF incorporation in biscuit samples caused a significant variation in their color values (L^*, a^*, and b^*). While a^* and b^* values increased from 6.89 to 11.39 and 27.66 to 33.27, respectively, L^* values decreased from 70.77 to 62.86. A decrease in L^* and an increase in a^* and b^* color values support the observation that as DCGF flour levels increase, biscuits become darker. Greene and Bovell-Benjamin (2004) found that the L^* values of bread samples decreased as the amount of sweet potato flour increased, while whole-wheat flour had the opposite effect. The lower L^* values could be explained by the distribution of water and the reaction between reducing sugars and amino acids, which can influence caramelization and the Maillard browning reaction.

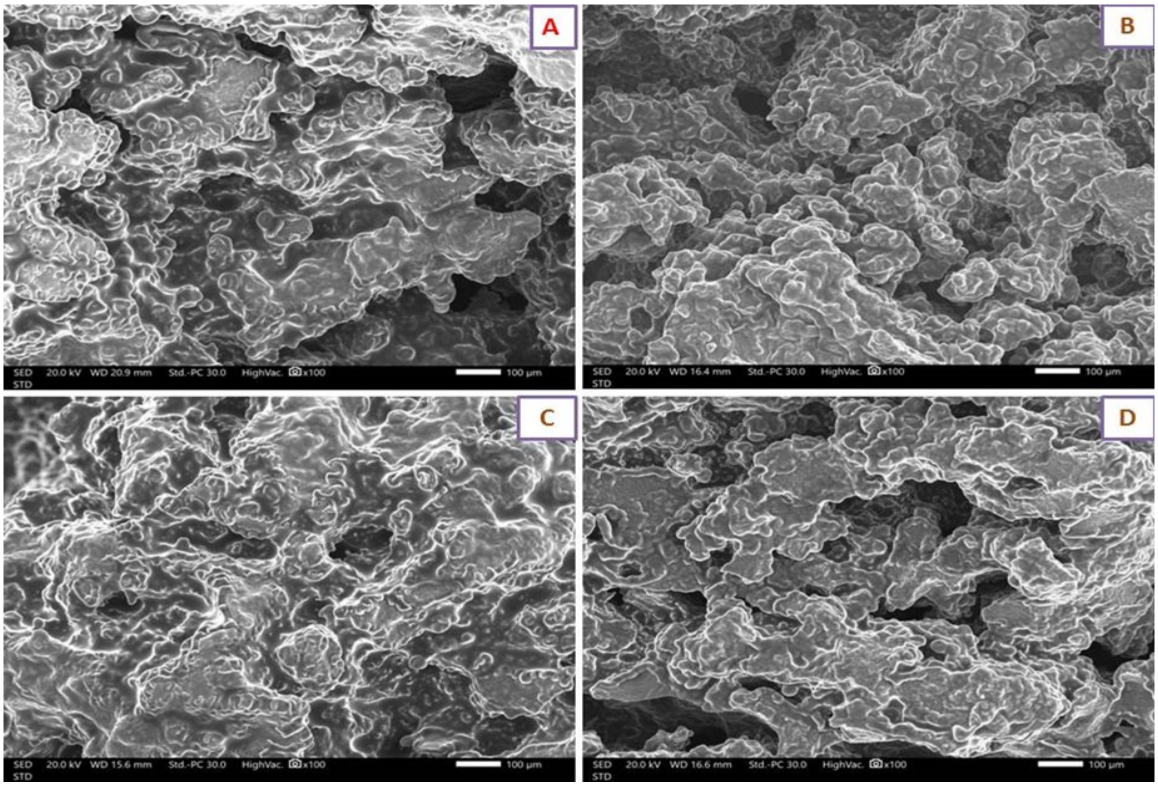

Figure 3. Scanning electron micrographs (SEM) of tortilla chips samples, A: control; B: fortified with 5% DCGF; C: fortified with 10% DCGF; and D: fortified with 15% DCGF

Table 7. Color measurements of tortilla chips fortified with defatted corn germ flour (DCGF)

Treatments	L* (Lightness)	a* (Redness)	b* (Yellowness)
Control	36.04±0.14[c]	10.05±0.15[c]	15.46±0.06[c]
5% DCGF	37.35±0.30[b]	10.52±0.10[b]	16.64±0.14[a]
10% DCGF	37.61±0.19[b]	10.92±0.08[a]	16.16±0.04[b]
15% DCGF	38.11±0.22[a]	7.14±0.07[d]	13.12±0.13[d]

Mean values (± SD) with different letters within treatments are significantly different at ($P < 0.05$)

Sensory evaluation of tortilla chips

Customers have shown a preference for food products containing naturally occurring health-promoting ingredients such as enzymes, antioxidants, probiotics, prebiotics, natural extracts, antimicrobials, and plant-based essential oils (Lee et al., 2015).

The sensory properties (color, taste, odor, texture and overall acceptability) of tortilla chips were significantly affected by DCGF fortification (Figure 4). The addition of DCGF to tortilla chips up to 15% was acceptable to the panelists; however, the most preferred samples were those fortified with 5% and 10% DCGF, as they received higher taste, texture, and overall acceptability scores compared to the control samples.

The results also showed that odor and color were not affected by DCGF fortification. Notably, the 10% DCGF samples received the highest overall acceptability score among all treatments. These findings are partially consistent with Farahat et al. (2020), who reported a significant (P<0.05) difference in taste, texture, flavor, and overall acceptability between control cookies and those made with DCGF. However, no significant (P<0.05) difference was found in the color scores, and DCGF fortification of up to 20% was considered acceptable in cookie sensory evaluation. Similarly, Nasir et al. (2010) investigated the use of DMG flour at 5%, 10%, and 15% as a partial substitute for wheat flour in cookies. Their study found that all cookies made with up to 15% DMG had sensory scores within an acceptable range (>5), which is considered the limit of marketability. However, 5% fortification yielded the highest overall acceptability score (6.6).

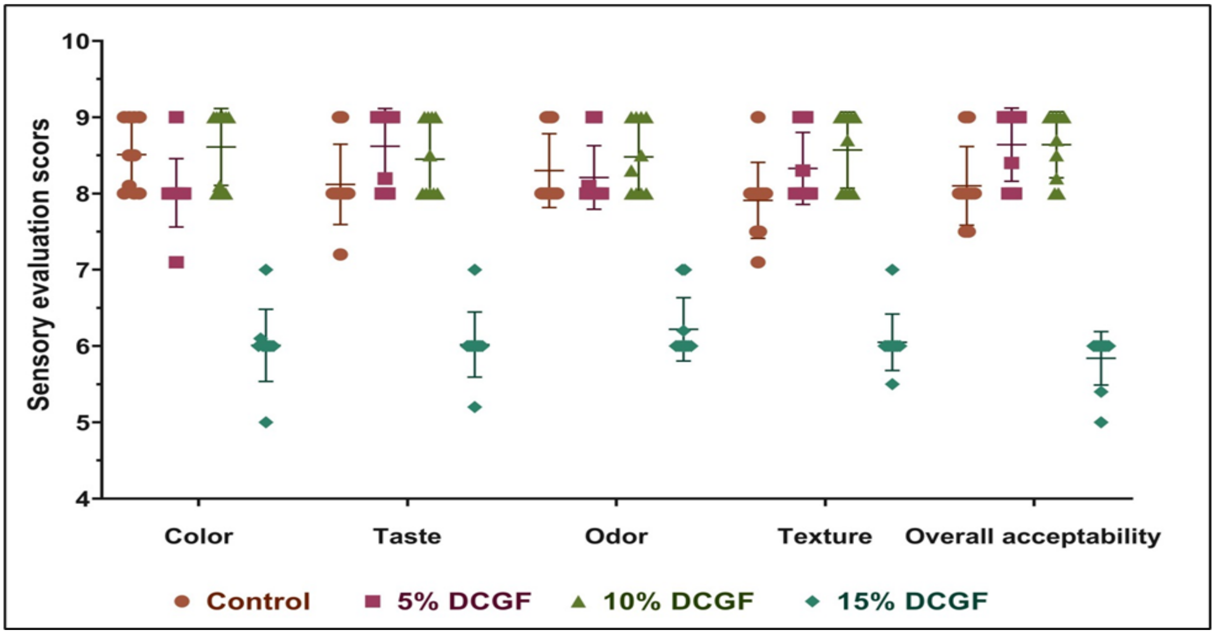

Figure 4. Sensory evaluation of tortilla chips fortified with defatted corn germ flour (DCGF)

4. Conclusion

Defatted corn germ flour (DCGF) is a by-product of the corn germ oil extraction process, rich in essential nutrients and bioactive compounds. This study aimed to evaluate the impact of incorporating DCGF into tortilla chip formulations on their physicochemical, textural, microstructural, antioxidant, and sensory properties. The results demonstrated that DCGF fortification significantly enhanced the nutritional value and antioxidant activity of tortilla chips compared to the control (100% corn flour). However, 5% and 10% DCGF fortification led to a reduction in water-holding capacity (WHC), while oil-holding capacity (OHC) remained unaffected. The highest hardness, cohesiveness, springiness, gumminess, chewiness, and fracturability values were observed in 15% DCGF samples. Sensory evaluation revealed that tortilla chips with 5% and 10% DCGF received the highest acceptability scores, making them the most preferred formulations. Based on these findings, this study recommends incorporating 5%–10% DCGF as a nutritional and functional ingredient in tortilla chip production.

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