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Apple Pomace: Transforming Waste into Wealth across Various Food Industries

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ABSTRACT

The processing of fruits and vegetables often results in discarded residues, contributing to food waste. This review highlights the potential of utilizing these byproducts, particularly apple pomace, which constitutes 30% of the raw fruit after juice extraction. Apple pomace includes seeds (2-4%), peel (up to 95%), and stem (1%). Immediate drying of fresh residues is essential to prevent microbial attacks, given their high moisture content of 75-80%.Apple pomace is rich in dietary fiber (35-60%), comprising cellulose (7-40%), pectins (5-10%), lignins (15-25%), and hemicellulose (4-25%). Extractives such as resins, tannins, pigments, and reducing sugars are also present. Addressing global food waste concerns, FAO data reveals that one-third of food produced for human consumption is wasted, with the fruits and vegetables industry being a major contributor. The food industry generates 1.3 billion tons of waste globally, with fruits and vegetables accounting for 0.5 billion tons. To mitigate this issue, incorporating apple pomace into bakery items, yoghurt, and meat products has proven successful, offering a rich source of dietary fiber. Recent innovations involve using defatted apple seeds in chewing gums for phloridzin suspension, indicating a potential avenue for phloridzin uptake. Studies also suggest the use of oat bran and apple pomace as stabilizers in oil-water emulsions. Overcoming food waste challenges is not only essential for food processors but also crucial for environmental sustainability.

Keywords: Food Waste, Apple Pomace, Dietary Fiber, Environmentally Sustainability

INTRODUCTION

Apple is among the most popular fruit in world and consumed in large quantity (Table 1). Its scientific name is *Malusdomestica*. Regardless of having differences in nutrients contents, apple pomace is abundant source of them. It is a rich source of phytochemicals and comprises considerable quantities of carbohydrates along with few concentrations of vitamins, minerals and proteins [1] (Table 2). The carbohydrates in apple pomace are majorly insoluble sugars which includes lignin (15 to 23.5 gram per kg of dry weight, hemicellulose (7 .2 to 43 gram per gram of dry weight)

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and cellulose (127.9 gram per kg of dry weight), while simple sugars includes fructose (23.6%), galactose (6 -15%) and glucose (22.7%). Furthermore few minerals were also present in pomace of apple for example phosphorus (0.07-0.076%), Magnesium (0.02-0. 36%), iron (31.8-38.3 mg per kilo gram of dry weight) and Calcium (0.06-0.1%).

Apple pomace is also known for having higher quantities of polyphenols (31-51%) particularly flavonals, cinnamate ester and dihydrochalcones [2]. More over apple pomace has wider varieties of antioxidants which include phloridzin, quercetin glycosides and some other phenolic components which possess strong antioxidant behavior [3]. Nutritional importance of apple pomace is very high and very beneficial to human health. Various studies stated that apple pomace helps in the reduction of hypertension and constipation and also have ability to scavenge the unwanted elements in human body like free radicals [1]. Apple is among the most popular fruit in world and consumed in large quantity. In 2017 the worldwide production of apple was 83.1 million tons (Mt) [4].

The byproducts obtained from the FVWs comprises high active compounds such as phenolic compounds, pigments, minerals, dietary fibers, organic acids and many more. These biological compounds have some health beneficial characteristics such as antitumor, anti-mutagenic, and antibacterial and cardio-protective attributes [5]. Different fruits and vegetables like apple, orange, peas, peaches, potatoes, onions carrots etc. are used for the pulp and the juice extraction, jellies, jams and they produces a major amount of waste [6].

According to Oroski & da Silva [7] the reductions in waste results in less use of water, lessen the liability, increases the profit, less waste and create noble relation with public. Waste from the fruits and vegetables contain substantial bioactive compounds which can be extracted and isolated and use in different industries such as cosmetic, textile food, and in pharmaceutical industries. However there are some sort of waste that cannot be avoided and their proper utilization is mandatory to avoid the environmental pollution, and also these waste can use to make food for the betterment of human health with substance that enhance the health such as carotenoids, phenols, vitamins, and dietary fibers.

Table 1: Chemical Composition of Apple Pomace

Composition (%)[1]	[8]	[9]	[10]	[11]
Carbohydrates	83.3	NR[2]	NR[2]	45.1
Moisture	5.8	7.1	10.5	4.4
Ash	1.5	1.7	2.5	1.8
Lipids	4.2	2.7	0.6	3.8
Total dietary fibers	NR[2]	42.5	14.5	26.5

1 Dry weight basis.2 Not reported

Table 2. Main apple producer countries and their annual production

Countries	Production (Million tons)
China	41.4
USA	5.2
Turkey	5.0
Poland	4.8
India	4.2
Iran	3.7
Italy	2.8

Adapted from Antal et al. [12]

APPLE POMACE AS FUNCTIONAL INGREDIENT IN FOOD INDUSTRY

Enriched with phenolic compounds, dietary fiber and many other compounds the apple pomace is considered to be a good enrichment source to be incorporated in many food items. Although the incorporation of the pomace in food products reduces the quality characteristics of the food items so it is added in comparatively low amount and it should be measured carefully [13].

Addition of apple pomace in bakery products:

Many baked goods such as cakes, cookies and bread have been eaten by humans for many years and they are broadly accepted. The use of apple pomace in bakery items is mainly for the enhancement of dietary fiber [14]. Although the incorporation of apple pomace powder reduces the sensory and the quality parameter of the baked goods [11]. For that reason the effect of addition of apple pomace on every bakery product have been optimized and evaluated.

Bread

From the last few decades the apple pomace has been used as the functional ingredient in bread as source of enhancement for the dietary fibers [15]. Chauhan and Masoodi, [16] observed the effect of apple pomace at different concentration of (%) 11, 8, 5 and 2 for making wheat bread. The outcome revealed that the as the level of apple pomace increases up to 11% the weight of the loaf increases up to 3.1% in neutralized dough and up to 7% in un-neutralized dough. The volume of loaf was noted to be decreased in both the un and neutralized dough up to 42.8% and 26.6% respectively. With the increase in the concentration of apple pomace the hardness and the color of crust increases. Further-more the organoleptic properties was decreased overall; only the bread prepared with 5% level of pomace was deliberately accepted in terms of taste, color and odor.

Ktenioudaki et al. [9] finds the same results with special focus on the rheological characteristics of dough. The result showed that the fortification of apple pomace in wheat flour reduces the uniaxial extensibility with the increase in the dough's biaxial extensibility viscosity. It decreases the volume of bread and makes the bread structure dense. Jannati et al. [10] investigated the result of addition of apple pomace on bread hardness. They assessed the parameters of Iranian bread which is called Sangak bread; which had apple pomace powder in different concentrations from (%) 1 to 7 w/w of the flour. The consequences described that the addition of apple pomace powder lessens the bread texture hardness and hinder the progression of staling. They conclude that the only the 3% of the concentration pomace powder had satisfactory results. While the sensory results displayed that the pomace concentration could be less than 3% for better texture, consumer acceptability and smell of bread. Consequently the addition of dried apple pomace as the functional component in the preparation of bread is feasible.

Sudha et al. [15] examined the buns comprising dough conditioners and 15% of dehydrated apple powder pomace. The volume of the final product increased up to 30% in comparison to the dough containing no dough conditioners. The dough conditioners includes (%) 0.25 sodium stearoyllactylate, 2 gluten, 0.25 mono-stearate, and 1 mili gram of α-amylase. Other than the volume the sensory features and firmness of buns containing both the conditioners and pomace were also upgraded.

Sweet Bakery Items (Cakes Together with Muffins and Scone)

Presently, various amount of research had been conducted in cakes and sweet baked items containing apple pomace powder for the better nutritional features and flavor [17]. Masoodi et al. [16] examined the characteristics of cake made with the apple pomace with various concentrations (%) of 15, 10, and 5. The results of this addition showed that the volume of the cake decreases drastically with the increases in the level of pomace concentration whereas the size of the particles increases. Furthermore the 15 and 10% concentrations showed no considerable differences in uniformity and shrinkage while the 5% concentration showed the notable increase in the uniformity index and shrinkage of the final product.

Sudha et al. [18] developed the cake with 30% of apple pomace powder. The result of this study showed that the 30% of cake containing apple pomace had decrease in volume by 37% in comparison to control product. The density of the product increases with the increase in concentration of apple pomace powder. From 10 to 30% addition of pomace the density increases from 0.49 to 0.67 g/cc which signify the harder texture of the cake. Although the result of sensory evaluation was satisfactory for cake with 10 and 20% level but for 30% the acceptability was negligible and got the lowest score. Due to the pleasing odor, Sudha et al. [18] stated the apple pomace as the capable flavoring element in cakes preparation which requires more testing for implementation at large scale. Furthermore the use of apple pomace as the

replacer of wheat flour in muffins has been examined. A latest research by Sudha et al. [15] described that the muffins containing 20% less pomace powder of apple were generally had normal regular shape and have acceptable taste, texture and color. On the other hand as the concentration of pomace powder of apple increase from 20% the color and the crust of the product changes from yellow to brown; a considerable change in color of the product was observed. The findings of this research were similar to Jung et al. [19] investigation.

Thomas and Wang [20] Conducted the preference test of the muffins with the addition of 50% pomace. The preference for the fortified muffins was 79.2% and for 20.8% for control product. Apart from better flavor the use of apple pomace powder was approved for increase in phenolic contents and dietary fibers along with the antioxidant activity. Thomas and Wang [20] were examine that the dried and powdered apple pomace was passed through 30, 50 and 60 mesh sieves to get pomace of different particle size. Blends were prepared by mixing (%) 5, 10 and 15pomace from each of the three particle sizes with wheat flour. The blends were estimated for cake. Batter viscosity increased with increasing pomace level and decreasing particle size. pH and specific gravity of the batter decreased with increasing pomace levels. Shrinkage, cake weight and uniformity index increases with the increasing pomace concentration, whereas, and symmetry index and cake volume presented a reverse trend.

Reise et al. [21] determined the use of apple pomace powder in scones. They stated that the 20% of addition of pomace of apple had considerably increased the pro-anthocyanidins, flavonoid and phenolic contents up to 3.1, 4 and 3.3 times respectively. Hence the powder form of apple pomace can be a potential functional element and can be used for the betterment of health of such bakery items.

Brittle Bakery goods (Crackers and Cookies)

Just like cake dough's, the dough of the cookies are high in lipids and sugars that might give the bitter taste to the final product because of the use of apple pomace [13]. Laukova et al. [22] examine the cookies prepared with partially substituting the wheat flour with apple pomace. The study was concluded as the level of replacement from 0 to 15% increases, the physical characteristics like diameter, porosity and volume sharply reduced 11, 25 and 23% respectively. On the other hand the grain taste lessens but the cookies fruity flavor increases after the replacement. The sensory analysis for the cookies was reduces but consumer's acceptance score was greater than the 90%.

Kohajdova et al. [23] stated that the incorporation of 5% of apple pomace powder does not affect the sensory qualities of the cookies.

Jung et al. [19] Made cookies of apple pomace flour by replacement level of 15 and 20%. The results stated that the cookies were redder and darker in color. The result of this study was synchronized with other baked goods as well. Moreover, these studies revealed the decrease in the firmness which became more prominent as the substitution level of apple pomace increases. Sudha et al. [15] noted the reverse behavior in firmness of fortified cookies made with the dehydrated powder of apple pomace. Furthermore the combination of two additives such as sodium stearoyllactylate and glycerol monostearate up to 0.25% for both; was added to stabilize the quality changes in cookies that are because of the addition of apple pomace.

Alongi et al., [24] Investigated that the glycemic index lowers with the incorporation of apple pomace. Glycemic index lowers to 60% from 70% as the substitution level increases up to 20% from 0%. The outcome of this research stated that the; this enriched apple pomace product could be graded as the food which has moderate glycemic index. Mir et al. [25] Made a cracker which is free of gluten with brown rice flour and apple pomace powder at 9, 6 and 3%. The result showed that the mineral contents (K and Cl) increases with the addition of apple pomace powder along with the antioxidant contents such as phenolic and dietary fibers.Hence the powder form of apple can be a potential functional element and can be used for the betterment of health of the bakery items.

Extruded food items

Supplementation of powder pomace of apple in extruded snack goods had been used by many scientists for the enhancement of the nutritive value without disturbing the physical characteristics of the product and causing no significant effect on the sensory parameters [26].The current focus of the research is on the processing conditions, seeing that other than the apple pomace, various other factors can disturb the quality of extruded snacks [27]. Muthukumarappan and Singha [28] Prepared the extruded snack by single screw extrusion which contains defatted soy flour, corn grits and apple pomace. The results showed that the; with the rise in pomace level of apple from 0 to 20%, the antioxidant concentration, phenolic content and the bulk density increases significantly. The extruded snack containing 5% of the apple pomace shows the increase in the expansion ratio while 10 and 20% addition level of the snack

followed the opposite behavior. The ideal conditions for the extrusion was die and barrel temperature 140ºC, screw speed 200 rpm feed moisture value 20%.

O' Shea et al. [29] Incorporated the apple pomace in extruded foods containing corn flour. The optimum requirements for making this product was die head temperature 150ºC, pomace quantity 7.7% and screw speed 69 rpm. The conclusion of the research was that the radical ratio of expansion reduces with the addition of apple pomace which automatically had the negative impact on the snack texture. Although the Masli et al. [30] described the opposite results, who prepared the extrudates containing corn starch with 30 and 15% level of apple pomace. Initial expansion index was higher and stable with the addition level of 15% although the less energy cost occurs. As level of incorporation increases the shrinkage level also increases markedly. As various snacks are free of gluten so the sensory analysis evaluation is of great importance.

Ackar et al. [31] have done the test for the organoleptic properties for corn based extruded snacks incorporated apple pomace. This enrichment with apple pomace into the snacks decreases the sensory characteristics such as flavor, appearance and chewiness. These variations in the sensory properties of the snacks were more noticeable as the level of pomace increases from 5 to 15%. Similar results were seen in the quality parameters of the snacks but in an acceptable range. Reis et al. [21] developed the extruded items with wheat, rice and semolina flour along with the apple pomace of different concentration of 30, 20 and 10%. Their main focus was on the nutritional value. The outcome of their work told that the stability index of nitrogen was reduced to 23% with the increase in pomace level to 30% which signifies the lower protein denaturation. The flavonol and phenolic components was increased to 4 and 2.8 times respectively.

Muthukumarappan and Lohani [32] prepared the CO2 extruded food with sorghum and apple pomace flour which showed the rise in the crispness and decreases in the hardness.The use of CO2 in extruded foods signifies the positive sides of the research in this field.

Meat products

The current focus is on the use of apple pomace; to minimize the deficiency of dietary fiber in meat products. Various works has been done on the meat products such as chicken and mutton nuggets, mutton meat balls and in chicken sausages [33].

Ahmad and Younis [34] developed the patties made with the buffalo meat. They replaced the meat quantity with apple pomace up to 2 to 8%. By replacing the result stated that the moisture, crude fiber and ash contents were have a considerable positive effect. Thickness and cooking yield of the meat patties along with texture characteristics such as toughness and firmness had positive effect. As the replacement amount increased from the 6%; the springiness and cohesiveness of the meat patties decreases sharply. Ahmad and Younis [35] made the buffalo sausages with same amount of apple pomace by replacing. They got the similar results as mentioned above.

Jung et al. [19] prepared the chicken patties with chicken meat with the fortification level of apple pomace of 10 and 20% as the meat substitute. The result described the decrease in the hardness of the final product in comparison to the control product. Verma et al. [36] also stated the same results that the sharp fall in the hardness of the product. The test was conducted on the less fat containing chicken nuggets comprising 8 to 12% of apple pomace. All these experimented meat items displayed the redder and darker color in the final product but with the better amount of dietary fiber. Less research has been done on pork meat with the use of apple pomace.

Confectionery products

Apple pomace is rich source of pectin and contains flavoring compounds so the use of it in the confectionery industry is beneficial for food market as it is appropriate ingredient [1]. Royer et al. [37] developed the jelly containing the quince fruit and apple pomace puree. Hussein et al. [38] prepared the jam from the apple pomace and from the other fruits by products such as banana peel carrot peel and mandarin peel. This blend of every by product along with sugar were continuously stirred until the pH reached to 3.2 by critic acid till the brix reached to 67ºC. The results showed that the phenolic and flavonoid content, along with the phosphorus were increased in apple pomace with 82.5 mg/100 g, 30.1 mg/100 and 220 mg/100 g respectively. In sensory evaluation of jams, the apple jam attains the maximum appreciation and over all acceptability among all the other jams.

Dairy products

Wang et al. [39] examined the study of set type of yoghurt containing apple pomace which was used as a texturizer and natural stabilizer. Different quantities of apple pomace 0.1, 0.5 and 1% were mixed with skim milk and then ferment with the starter culture such lactobacillus Bulgaricus and

streptococcus thermophilus and incubate at 42ºC. The result of this research stated that the incorporation of 1% of apple pomace showed the increase in pH and gelation time shorter. Furthermore the enriched yoghurt showed the better cohesiveness and better consistency in storage conditions of 28 days.

Wang et al. [40] evaluate the stir type of yoghurt containing free-zed apple pomace powder. This study stated that the by incorporation of 1% of apple pomace powder fermentation time of yoghurt preparation reduces, and gelation pH increased; ultimately developed more consistent, firmer and viscoelastic yoghurt gel. This research also stated that the by addition of apple pomace in to 3% and even more high concentration; drastically reduces the syneresis and provide the better cohesiveness, firmness and viscosity of the final product until the storage period of 28 days.

It is stated that the apple pomace powder as s potential ingredient can be used as texturizer and stabilizer and it can be good way for the polyphenols and dietary fiber in dairy industry [39]. More research and work should be done on dairy products containing apple pomace powder.

Utilization of apple pomace in beverage industry and as a substrate of food

Apple pomace for the production of alcoholic beverages

For many years the apple pomace has been used for the production of ethanol by the process of fermentation because of its low cost and less requirement of land [41]. For the production of ethanol the most common method is solid state fermentation solely on apple pomace [42]; an on the combination of molasses and pomace substrate [43]. In latest studies concurrently the fermentation (solid state) and saccharification methods are also mentioned [44]. Apple pomace is used for the development of alcoholic beverages which might impart flavor to the drink [45].

Madrera et al.[46] developed spirits from yeast strains such as *Hanseniasporauvarum* and *Saccharomyces cerevisiae* and dried apple pomace along with dry wine yeast which containing enzyme beta gluosidase. The optimum condition for carrying fermentation was 16ºC for time period of 4 weeks. In the first phase the spirits were two times distilled with 20 to 22% of alcohol strength. In the second phase it was distilled with 60% of alcohol strength. All the spirit had higher contents of alcohol. For the H.uvarum the alcohol contents was261 g per hL AA. For *S. cerevisiae* the alcohol content was 509 g per hL. Nevertheless due to its excess methanol quantity the treatment for the enzymes was not recommended. Another important conclusion was; the spirits comprising different species of yeast had considerable differences in composition of aromatic compounds, which had commercial importance.

Li et al. [47] developed the apple pomace containing homogenate cider with species such as *S. cerevisiae* and *Koji*. They prepared it separately and with the mixture of both. After the 6 days of fermentation the end products obtained by giving the ageing period of 7 days. The better fermentation abilities were found in solo culture of *S. cerevisiae* with 7.50% ethanol production. Cider containing the *koji* species had the highest quantities of reducing and total sugars along with ester compounds. The value increases up to 22.93gram per 100, 24.12 gram per 100 and 37.35% correspondingly. Moreover in solo culture of *koji* the volatile components like alpha farnesene and 2-methyl 1-butanol were rich in it because they were produced by apple pomace. For the cider production and for its products these results stated the apple pomace might be a significant element and can b use a fruity flavor.

Use as a substrate for production of mushrooms

For the production of mushrooms the apple pomace is recognized as a worthyaidingagent.It is due to the presence of polymers of carbohydrates for example lignin along with minerals which includes nitrogen. Both of them are important nutrients for the growth of mushrooms. Yang and Worrall [48] cultivated the oyster mushrooms (*Pleurotus. Sajorcaju* and *Pleurotusostreatus*) and shiitake (*Lentinulaedodes*) on sawdust and apple pomace both in combination and separately. More production of mushrooms was noticed in pomace instead of sawdust. Two species of pleurotus and five shiitakes isolates was produced on combined substrate comprising pomace 50 %. They had more weight in comparison to the substrate alone.

Park et al. [49] cultivated the *pleurotusostreatus* on saw dust comprising the different concentration of apple pomace such as 2.5, 5 and 10%. The conclusion of this study was that the by the addition of 2.5% apple pomace, the growth rate of mycelial increases in liquid culture, solid fermentation and in solid culture by 20, 26 and 34.5% respectively. Although the addition of apple pomace; greater than the 5% had negative impact on the growth rate of mycelia. Park et al. [50] stated the optimum requirements for P.ostreatus to produce laccase by addition of 2.5% apple pomace and cultivation time is for 9 days.

Currently the mushrooms cultivation is on the experimental

phase by the use of apple pomace as the substrate. This needs more commercialization and more focus in future to enlarge its use.

CHALLENGES IN UTILIZATION APPLE POMACEAND FUTURE PROSPECTS

The issue of apple pomace in the food and beverage industry indeed presents significant challenges, ranging from environmental concerns to waste management issues. However, as you've pointed out, innovative solutions and a commitment to sustainable practices can turn this problem into an opportunity [51].

The adoption of advanced processing technologies, such as those offered by ADAR Technologies, is a crucial step in this transformation. These technologies enable efficient extraction and utilization of valuable components from apple pomace, thereby reducing waste and maximizing resource utilization [52].

Furthermore, embracing a circular economy approach is essential in tackling the apple pomace challenge effectively. By designing processes and systems that prioritize reuse, recycling, and regeneration of resources, we can minimize environmental impacts and create a more sustainable value chain [53].

Collaboration among stakeholders in the food and beverage industry is key to addressing the apple pomace issue comprehensively. By working together, companies can share knowledge, leverage resources, and drive innovation towards sustainable solutions [54].

Overall, by managing and utilizing apple pomace efficiently, we not only mitigate environmental impacts but also unlock new opportunities for value creation. This concerted effort will not only benefit the apple industry but also contribute to a more sustainable future for the broader food and beverage sector [55].

To effectively manage apple pomace, a combination of these approaches, along with proper waste management infrastructure and regulatory oversight, is essential. Collaboration between stakeholders, including apple producers, processors, waste management companies, and policymakers, is crucial to develop sustainable solutions and mitigate the environmental impact of apple pomace disposal [32].

CONCLUSION

In conclusion, apple pomace, a byproduct of the fruit and vegetable processing industry, holds significant nutritional value and bioactive compounds. Rich in polyphenols, antioxidants, and dietary fibers, apple pomace has been explored for its potential applications in various food and beverage products. Despite its nutritional benefits, incorporating apple pomace into food formulations, especially in bakery and dairy products, presents challenges such as changes in texture, taste, and sensory properties.

The utilization of apple pomace in the production of alcoholic beverages, mushrooms, and as a substrate for various food items showcases its versatility. However, challenges in waste management and environmental concerns associated with apple pomace need to be addressed through innovative solutions and a commitment to sustainable practices. Advanced processing technologies and a circular economy approach can contribute to more efficient resource utilization and reduced environmental impact.

Collaboration among stakeholders in the food and beverage industry is essential for developing comprehensive and sustainable solutions. By managing and utilizing apple pomace effectively, not only can environmental impacts be mitigated, but new opportunities for value creation can also be unlocked. The future prospects for apple pomace lie in continued research, technological advancements, and a collective effort to turn this byproduct into a valuable resource for the industry.

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