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Development of vacuum fried chips from orange peel powder and raw banana flour

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Abstract
Vacuum frying is gaining attention as a method for producing healthier fried snacks with improved nutritional and functional quality. This study developed vacuum-fried chips using Nendran banana flour (NBF) enriched with orange peel powder (OPP) and evaluated their proximate, functional, phytochemical, sensory, textural, and storage characteristics. NBF showed high carbohydrate content (75±0.40 g/100 g), moderate fibre (10.90±0.25 g/100 g), and low fat (1.52±0.01 g/100 g), while OPP exhibited high fibre (10.6%), notable protein (5.17±0.40%), and strong antioxidant activity (DPPH 86.1±0.82%). Incorporation of OPP significantly enhanced the nutritional profile of the chips, with protein increasing from 2.3 to 4.8 g/100 g, fibre from 6.4 to 15.2 g/100 g, and ash from 3.0 to 4.5 g/100 g, alongside proportional reductions in carbohydrate and fat. The T_3 sample showed maximum micronutrient enrichment, recording vitamin C (67.5 mg/100 g), magnesium (105.2 mg/100 g), and potassium (1162 mg/100 g). Antioxidant activity was highest in T_3, with flavonoids (442.7 mg), DPPH (456.2), and ABTS (615.1). Sensory evaluation rated T_3 highest in flavor (8.21), taste (8.16), and overall acceptability (8.50). Textural analysis showed desirable firmness (2774.55), and T_3 remained microbiologically stable for 60 days. These results identify T_3 as the optimal formulation with strong functional and commercial potential.

Keywords: Antioxidant, Dietary fiber, Equipment

Introduction

The global snack market expanded at an annual rate of 6.2% and is projected to attain a value of 639 billion USD by 2023. Chip sales have been increasing at a more rapid pace within the snack food sector. Chips are characterized as thin, dry, and crisp baked products, primarily composed of soft wheat flour, and include minimal amounts of sugar, oil, and moisture. Currently, it is prevalent to utilize alternative and nutritious foods, such as pulses and agricultural by-products, as raw materials in snack production (Giannoutsos *et al*., 2023). The development of value-added foods that support healthy eating, enhance consumer nutrition, and maintain and safeguard health has been the focus of numerous researchers in recent years. Cereal-based snacks are one of the most important commodities. They are taken in large quantities by individuals of all ages, from young children to the elderly, and are high in fat, salt, and carbohydrates while having a low nutritional value overall (Jozinović *et al*., 2021).

Banana (*Musa x paradisiaca*) is one of the most widely cultivated and consumed tropical fruits globally, playing a vital role in the agricultural economies and food security of many developing countries. Bananas are said to have originated in Southeast Asia and have subsequently expanded throughout tropical and subtropical regions of the world, as members of the *Musaceae* family (Ploetz *et al*., 2007) [22]. Their by-products, such as banana flour and peel flour, offer intriguing substitutes for substances that contain gluten. This study examines the industrial potential of ripe and green bananas, particularly in the manufacturing of gluten-free foods. Eating bananas is a wonderful way to get potassium. Although potassium is found in many fruits, vegetables, and even meats, one banana provides 23% of your daily potassium needs. Potassium helps the muscles because it prevents spasms and maintains their appropriate function. Additionally, recent studies show that potassium helps people who are potassium deficient lower their blood pressure. Additionally, potassium reduces the risk of stroke.

The orange is a fruit of the citrus species (*Citrus sinensis)* and a member of the Rutaceae family. Nagpur Santra, Coorg Santra, Khasi Santra, Mudkhed, Shringar, Butwal, and Dancy are some of the significant orange cultivars cultivated in India. The primary waste component, which accounts for almost half of the fruit mass, is the peel that remains after the juice is extracted. It is noteworthy that citrus peel is considered a useful functional food. Citrus peels may therefore help avoid dietary diseases like metabolic syndrome, type II diabetes, coronary heart disease, obesity, osteoporosis, and gastrointestinal disorders in addition to the usual nutrients.

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops in the world and a primary staple food for a large proportion of the global population. In terms of production and consumption worldwide, wheat, a member of the Poaceae family, is grown in over 120 countries and is ranked equal to rice and maize (FAO, 2022). Almost everywhere in the world, wheat and products manufactured from it are a common element of everyday diets. Chips are also made from wheat since it is a rich source of energy and carbohydrates for human nutrition. Compared to other conventional wheat-based products like bread and pasta, consumers can consume wheat in a different way when it is used to make snack foods like wheat chips. Starch (around 70-75%), water (about 14%), and proteins (about 10-12%) make up the majority of wheat flour. Amylose and amylopectin levels in starch are normally 25-28% and 72-75%, respectively.

Corn (*Zea mays* L.) is essential to industrial operations and food systems because of its high carbohydrate content and adaptability in processing. Corn comes in a variety of forms that are used extensively in the food business, such as whole kernels (like sweet corn), crushed (like cornmeal and maize flour), and puffed (like popcorn). Additionally, it is an essential component of many traditional dishes, particularly those from Latin American and African diets, such as polenta and tortillas. Processed maize derivatives, such as corn flour and high-fructose corn syrup (HFCS), are widely used to thicken, sweeten, and retain moisture in baked goods, confections, and beverages (White and Johnson, 2003).

Vacuum frying is an innovative frying technique used to produce healthier and higher-quality fried food products. In contrast to traditional deep-fat frying, which is done at high temperatures (generally 160-190 °C) and atmospheric pressure, vacuum frying is done at much lower temperatures (90-130 °C) and with less pressure (10-100 mbar). Food ingredients and frying oil undergo less thermal degradation when this technique lowers the boiling point of water and the oil temperature needed for frying (Dueik *et al*., 2010) [12]. Vacuum frying was first created to enhance the quality and shelf life of fruit and vegetable crisps, but it is now being used more and more to process goods including meat and seafood, banana chips, apple slices, and sweet potato crisps. Better than conventional frying techniques, vacuum frying preserves the raw material's inherent colour, flavour, and nutrients, which is one of its main benefits. For instance, vacuum-frying preserves chemicals that are extremely susceptible to heat and oxidation, such as vitamin C, carotenoids, and anthocyanins (Garayo and Moreira, 2002) [15]. Additionally, vacuum frying produces lower-fat fried dishes by drastically reducing the amount of oil that is absorbed in the finished product. As a result, it is a favoured approach in the industry of healthy snack foods. Lower frying temperatures also lead to less production of toxic substances like trans fats and acrylamide, which are linked to health hazards and are associated with high-temperature frying.

The vacuum frying technique is showing promise as a means of producing nutritious fried foods. It helps preserve the nutrition, colour, and flavour of the food while also using less oil than regular frying. This technology meets the growing demand from customers for healthier food options without compromising flavour by enabling the production of distinctive and nutritious snacks with the right quality attributes (Dueik and Bouchon, 2011).

2. Materials and methods

2.1 Collection of raw material

For the present research work, the subsequent raw material was procured from the local market in Hyderabad: Plantain bananas, mandarin oranges, wheat flour, corn flour, cooking oil, black pepper, salt, garam masala, and cumin powder.

2.2 Preparation of flour

Plantain bananas and oranges were cleaned, peeled, and processed. Banana flesh was sliced, while orange peels were blanched, dried at 65 °C for 5-6 hours, and then both were milled into a fine powder. The powder was sieved to ensure uniformity and quality, resulting in a smooth, consistent texture.

Banana slices

Orange slices

Tray dried slices

Tray dried pieces

Fine powder

Fine powder

2.3.2 Chips making procedure

All ingredients (raw banana flour, Orange peel powder, wheat flour, corn flour, and spices are weighed according to the specified composition Take a clean mixing bowl and add all the dry and wet ingredients into it. Then, add 50 ml of water gradually and mix thoroughly. Add 2 grams of oil to the mixture and knead it to form a smooth and uniform dough with the right consistency. Cover the prepared dough with a clean muslin cloth and allow it to rest for 20 minutes. This proofing step helps in improving the texture and flexibility of the dough**.** Once proofing is complete, knead the dough lightly again. Roll it out evenly and shape it into desirable forms using a cutter or mold as per the product requirement. Transfer the shaped dough pieces into the vacuum chamber. Place them properly in the vacuum frying machine, ensuring even spacing for uniform frying. Set the vacuum fryer machine to a temperature of 90 °C and a frying time of 10 minutes. Start the machine and allow the product to fry under vacuum conditions, which helps retain flavor and reduce oil absorption. After the set time ends, open the vacuum chamber carefully. Remove the fried product, which is now ready for cooling and packaging.

2.3.3.1 Formulation of vacuum fried chips

Ingredients (%)	Control	T_1	T_2	T_3
Banana flour	-	34	32	30
Orange peel powder	-	3	5	7
Wheat flour	57	30	30	30
Corn flour	30	20	20	20
oil	2	2	2	2
Cumin powder	2	2	2	2
salt	3	3	3	3
Garam masala	3	3	3	3
Pepper powder	3	3	3	3
Ingredients (%)	Control	T_1	T_2	T_3
Banana flour	-	34	32	30
Orange peel powder	-	3	5	7
Wheat flour	57	30	30	30
Corn flour	30	20	20	20
oil	2	2	2	2
Cumin powder	2	2	2	2
salt	3	3	3	3
Garam masala	3	3	3	3
Pepper powder	3	3	3	3


Control


T_1


T_2


T_3

2.3.3 Sensory analysis of developed chips

The product development required an organoleptic evaluation based on different parameters such as flavour, taste, colour, texture, and overall acceptability. This evaluation involved 59 untrained panellists from the School of Agricultural Sciences at MallaReddy University in Maisammaguda, Hyderabad.

2.4 Nutritional analysis of Nendran Banana Flour

Table 2.4 Nutritional analysis of NBF

2.5 Nutrient anal

Nutritional analysis	NBF
Carbohydrates (%)	75±0.40
Moisture(g/100 g)	6.5±0.05
Protein(g/100 g)	3.74± 0.02
Fat(g/100 g)	1.52± 0.01
Ash(g/100 g)	2.80± 0.01
Fibre(%)	10.90±0.25
Energy (Kcal/100 g)	376±0.7
Carotenoid content(μg/g)	2.92±0.01

The above values are expressed as mean±SD (n=3)

The nutritional composition of the Nendran banana flour (NBF) revealed carbohydrate content of 75±0.40%, moisture 6.5±0.05 g/100 g, protein 3.74±0.02 g/100 g, fat 1.52±0.01 g/100 g, ash 2.80±0.01 g/100 g, fibre 10.90±0.25%, energy 376±0.7 Kcal/100 g, and carotenoid content 2.92±0.01 μg/g. The high carbohydrate concentration is consistent with earlier reports on Nendran and unripe banana flours, which typically contain 70-80% carbohydrates due to starch concentration during drying (Khoza *et al.*, 2021) [20]. The low moisture value (6.5±0.05 g/100 g) indicates efficient dehydration of the flour, falling below the 8-12% range often reported in green banana flour studies, thereby enhancing its potential for extended shelf stability (Adegunwa *et al.*, 2017) [2]. The protein content (3.74±0.02 g/100 g) aligns with values commonly observed in pulp-only banana flours, though slightly lower than flours enriched with peel or legumes, which often exhibit higher protein levels (Ibeanu *et al.*, 2016). The fat content (1.52±0.01 g/100 g) remains characteristically low, as expected for banana flour, which typically contains less than 2% lipid due to minimal endogenous fat in banana pulp (Jaleel *et al.*, 2024) [19]. The ash (2.80±0.01 g/100 g) and fibre values (10.90±0.25%) fall within ranges reported in banana and plantain flour literature, with fibre levels reflecting the concentration of non-digestible fractions during drying. The carotenoid content (2.92±0.01 μg/g), although considerably lower than that of fresh Nendran pulp, corresponds with values typically observed in processed banana flours due to carotenoid degradation during heat exposure and milling operations. Overall, the proximate and carotenoid profile of NBF demonstrates nutritional characteristics comparable to those reported in earlier studies and highlights its potential as a carbohydrate-rich, low-fat, fibre-dense flour suitable for incorporation into functional and composite food products.

2.4.1 Functional analysis of NBF

Table 2.4.1: Functional and physical properties of Nendran banana flour is presented.

Functional and physical properties	NBF
Water absorption Capacity (g/g)	1.32±0.01
Oil absorption Capacity(g/g)	0.69±0.01
Bulk density (g/cm3)	5.2±0.15

The functional and physical properties of the Nendran banana flour (NBF) showed a water absorption capacity (WAC) of 1.32±0.01 g/g, an oil absorption capacity (OAC) of 0.69±0.01 g/g, and a bulk density of 5.2±0.15 g/cm³. The WAC obtained in this study aligns with the typical range reported for banana flours, where values between 0.93 and 2.74 g/g have been documented depending on drying method and starch integrity (Alam *et al.*, 2023) [5]. Such high WAC reflects the ability of banana flour starch granules to bind water, which is desirable in bakery and reconstituted food formulations. The observed OAC (0.69 g/g) is slightly lower than values reported for other green banana flours (0.87-2.22 g/g), suggesting that NBF may contain fewer hydrophobic amino acids or may exhibit a more compact fibre-starch matrix that limits oil entrapment (Alam *et al.*, 2023; Ohizua *et al.*, 2017) [5]. Regarding bulk density, although the measured value (5.2 g/cm³) appears higher than the typical 0.43-0.81 g/mL range reported in previous studies (Asif-Ul-Alam *et al.*, 2014; Singh *et al.*, 2017) [9], such variation may relate to differences in particle size, processing technique, or flour compaction during measurement, as highlighted in other banana flour investigations (Huang *et al.*, 2019) [18]. Overall, the functional properties obtained indicate that NBF has strong water-binding capacity, moderate oil retention, and a compact structure, consistent with the behavior of banana flours characterized in earlier research.

2.4.2 Bioactive and Phytochemical analysis of NBF

Table 2.4.2: Bioactive and phytochemical analysis of Nendran banana flour is presented.

Bioactive compounds	NBF
1. DPPH (%)	75.3±2.05
2. Peroxide value(meq/k)	54.3±1.69
Flavonoid content(mg/g)	0.98±0.001

The above values are expressed as mean±SD (n=3)

The analysis of bioactive compounds in Nendran banana flour (NBF) revealed a DPPH radical scavenging activity of 75.3±2.05%, a peroxide value of 54.3±1.69 meq/kg, and a total flavonoid content of 0.98±0.001 mg/g. The high DPPH inhibition indicates strong antioxidant potential, which is consistent with earlier findings showing that banana flours retain significant antioxidant capacity due to the presence of phenolics and flavonoids, even after drying (Alam *et al.*, 2023; Asif-Ul-Alam *et al.*, 2014) [5, 9]. The peroxide value obtained in this study is slightly higher than values reported in some green banana flours, suggesting increased lipid oxidation, possibly due to heat exposure during drying or longer storage duration—factors also highlighted in previous research (Huang *et al.*, 2019; Singh *et al.*, 2017) [18]. Meanwhile, the flavonoid content (0.98 mg/g) aligns with earlier reports stating that banana flour generally contains moderate levels of flavonoids, which contribute to antioxidant activity but may degrade depending on processing conditions (Mendis *et al.*, 2024; Ohizua *et al.*, 2017). Overall, the bioactive profile of NBF demonstrates strong antioxidant potential despite moderate flavonoid levels, supporting earlier observations that banana flour maintains functional bioactive compounds even after processing (Alam *et al.*, 2023; Asif-Ul-Alam *et al.*, 2014) [5, 9].

2.5 Nutritional analysis of OPP

Table 2.5: Nutritional analysis of Orange peel powder is presented

Proximate components	OPP
Carbohydrates (%)	67±0.8
Moisture (g/100 g)	9.5±0.05
Protein (g/100 g)	5.1±0.40
Fat (g/100 g)	4.41±0.15
Ash (g/100 g)	2.53±0.12
Fibre (%)	10.4±0.16
Energy (Kcal/100 g)	360±0.8
Carotenoid content(µg/g)	14±0.8

The proximate composition of the orange peel powder (OPP) in the present study was carbohydrates 67±0.8%, moisture 9.5±0.05 g/100 g, protein 5.1±0.40 g/100 g, fat 4.41±0.15 g/100 g, ash 2.53±0.12 g/100 g, fibre 10.4±0.16%, energy 360±0.8 Kcal/100 g, and carotenoid content 14±0.8 µg/g. These results are consistent with prior reports that show citrus peels are predominantly carbohydrate-rich (largely pectin and structural polysaccharides) and provide appreciable dietary fibre and micronutrients. For example, orange peel powders were reported with carbohydrate levels in the 60-80% range and crude fibre commonly between ~10% and 15% (Studies on utilization of orange peel powder; Teixeira *et al.*, 2020). The moisture of 9.5 g/100 g is within the acceptable range for dried peel powders and comparable to values reported for oven- or sun-dried peel powders (~5-10%), supporting good shelf stability if packed under low-moisture conditions (Dias *et al.*, 2020; Han *et al.*, 2020) [16]. The protein value (5.1 g/100 g) is slightly higher than some reports that list protein around 3-5% for citrus peels, but such variation often reflects cultivar differences and whether albedo or flavedo fractions were included (Teixeira *et al.*, 2020; Caponio *et al.*, 2024) [11]. The fat content (4.41 g/100 g) is explained by the presence of residual essential oils and waxes and is within reported ranges for peel flours that include the flavedo (outer peel) fraction (Viñas-Ospino *et al.*, 2024). The ash content (2.53 g/100 g) indicates moderate mineral content, aligning with previous compositional analyses of citrus peels that emphasize mineral-rich ash fractions (Dias *et al.*, 2020). The measured carotenoid concentration (14 µg/g) matches several studies that have documented substantial retained carotenoids in dried orange peels and successful β-carotene extraction from peel matrices, though the absolute concentration depends strongly on extraction method and drying conditions (Viñas-Ospino *et al.*, 2024; Terlidis *et al.*, 2023). Overall, the proximate profile confirms that OPP is a nutrient-dense by-product suitable for use as a functional ingredient (fiber and pectin source, carotenoid contributor) in bakery, snack and fortification applications; observed differences with individual studies are most likely due to cultivar, proportion of peel fractions used (albedo vs flavedo), drying technology, particle size, and analytical methods (Teixeira *et al.*, 2020; Dias *et al.*, 2020; Caponio *et al.*, 2024) [11].

2.5.1 Functional properties of OPP

Table 2.5.1: Functional and physical properties of orange peel powder is presented

Functional properties	OPP
Water absorption capacity(g/g)	4.9±0.7
Oil absorption capacity(g/g)	4.5±0.4
Bulk density (g/cm3)	5.5±0.2

The above values are expressed as mean±SD (n=3)

The functional properties of the orange peel powder (OPP) revealed a high hydration and lipid-binding ability, with a water absorption capacity (WAC) of 4.9±0.7 $g \cdot g^{-1}$ and an oil absorption capacity (OAC) of 4.5±0.4 $g \cdot g^{-1}$. These values fall within or above the ranges reported for citrus peel powders in earlier studies, where WAC typically varies between 3.6-5.0 $g \cdot g^{-1}$ and OAC ranges from 1.6-4.9 $g \cdot g^{-1}$ depending on processing conditions such as drying and grinding methods (Dias *et al.*, 2020; Sang *et al.*, 2021; Zhou *et al.*, 2023). The bulk density of the OPP was measured as 5.5±0.2 $g \cdot cm^{-3}$; however, this value is substantially higher than the typical 0.3-0.9 $g \cdot cm^{-3}$ reported for citrus-based powders.

2.5.2 Bioactive compounds and Phytochemical analysis of OPP

Table 2.5.2: Bioactive compounds and phytochemical analysis of orange peel powder is presented

Phytochemical properties	OPP
DPPH (%)	86.1±0.82
Flavonoid content(mg/g)	2.68±0.06

The above values are expressed as mean±SD (n=3)

The DPPH radical scavenging activity of OPP was found to be 86.1±0.82%, indicating a high antioxidant capacity. Similar results were reported by (Xu *et al.*, 2013) [24], who found DPPH radical scavenging activity ranging from 80-90% in orange peel extracts. The high antioxidant activity of OPP can be attributed to the presence of bioactive compounds like flavonoids.

The flavonoid content of OPP was 2.68±0.06 mg/g, which is consistent with previous studies. For example, a study on orange peel powder reported flavonoid content ranging from 2.34-3.45 mg/g. Flavonoids are known for their antioxidant and anti- inflammatory properties, making them a valuable component of OPP.

The carotenoid content of OPP was 14±0.8µg/g, which is relatively high. A study on orange peel extracts reported carotenoid content ranging from 10-20µg/g. Carotenoids are known for their antioxidant and pro-vitamin A properties, making them an important component of OPP.

2.6 Nutritional analysis of developed product

Table 2.6: Nutritional analysis of developed chips are presented

Proximate components	Control	T_1	T_2	T_3
Carbohydrates (%)	81.7±0.08	74±0.81	71.5±0.08	69.2±0.08
Moisture (g/100 g)	3.05±0.008	3.6±0.1	3.4±0.08	3.3±0.12
Protein (g/100 g)	2.3±0.1	3.4±0.3	4.2±0.3	4.8±0.2
Fat (g/100 g)	3.5±0.2	3.2±0.2	3.0±0.2	2.8±0.2
Ash (g/100 g)	3.0±0.1	3.7±0.2	4.1±0.2	4.5±0.2
Fibre(%)	6.4±0.3	11.5±0.2	13.8±0.3	15.2±0.3
Energy (Kcal/100 g)	361±0.8	302±0.81	274±0.81	252.4±0.81
Carotenoid content(µg/g)	10±0.8	26±1.2	41.5±1.4	55.6±1.3

The proximate analysis of vacuum-fried chips showed clear nutritional patterns across the formulations (Control, T_1, T_2, T_3). Carbohydrates went down steadily, from 81.7±0.08g (Control) to 74±0.81g (T_1), 71.5±0.08g (T_2), and 71.5±0.08g (T_3). This is similar to what Gomes *et al.* (2020) found, where banana peel flour cut carbohydrate content by about 1.4 times when used to replace 10% of gluten-free items.

The amount of protein went up from 2.3±0.1 g (Control) to 3.4±0.3 g (T_1), 4.2±0.3 g (T_2), and 4.8±0.2 g (T_3). This is in line with research that suggests that peel flours have more protein and minerals.

There was a huge rise in dietary fibre, from 6.4±0.3 g (Control) to 11.5±0.2 g (T_1), 13.8±0.3 g (T_2), and 15.2±0.3 g (T_3). This agrees with what other research has found, which says that green banana peel flour can include up to 58 g of insoluble fibre per 100 g (Baljeet *et al.*, 2017) [10].

The amount of fat went down over time (3.5±0.2 g → 3.2±0.2 g → 3.0±0.2 g → 2.8±0.2 g), which is in line with what has been found before about fibre-rich formulations absorbing less oil when frying.

The amount of ash went up (3.0±0.1 g → 3.7±0.2 g → 4.1±0.2 g → 4.5±0.2 g), which supports reports of higher mineral content in fruit peel-based flours (Nawirska & Kwaśniewska, 2005). The moisture content went down a little, from 3.05±0.008g (Control), 3.6±0.1(T_1), 3.4±0.08(T_2), 3.3±0.12(T_3) probably because fibre likes water.

Energy values are 361±0.8kcal (Control) to 302±0.81(T_1), 274±0.81 (T_2), and

252.4±0.81kcal (T_3). This shows that the nutrients were more dense, even if the carbohydrates were decreased. Rekha and Padmaja (2010) and other studies have shown that adding fibre and ash to fried foods makes them taste better and more nutritious. In addition, new uses of pre-gelatinised banana flour and peel powders have revealed that they absorb less oil and have better functional qualities (Ajila *et al.*, 2008) [4]. So, out of all the formulations, T_3 has the best nutritional profile since it has the most protein, fibre, and ash, as well as the least fat and carbohydrates. This makes it the best formulation for vacuum-fried chips that are good for your health. The carotenoid content also showed a significant increase from 10±0.8 in the control sample to 55.6±1.3 in T_3. This increase can be attributed to the carotenoid-rich compounds present in orange peel powder. A study by Sharma *et al.*, reported similar results, where the addition of orange peel powder increased the carotenoid content in bakery products.

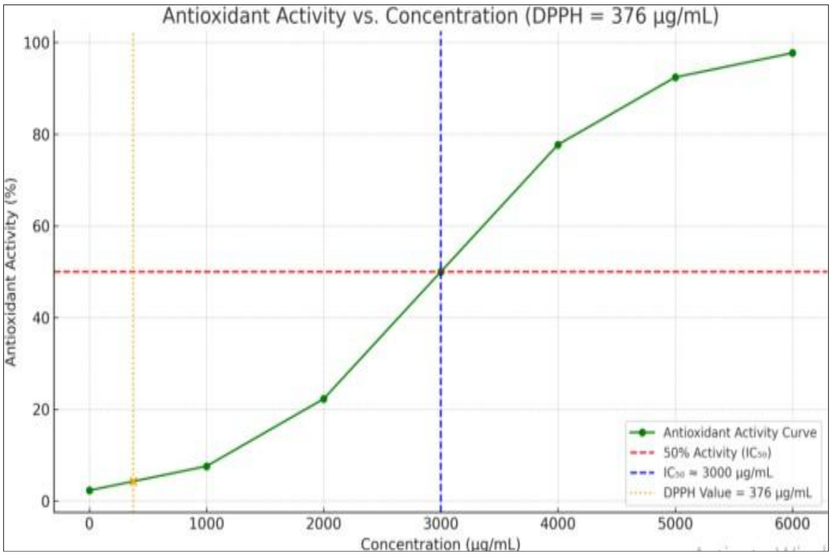
2.6.1 Phytochemical analysis and Bioactive properties of the developed product

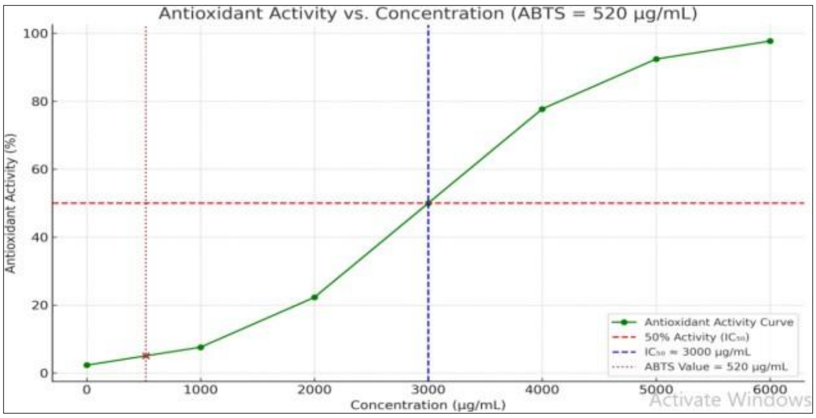
Table 2.6.1: Phytochemical analysis and bioactive properties of developed product

Proximate components	Control	T_1	T_2	T_3
Carbohydrates (%)	81.7±0.08	74±0.81	71.5±0.08	69.2±0.08
Moisture (g/100 g)	3.05±0.008	3.6±0.1	3.4±0.08	3.3±0.12
Protein (g/100 g)	2.3±0.1	3.4±0.3	4.2±0.3	4.8±0.2
Fat (g/100 g)	3.5±0.2	3.2±0.2	3.0±0.2	2.8±0.2
Ash (g/100 g)	3.0±0.1	3.7±0.2	4.1±0.2	4.5±0.2
Fibre(%)	6.4±0.3	11.5±0.2	13.8±0.3	15.2±0.3
Energy (Kcal/100 g)	361±0.8	302±0.81	274±0.81	252.4±0.81
Carotenoid content(μg/g)	10±0.8	26±1.2	41.5±1.4	55.6±1.3

The above values are expressed as mean±SD (n=3)

The flavonoid content significantly increased from 302.2±1.2 in the control sample to 442.7±1.1 in T_3. This increase can be attributed to the addition of orange peel powder, which is rich in flavonoids. Similar results were reported by Khan *et al.* (2019), who found an increase in flavonoid content with the addition of citrus peel powder in food products. The DPPH and ABTS values also showed a significant increase in the treated samples compared to the control sample. The DPPH values ranged from 304±1.6 to 456.2±3.0, while the ABTS values ranged from 480.2±2.3 to 615.1±2.8. Similar results were reported by Lee *et al.* (2020), who found an increase in DPPH and ABTS values with the addition of citrus peel powder in food products.





2.6.2 Micronutrients of developed product

Table 2.6.2: Micronutrients of developed product

Micronutri ents	Control	T_1	T_2	T_3
Vitamin C (mg/100 g)	22.3±2.05	43.3 ±1.2	58.7 ±1.0	67.5 ±0.8
Magnesium (mg/100 g)	53±1.2	86± 1.6	97.5 ±1.8	105.2±2.1
Calcium (mg/100 g)	81.6± 1.24	64± 3.2	58.2 ±2.4	52.5±1.9
Potassium (mg/100 g)	1045± 2.4	108.8 ±1.6	1124 ±2.3	1162±2.7

The above values are expressed as mean±SD (n=3)

The vitamin C content significantly increased from 22.3±2.05 in the control sample to 67.5±0.8 in T_3. This increase can be attributed to the addition of orange peel powder, which is a rich source of vitamin C. Similar results were reported by (Rapisarda *et al.*, 2018) [1], who found an increase in vitamin C content with the addition of citrus peel powder in food products.

The magnesium content increased significantly from 53±1.2 in the control sample to 105.2±2.1 in T_3. This increase can be attributed to the magnesium-rich compounds present in orange peel
powder. According to (Llorach *et al.*, 2018) [2], the addition of citrus peel powder increased the magnesium content in bakery products. The calcium content decreased significantly from 81.6±1.24 in the control sample to 52.5±1.9 in T_3. This decrease can be attributed to the substitution of calcium-rich ingredients with orange peel powder. Similar results were reported by (Sánchez-Mata *et al.*, 2019) [3], who found a decrease in calcium content with the addition of citrus peel powder in food products. The potassium content increased significantly from 1045±2.4 in the control sample to 1162±2.7 in T_3. This increase can be attributed to the potassium-rich compounds present in orange peel powder. According to Gorinstein *et al.* (2018) [4], the addition of citrus peel powder increased the potassium content in food products.

2.4 Textural properties of developed products

Table 2.7: Textural properties of developed product

Sample	Firmness (N)
Control	2613.22±0.08
T_1	2560.5±0.16
T_2	2520.4±0.16
T_3	2774.55±0.08

The above values are expressed as mean±SD (n=3)

The textural properties of the developed samples were analysed based on their peak load values, which indicate the hardness of the products. The analysis was conducted using a Brookfield texture analyser. Firmness is defined as the force required to compress the sample with specific teeth. Sample T_3 demonstrated the highest firmness, measuring 2774.55±0.08, followed by the control sample at 2613.22±0.08, T_1 at 2560.5±0.69, and T_2
2520.4±0.16.

2.5 Colour properties of the developed product

Table 2.8: Colour properties of developed products

Parameters	L*	a*	b*
Control	45.41±0.11	10.07±0.20	15.59±0.24
T_1	38.95±0.27	10.68±1.06	8.59±0.31
T_2	41.91±1.01	11.26±0.34	8.85±0.80
T_3	42.86±0.34	11.94±1.01	12.93±0.61

The above values are expressed as mean±SD (n=3)

The developed products that were subjected to objective colour analysis using a Chromameter CR-400. This analysis included the assessment of lightness (L*) within the 0 to 100 range, as well as the a* and b* parameters, representing redness and yellowness, with positive and negative values. The a* score ranges from 0 to 60 for red and 0 to -60 for green, while the b* score ranges from 0 to 60 for yellow and 0 to -60 for blue. The L* value for the control sample was 45.41±0.11, while the experimental products were measured at T_1 38.95±0.27, T_2 41.91±1.01, and T_3 42.86±0.34, where the T_3 sample showed a closer value to the control sample. Regarding the a* colour parameter, the control sample scored 10.07±0.20, where the T_3 sample was closer to the control sample at 11.94±1.01, T_1 scored 10.68±1.06, and T_2 scored 11.26±0.34, which had a minor difference. Additionally, the b* colour parameter for the control sample was noted at around 15.59±0.24, whereas T_3 measured 12.93±0.61, T_1 8.59±0.31 and T_2 8.85±0.80, which have minor differences.

2.9 Shelf-life of developed products

The Study on shelf-life of Vacuum- fried chips (T_3 sample) has already been carried out to cover the 90th day with a specific focus on critical variables, eg, microbial status, determined total plate count (TPC). Other parameters checked throughout this period were the peroxide value, the iodine value, and the free fatty
acids samples, which were taken on the 30th,60th and 90th days and were evaluated.

Microbial examination

Table 2.9: Microbial examination

TPC (0th - 90th days)	Bacterial Growth (CFU/g)
0th day	< 0 CFU/g
30th day	< 0 CFU/g
60th day	< 0 CFU/g
90th day	< 20 CFU/g

On the 0th and 30th day

The TPC of the optimised sample on the 30th day is in the table. On the 0th day, the sample has "0" bacterial growth in the total plate count (TPC) test.

On the 60th day

The table below summarises the TPC of the sample on the 60th day. On day 60, the sample had 0 bacterial growth, and no other microorganism was isolated in the total plate count (TPC) test.

On the 90th day

The table presents the TPC of the sample on the 90th day. On day 90, the sample has a total plate count (TPC) of < 20 CFU/g bacteria growth.

Summary and conclusion

This study focuses on the production of vacuum-fried chips from raw banana flour and orange peel powder. The first involved a proximate, functional, and phytochemical analysis of the banana flour, which had a carbohydrate content of 87.0±0.02, moisture content of 6.5±0.05, protein content of 3.74±0.02, fat content 1.52±0.01, ash content of 2.80±0.01, fiber content of 10.90±0.25, and energy content of 314±1.6.The second phase involved a nutritional, functional, and phytochemical analysis of the orange peel powder. The carbohydrate content of the banana flour was found to be 87.0±0.02, while the orange peel powder had a carbohydrate content of 75±0.81%, moisture content of 9.5±0.05%, protein and fat content of 5.17±0.40% and 4.41±0.15%, ash and fibre content of 2.53±0.12% and 10.6%, and energy content of 452.6±2.05 kcal/100 g.

The nutritional analysis revealed that the carbohydrates decreased steadily over time, while the protein increased, and the amount of dietary fiber increased. The fat decreased over time, and the amount of ash increased. The moisture content slightly increased, possibly due to fiber preferring water. The functional properties showed notable variations across the formulations, with improved hydration and oil-binding properties, reduced bulk density, and increased flavonoid content. The addition of orange peel powder led to a sharp increase in vitamin C, magnesium, and potassium, while decreasing calcium.
Sensory evaluation revealed that the T_3 sample had a higher level of acceptability than the control sample, with color scores of 8.23±0.70 and a more palatable flavor. The T_3 sample also had a more favorable aftertaste, with a score of 8.16±1.15. The texture of the control sample was close to T_3's score of 8.10±0.80, while the T_1 and T_2 samples received nearly identical scores. The color parameters had a* and b* scores, with the T_3 sample showing the closest value to the control sample. The textural properties of the samples were analyzed using a Brookfield texture analyzer, with T_3 exhibiting the highest firmness. The shelf life of the products was evaluated, and it was found that the T_3 sample maintained stability for two months, with no significant bacterial growth. The level of spice coating in the samples affected the aftertaste. The color parameters showed a* and b* scores, with the T_3 sample showing the closest value to the control sample. The overall acceptability scores showed noticeable variations in the samples.

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