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Apple Peel Valorization: A Sustainable Approach to Food Waste Upcycling

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Abstract
Apple peel, a by-product of processing apples, has the potential to be used in the production of functional meals since it is a rich source of bioactive compounds and dietary fibre. Apple peel, being abundant in polyphenols, flavonoids, and vital minerals, has potent antioxidant qualities that increase food quality and promote better health. Apple peel can improve the nutritional profile of a range of culinary goods while preserving flavour. Beyond its use in culinary applications, apple peel shows promise in giving biodegradable substitutes for functional packaging, increasing shelf life, and enhancing microbiological stability. Apple peel is used in food compositions to boost antioxidant activity and dietary fibre, in addition to helping to prevent and improve health. Its versatility and useful benefits are demonstrated by its application in a range of food systems, including dairy, meat, baked items, and beverages. Additionally, by offering biodegradable substitutes for synthetic materials, packaging materials made from apple peels provide an environmentally responsible way to lessen their influence on the environment. Reusing leftover apple peels to make useful components reduces waste and improves the nutritional content of food items, which is consistent with the circular economy and sustainability tenets. This strategy encourages the effective use of food sector byproducts and fosters the creation of value-added goods. Apple peel is a prime option for use in functional food formulations and environmentally friendly packaging solutions because of its bioactive capabilities, which can enhance public health and environmental sustainability.

Keywords: Apple Peel, Antioxidant, Functional Food, Food Waste, Health Benefits, Nutritional Parameters

1. Introduction

The global food business produces a large number of wastes and by-products every year from a variety of sources. Large amounts of food processing industry by-products are created; however, due to their unfavorable characteristics, they are usually thrown away, costing valuable resources. Rich in bioactive substances, by-products can be utilized in a variety of industrial settings to improve nutrition and promote health. [1] However, the byproducts of plants are abundant in valuable compounds that, through various extraction, purification, and fermentation processes, can be used in a variety of industries as new, affordable, and organic sources of food additives, pectin, enzymes, dietary fibre, antioxidants, organic acids,

essential oils, etc. [2] Natural antioxidants can be found in abundance in fruits and vegetables. It is reasonable to hypothesize that purposefully consuming more of these fruits will result in a higher intake of natural antioxidants, which could offer an alternative to aging intervention by guarding against oxidative damage. Due to their varying antioxidant capacities, different fruits may offer varying levels of protection against oxidative stress. Apples are among the fruits that have significant levels of antioxidants. Flavonoids and phenols, which are ingested all year round, are found in it in significant amounts. [3] Numerous health-promoting phenolic compounds are prevalent in apples, particularly in the skin. In addition to having three to six times as many flavonoids as apple flesh, apple skin also contains special flavonoids that are absent from the flesh, like quercetin glycosides. Apple skin extracts considerably reduced the proliferation of human hepatocellular liver cancer cells compared to the whole apple. With a balanced ratio of soluble and insoluble fibre parts, it is also a great source of nutritious fibre. [4] Utilizing natural antioxidants to replace synthetic food additives A lot of items have become more well-known in recent years. Owing to their high phenolic content, apples including by-products, have garnered attention as potential natural sources of antioxidants. There are many by-products created when apples are processed. This by-product, known as pomace, is made up of a blend of soft tissue, calyx, peel, core, and seed. [5] Apples and apple peels have been shown to contain a number of antioxidant chemicals, including cyanidin-3-galactoside, procyanidin, coumaric acid, gallic acid, phloridzin, quercetin-3-galactoside, epicatechin, catechin, and chlorogenic acid. However, many compounds, such as epicatechin, catechin, phloridzin, and procyanidin, are found in smaller amounts in apple flesh rather than in peels. [6] The apples are industrially processed for juice, cider, and powder, producing a variety of byproducts such as seed, peel, core, and stem. Approximately 68% of apples are eaten raw. Approximately 13% of the weight of the fresh apple fruit is made up of the peels from cutting the fruit and creating apple pie and sauce. The seeds stand in for the other result of the apple pomace. They are separated from apple pomace in a 4–7% bulk fraction by sieving and separating. Amygdalin is a cyanogenic glycoside found in apple seeds. When β-glucosidase, which is naturally found in the human intestine, breaks it down, cyanide can be formed, which is extremely dangerous to humans. Apple by-products are primarily regarded as waste materials, and manufacturing companies struggle to dispose of them in an environmentally friendly manner. Apple pomace is typically utilized as a substrate for aerobic fermentation, as feed for animals, or as fertilizer. However, there can be substantial losses when apple by-products are disposed of as waste. [5] In production facilities, apples are completely peeled, and their peels are usually utilized to make juice or compost. The processing of apples is thought to produce about 9000 metric tons of peels each year. [7] Peels are either utilized as feed or thrown out or discarded in the trash. Flavonoids, ash, soluble dietary fibre, polyphenols, and lipids are all more abundant in the peels than in the pomace. [8] The apple peels were ideally converted into dried and crushed material in bulk conducive to fibre formulation as well as nutraceutical usage . [9] A nutritional profile is barely affected by drying; phenolic compounds are reduced by 15%, and dietary fibre (dry basis) is reduced by 17% if compared to the raw material. As an outcome, dried apple peel can be used to increase the amount of fibre and antioxidants in food compositions. Its use also minimizes processing waste, which increases economic value and lessens environmental impact. [7] Without affecting the final products' sensory qualities, the high phenolic content of apples and their by-products, i.e., an extract, makes it easier to create products with enhanced antioxidant qualities. Additionally, utilizing apples and their byproducts properly minimizes their negative environmental effects and boosts the economy. [5] Incorporating apple peel into healthy food products is a beneficial and appealing addition. Products' phytochemical content and antioxidant activity could be significantly enhanced by just a small proportion. Cereals, fruit leathers,

granola, and sports bars are a few potential applications. Adding apple peels, which are rich in phytochemicals, to a diet rich in fruits, vegetables, and whole grains may help prevent and treat chronic illnesses. [10]

2. Nutritional Composition

Carbohydrates are the Energy production is the primary metabolic function of carbohydrates in the diet. Although there are various kinds of carbohydrates, only total carbs—what remains after the removal of protein, fat, moisture, and ash from food—are taken into account. Based on prior research, the star apple's carbohydrate content was 80.60% on average, with peel, pulp, and seed having corresponding carbohydrate percentages of 79.392%, 79.025%, and 83.38%.[11] Apple peel powders, which have higher levels of carbohydrates, had been studied in another investigation. Their concentration ranged from 61.78 to 65.44%, which is between the body's natural functions and structural elements like energy storage. The average carbohydrate content of 63.84 ± 1.53% provides additional evidence in favor of using the studied apple peel powder as a carbohydrate source.[12]

Proteins are essential macromolecules for the human body's optimal functioning, especially the development of muscles. Thus, it has been shown that protein deficits are strongly associated with a variety of ailments, such as oedema, mental disorders, organ dysfunction, immunological weakness, Kwashiorkor, and marasmus (energy lack). [13] With an average protein content of 6.73%, star apple peel, pulp, and seed had protein contents of 6.78%, 4.73%, and 8.75%, respectively. These are higher than the initial 0.98% for the seed shell's pericarp.[11] Analyzed apple peel powder includes protein and important macronutrient concentrations ranging from 3.86 to 4.94%, according to human nutrition data. Peel powder has a low protein intake, as indicated by its average value of 4.31 ± 0.48% for this nutritional criterion. [12] The human body uses lipids as vital macronutrients for a variety of physiological and biochemical processes, including energy storage, the formation of biological membranes, electron transport, cofactors for enzymes, pigments that absorb light, hydrophobic protein anchoring, and digestive system emulsifiers. [12] The average fat level of the star apple was 7.46%, with the peel, pulp, and seed having fat amounts of 8.94%, 10.00%, and 3.45%, respectively. Therefore, pulp has more fat than peel and seed. [11] Previously examined apple peel powder samples' fat concentration ranges from 3.11 to 3.03. The average fat concentration result (3.48 ± 0.40%) indicates that the powdered apple peel is a low-calorie source. [12] Dietary fibre compounds may be extracted from the by-products of many food processing industries, such as the beverage, canning, and juice sectors. Mostly made up of pomace and peels, this latter likely generates the most quantities of by-products. Due to its ability to improve digestion, prolong freshness, and retain more water, DF has seen extensive use in the food sector when added to baked items. [13] As a result, scientists and businesses have concentrated on creating foods high in fibre by using by-products as sustainable and alternate sources of dietary fiber. Its ability to reduce a number of illnesses is closely linked to the interest in learning more about it. Furthermore, the food industry can make extensive use of dietary fibres by adding them to a variety of meals to improve their nutritional and sensory qualities. Additional baked products, such as macarons, muffins, and biscuits, were enhanced by 20%, 30%, and 50%, respectively. However, when the substitution level was less than 10%, they were generally regarded as acceptable. Notably, the finished products get darker and tougher as the fibre content increases. [14] Further, from a technological standpoint, dietary fiber improves the ability of foods to hold water and oil, emulsification and gel formation (which alter food texture, color, and aroma), stabilizes products with high fat and emulsion content (extending their shelf life), and lowers the energy of the finished products.

[15] According to earlier studies, the concentration of the macronutrients in the examined apple peel samples ranges from 35.15 to 38.31%. With an average dietary fibre level of 36.39 ± 1.23 percent, apple peel powder is a reliable source of dietary fiber. [12] As previously stated, samples containing 4 and 8% APP are classified as "fibre source," but samples containing 16, 24, and 32% APP are classified as "high fibre source" products. [15] APP's TDF, IDF, and SDF values were 68.8 g/100 g, 52.33 g/100 g, and 16.51 g/100 g, respectively, in earlier studies on apple peels. These studies also demonstrated that APP's IDF content was higher than its SDF content, with other comparable studies reporting values of 43.89 g/100 g, 11.86 g/100 g, and 32.03 g/100 g, respectively. Additionally, it was noted that apple peels had a larger percentage of SDF than IDF. [8,15,16]

3. Polyphenols and Antioxidants

Food ingredients with potential health-protective qualities, such as flavonoids, which are polyphenolic antioxidants, are gaining. [17] Important antioxidants called phenolic acids and flavonoids are found in significant concentrations in fruit and vegetable waste products such as peels, seeds, pomace, and leaves.[18] Rather than vital nutrients like vitamin C, polyphenols make up most antioxidants in apples and are the most prevalent antioxidants in the human diet. Due to their year-round availability and widespread use, apples are one of the most significant fruit sources of dietary polyphenolic compounds in the Western diet. [19] Thus far, apples have been identified to contain around 60 phenolic compounds, primarily composed of flavonoids and phenolic acid. [5] Apples include five primary classes of polyphenolic compounds: anthocyanins (cyanidins), dihydrochalcones (phloretin glycosides), phenolic acids (mostly chlorogenic acid), flavanols (catechin, epicatechin, and procyanidins), and flavanols (quercetin glycosides). Numerous investigations show that a variety of factors, including cultivar, tissue zones, harvest time, geographic location, and storage conditions, influence the antioxidant capacity (AOC) and polyphenolic profile and content in apples. [19] Among its biological effects, flavonoids, a family of polyphenolic compounds, have anti-inflammatory, anti-hepatotoxic, anti-ulcer, anti-allergic, antiviral, and anticancer qualities. [20] There are also differences in the type and distribution of these phytochemicals between the apple's peel and flesh. Catechins, procyanidins, phloridzin, phloretin glycosides, caffeic acid, and chlorogenic acid are among the compounds found in the flesh. All of these substances are present in the peel, along with extra flavonoids containing quercetin glycosides, which are absent from the flesh. [21] Red apple peel is the most common source of cyanidin 3-galactoside, one of the "anthocyanins" that gives it its red hue. [5] The distribution of phenolic chemical levels varies between the peel and the meat. The peel of red apples often contains significant levels of flavanols and anthocyanins, along with phenolic acids and flavan-3-ols. However, anthocyanins are typically either absent from or present in small amounts in flesh. [22] Prior research has shown that because anthocyanins are not present in the flesh of these apples, the anthocyanin content of the flesh and flesh + peel was not investigated. [22] The main constituents of phenolic compounds' non-flavonoid category are phenolic acids. They are aromatic acids having an organic carboxylic acid (C_6-C_1 skeleton) and a phenolic ring. Phenolic carboxylic acids are another name for them. The most common phenolic acid found in apples is chlorogenic acid. [5] Compared to apple flesh, apple peels contain more polyphenols, and the polyphenolic content varies significantly between crop kinds and apple portions. Phloretin glucosides, quercetin glucosides, and chlorogenic acid are the three most prevalent polyphenols found in apple byproducts. Low concentrations of other polyphenolic substances, including procyanidins and catechins, have been discovered. [18] Prior studies have demonstrated that the Ljestarka variety has significantly more quercetin derivatives than other

varieties—up to two or six times more. The greatest levels of flavonols and phenolic acids were found in Adamova Zvijezda. Because the peel contains a significant amount of the polyphenols, these two types—Ljestarka and Adamova zvijezda—can be distinguished from other varieties. [23] Earlier studied the Total Oxyradical Scavenging Activity (TOSC) assay was used to measure the overall antioxidant activity of the apple peel, flesh, and flesh + peel of the four apple cultivars. This test examined the extent to which apple extracts inhibited an oxidizing reaction. The highest antioxidant activity was found in the peels of all varieties, followed by the flesh+peel combination and the flesh. In North American and European diets, apples are a significant source of phenolic compounds. When consumed, it can help avoid chronic diseases when combined with a diet rich in fruits, vegetables, and grains. The values contrasted with those of the flesh and flesh + peel components. Within each variety, the highest total phenolic concentration was found in the peels, followed by the flesh + peel and the flesh. Compared to the apple kinds under investigation, the peels all exhibited noticeably greater total antioxidant activity than the flesh + peel and flesh. [21] With the potent antioxidant properties of the extracts, apple peels from the Kurdistan area of Iraq (the pottery mountains) seemed to be a plentiful natural supply of bioactive components. [20]

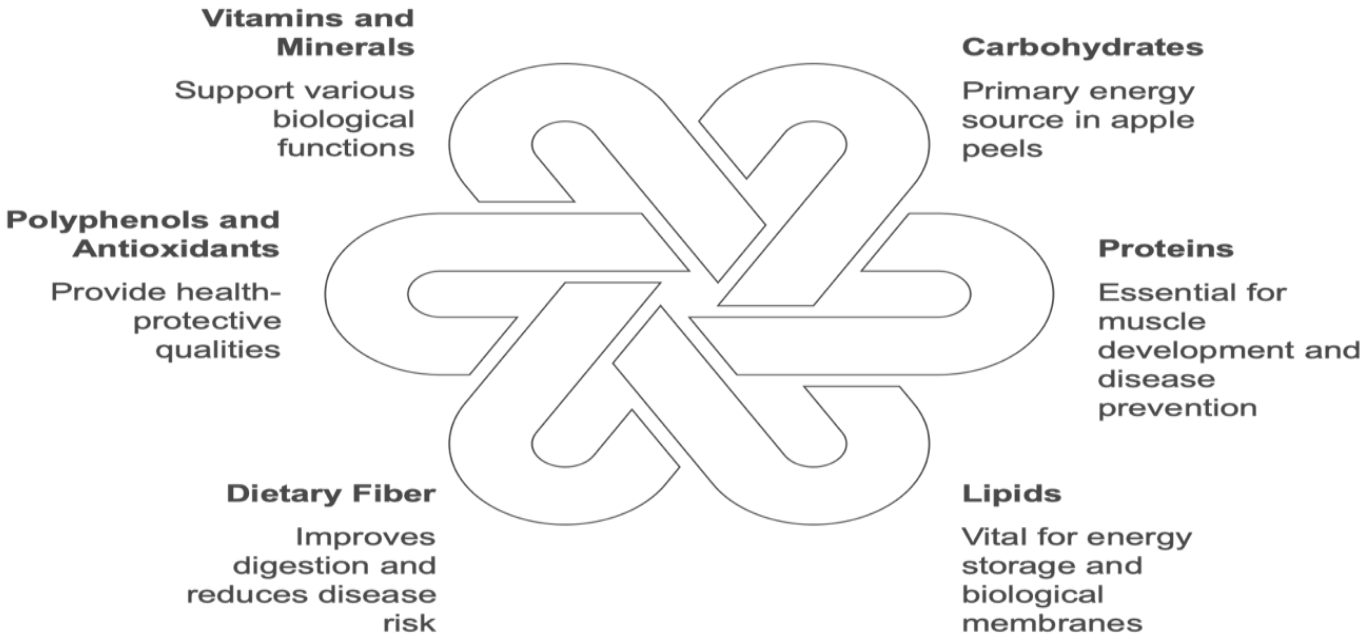

Figure 1: Nutritional Breakdown of Apple Peels

4. Vitamins and Minerals

Apples include a lot of certain micronutrients, such as iron, zinc, vitamin C, and vitamin E. Essential micronutrients that support the body's regular biological and biochemical processes are also provided by the vitamins and minerals found in apples. Vitamins C and E, for instance, provide free radicals with single hydrogen equivalents, which stabilizes them and eventually aids in their detoxification, adding to the fruit's overall antioxidant capacity. The vitamins also restore the oxidized forms of other antioxidants to their reduced, active forms. [24] Carotenoids, vitamin C, and vitamin E, which are mostly included in plant-based diets, may be useful scavengers of oxidants and radicals, among other plant components. [25] One of the most abundant antioxidants in apples is vitamin C, which has a free radical-scavenging activity of

EC50 = 0.35 (EC50 is the concentration needed to provide a 50% antioxidant effect). Conversely, the apple seeds contain the majority of vitamin E. Consequently, apple pomace is a rich vitamin E source , with an EC50 = 0.30 free radical-scavenging activity and a vitamin E content of 5.5 mg/100 g from apple pomace. [5] The pulp, seed, and peel of star apples included the following mineral elements: calcium, magnesium, sodium, potassium, iron, and zinc, showed that the seed had high levels of calcium and magnesium, while the pulp had higher levels of sodium and iron. The peel of the star apple also had higher levels of potassium and zinc. Therefore, the mineral supplement in food and related businesses can be obtained from any of these samples (peel, pulp, and seed). The mineral element makeup of star apple peel is as follows: calcium (8.25 mg/kg), magnesium (6.16 mg/kg), zinc (13.46 mg/kg), sodium (43.86 mg/kg), and potassium (62.26 mg/kg). [11]

5. Health Benefits

Flavonoids are a significant class of phytochemicals that are frequently present in fruits and vegetables. Quercetin and its conjugates are the most prevalent flavonoids in fruits and vegetables. It should come as no surprise that because of their high antioxidant content, apples in particular are associated with a decreased incidence of chronic illnesses. The characteristics of apples and the substances they contain may account for their ability to ward against illness. Apples, particularly apple peels in particular, have strong antioxidant properties and may considerably decrease the development of cancer cells in the liver and colon. [26] However, in recent years, its beneficial health effects have been brought into emphasis. As a natural antioxidant, it offers a number of preventative benefits against a number of illnesses, such as lowering inflammatory processes and blood cholesterol levels. [18] Apple phenolic compounds have been investigated for potential prevention of colon cancer. Studies conducted in vitro on colon cancer cell lines showed that apple phenols may benefit the colon. In a concentration-determined way, apple polyphenols inhibit human colon cancer cells' motility, invasion, colony formation, and adhesion. Additionally, when colorectal cancer cells were cultured with annurca apple polyphenols, they induced apoptosis and decreased cell viability in a way that depended on time and concentration. [27] The ability of apple peel to suppress cell growth was also superior to that of apples without the peel. The assay for cell proliferation measures a compound's or fruit extract's capacity to stop tumor cell growth. Accordingly, a compound's potential for anticancer activity increases with its capacity to suppress cell proliferation. [26] Among the particular fruits linked to a lower risk of lung cancer were apples. Lung cancer risk was lower for women who ate at least one dish of apples and pears each day. A decreased risk of cardiovascular disease is associated with eating apples. Through a 6.9-year follow-up survey of over 40,000 women, the Women's Health Study examined the connection between flavonoids and cardiovascular disease. Women with the highest flavonoid intake had a 35% lower risk of cardiovascular events. Consuming flavonoids was not linked to a higher risk of stroke, myocardial infarction, or cardiovascular disease-related mortality. There was no correlation found between quercetin and myocardial infarction, stroke, cardiovascular events, or cardiovascular illness. [28] Supplementing with apple peels, which are a high source of fibre and antioxidant chemicals, may help prevent MetS (metabolic syndrome) In vitro and animal model studies have demonstrated that supplementing with apple peel improves lipid profiles, glucose levels, and blood pressure regulating mediators. [29] Although vitamin C is an effective antioxidant, the study demonstrates that almost all of apples' antioxidant activity is derived from a number of different substances. Apples contained less than 0.4% vitamin C in their overall antioxidant activity. [28] Numerous investigations demonstrated that in human clinical trials, supplementing with vitamin C did not lower the risk of coronary

heart disease or cancer. [30]According to the previous study, DAPP increased antioxidant status, decreased pain, and improved joint function after 12 weeks of use. It decreased inflammation by blocking the COX-2 and lipoxygenase enzymes. Improvements in joint health were facilitated by DAPP's anti-inflammatory and antioxidant properties. According to these results, DAPP may be used as a natural anti-inflammatory. [31]

Table 1: Health Benefits of Apple Peel and Its Bioactive Compounds in Relation to Specific Diseases and Mechanisms of Action

	HEALTH CONDITION/DISEASE	**MECHANISM OF ACTION**	**REFERENCE**
Apple Peel	Liver Cancer	Inhibits HepG 2 (humab hepatocellular carcinoma cell line) human liver cancer cells from growing and plot of proliferating	[21, 26]
Apple peel supplementation	Prevent Mets (metabolic syndrome)	Enhances blood pressure regulating mediators, glucose levels, and lipid profiles.	[29]
Dried Apple peel powder	Improve joint function	Reduced inflammation by inhibiting the enzymes lipoxygenase and COX-2	[31]
Apple peel Extract	Hyperlipidemia.	Treatment of patients' impaired glucose metabolism by preserving random blood sugar, fasting blood sugar, and HbA1c at a lower level than before consuming apple peel extract	[32]

Apple peel polyphenol	Inflammatory Bowel Disease (IBD)	By decreasing inflammatory cytokines, oxidative stress, and healing pathways, dried apple peel powder (DAPP) reduces inflammation. It also helps to reduce intestinal inflammation by balancing the gut bacteria and enhancing mitochondrial activity.	[33]
Apple peel Extract	Breast Cancer (MDA-MB-231 cells)	Suppresses the IGF-1R/PI3K/Akt pathway and increases PTEN(phosphates and Tensin homolog deleted on chromosome 10)tumour suppressor function to prevent cell division.	[34]
Apple peel (fuji)	Obesity	Ursolic acid may help with weight control since it decreases fat buildup in 3T3-L1 cells.	[35]

6. Utilization of Apple Peel in Bakery and Confectionery Products

Bread, cakes, muffins, biscuits, pies, and other bakery goods are made with large quantities of flour, combined with other ingredients, and then dried in a baking oven. The vast majority of baked goods, however, are poor in fibre and heavy in calories, fat, and carbs. A popular bakery item with a long shelf life among both urban and rural consumers is biscuits. Apple fibre also contains phytochemicals, namely flavonoids and phenolic acids, which are linked to antioxidant properties. By altering the proportion of raw ingredients, whole grains other than wheat, or the proportion of fibre content in simple recipes, biscuits with fibre content have better nutritional value and are more palatable. [36] Because of its excellent nutritional value and abundance in dietary fibre and phytonutrients, apple peel shows great promise as a component for functional food products. When APP was included, a new and effective muffin structure was created. Higher quantities of bioactive substances and dietary fibre were found in the muffins made with APP at different concentrations. The color and texture quality of muffins were improved when they were supplemented with APP. Furthermore, the physical properties of muffins were not substantially impacted by the addition of APP to the batter. In terms of organoleptic properties, the muffins with 12% APP obtained the highest overall acceptance score of any sample. By evaluating their by-products, including peels and pomace, the apple processing companies may be encouraged by the research's findings to make better use of them and reduce waste output.[8]

7. Utilization of Apple Peel in Dairy and Beverage Industries

To boost the antioxidant activity of commercial carrot and tomato juices (final concentration: ninety percent juice, v/v), a phenolic extract from apple peels was added. This extract is mostly made up of flavonol glycosides, dihydrochalcones, and flavan-3-ols (>50%). Ascorbic acid equivalents with ferric reducing antioxidant power and radical scavenging ability against DPPH˙ tests were used to evaluate the antioxidant contribution of the added extract to the hydrophilic and lipophilic components of the juices

using an emulsified lipid in an oven test. According to research, adding apple peel flavonoids to the juices at concentrations of 160 mg gallic acid equivalents (GAE)/L or more as total phenolics led to a significantly higher ($p < 0.05$) ability to scavenge radicals and a greater defense against lipid peroxidation when compared to the control. The model emulsified lipid with increased juices (20 mg/L as GAE) showed an oxidative index that was comparable to a mixture of synthetic antioxidants (25 μM). Its antioxidant activity was mainly due to the hydrophilic components of the improved juices, particularly its medium-to-high polarity flavonoids, such as catechins, dimers of (+)-catechin and (−)-epicatechin, and quercetin glycosides. [37]

Yogurt enriched with APPE and fermented with Lactobacillus lactis and Lactobacillus acidophilus was shown to be a satisfactory probiotic milk product. One served as a control, while the remaining five components were combined to create probiotic yogurt using varying amountss of APPE (apple peel powder extract) (1%, 2%, 3%, 4%, and 5%; AE1, AE2, AE3, AE4, and AE5). Yogurt starter cultures (L. bulgaricus and S. thermophilus) and probiotic strains (L. acidophilus and Bifidobacterium lactis) were used to incubate the samples. APPE-fortified yogurt samples showed the least amount of probiotic bacterial viability loss at 5%. When APPE was added to yogurt as a prebiotic, it was found to improve probiotic viability when compared to a control yogurt that did not include APPE. Yogurt's hardness and viscosity increased when APPE was added, while syneresis decreased. [38]

8. Utilization of Apple Peel in Meat Products

Prior studies have looked at how whole dried apple peel powder (DAPP) levels of carcinogen when grilling and the effects on microbiological development during cold storage of ground beef. All meals, including cut meat, seafood, vegetables, and baked products, can benefit from the surface application of a marinade or baste using dried apple peel powder (DAPP) before grilling. When DAPP was added to ground beef, pig, and turkey samples before they were placed in cold storage, the growth of various microbiological forms in all three food products was significantly decreased. DAPP might decrease heterocyclic amine levels when taken with meals. DAPP may offer a natural means of improving food quality, as it can reduce norharman production when it is kneaded into meat before storage and used in a marinade before grilling. [39]

Earlier research also proved to examine the antioxidant activity of bioactive components found in aloe vera gel extracts and apple peel, as well as their effect on the oxidative stability and colour of a turkey meat sample stored at 4±1 °C. Six solvent extracts were made in total, and the finest extracts from apple peels and aloe vera gel were applied on a 0.5% level to improve the quality of turkey meat. The results showed that the highest 2,2'-Azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) radical cation, DPPH, and superoxide anionic scavenging activities were shown by methanol extract of apple peel and ethanol extract of aloe vera gel. The methyl extract of the AP sample had the lowest total phenolic levels; however, the aloe vera gel's ethanol extract had the highest. According to the colour values from the Lovibond tintometer, the addition of MeAP and EhAG to the turkey meat sample significantly affected the redness (α-value) and yellowness (β-value) values during storage. Aloe vera gel ethanol extract and AP methyl extract demonstrated higher antioxidant capacity, making them useful components for enhancing the quality of raw turkey meat with additional health advantages. [40]

9. Utilization of Apple Peel Powder for Enhanced Packaging Stability

The resilience of drum-dried apple peel powder, which may be used to choose between high-density polyethylene and high-barrier metalized films as packaging materials. Both regular (25, 10, and 4 °C, 60–70% RH) and accelerated (38 °C, 90% RH) storage conditions were applied to the samples for a total of 120 days. The samples of apple peel powder that were placed in MFHB pouches showed minimal moisture rise and retained the majority of the phenolic components. The samples packed in MFHB also had a longer shelf life: 298 ± 18.41 days as opposed to 120 ± 4.59 days under normal and accelerated circumstances, respectively. [41]

10. Utilization of Apple Peel Powder in Edible Film Development

Presently, the market's favored packaging materials—renewable, recyclable, and biodegradable—are causing growing worry. The edible film is a novel and popular notion since it is food-grade and made by adding biomolecules to fruits and vegetables to give them a nutritious value that is good for human consumption. Edible film is prepared using the apple peel powder. As a plasticizer, glycerol was added to the film to make it more flexible. Calcium chloride is used as a cross-linking agent to make films stronger. The films' moisture content was much higher ($p < 0.05$). climbed from 12.85% to 18.04%. As the concentration of apple powder rose, the solubility of the films increased considerably ($p \leq 0.05$), and the amount of peel powder increased. As a result, films made from apple peels exhibit lower solubility at greater concentrations; this might be because essential oils are present, which restrict the interaction of hydroxyl groups and reduce solubility. Low-solubility films may be used for meals with a high moisture content, whereas high-solubility films can be used for foods with a low to intermediate moisture content. Because they melt quickly when food items boil, they can also be utilized as edible pouches or ready-to-eat foods. [42]

11. Conclusion

Apple peel, which is sometimes seen as a by-product of the apple processing industry, is a potent source of vital nutrients and bioactive substances. It has a lot of phenolic compounds, flavonoids, antioxidants, and dietary fibre (both soluble and insoluble), all of which are good for your health. These substances are important for decreasing cholesterol, reducing oxidative stress, promoting gut health, and avoiding chronic illnesses, including heart disease and some types of cancer. Apple peel powder's high dietary fibre and polyphenol content make it a useful addition to functional food compositions, including baked products, drinks, and nutraceuticals, improving their nutritional profile. Valuing apple peel also increases the economic worth of the apple processing sector and decreases environmental waste. So using apple peel as a functional component promotes health and well-being and is in line with sustainable food practices.

12. Authors' Biography

Sejal Chauhan is a final-year M.Sc. student in Food Science and Technology at Babasaheb Bhimrao Ambedkar University (A Central University), Lucknow.My areas of interest include functional foods, product development, and the use of natural ingredients to enhance nutritional value. She is particularly focused on the utilization of food industry by-products for sustainable innovation. I aims to contribute to the development of healthier and eco-friendly food solutions.

Dr. Priyanka Shankar is an assistant professor at Babasaheb Bhimrao Ambedkar University (A Central University) in Lucknow. Her knowledge of food and nutrition has given her a solid basis for her academic and scientific endeavors. Through academic papers, conference participation, and cooperative initiatives, she has made a significant contribution to the discipline. Her work focuses on advancing scientific understanding in her field, fostering innovation, and assisting academic development.

Dr. Anu Ram Kailash Mishra is a well-regarded academic and resource person at Babasaheb Bhimrao Ambedkar University (A Central University), Lucknow. Her area of expertise is food and nutrition, and she is interested in food safety, functional foods, and human nutrition. Through scholarly conferences, research articles, and cooperative initiatives, she has made a substantial contribution to the subject. Dr. Mishra is dedicated to promoting evidence-based health and sustainable food systems practices and furthering the field of nutrition research.

Shailesh Kumar is a committed Ph.D. student at Babasaheb Bhimrao Ambedkar University (A Central University), in Lucknow,. His area of academic interest is food and nutrition, where he seeks to investigate novel strategies for tackling important scientific issues. He has actively participated in scholarly endeavors over the years, including research papers, seminars, and joint ventures with other scholars. His enthusiasm for scientific research and dedication to advancing our understanding of his profession are what motivate his work.

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