The Pharma Innovation Journal 2023; SP-12(10): 11-13

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; SP-12(10): 11-13

www.thepharmajournal.com
Received: 14-07-2023
Accepted: 24-08-2023

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Antidiabetic potential of apple pomace

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Abstract
Waste management in the field of food sector is of utmost importance, since the amount is growing at an alarming rate. United States Food and Agriculture Organisation (UNFAO) reports that about 1.3 billion tonnes of food is wasted every year. Fruit and vegetable waste has immense potential in terms of valuable compounds in the form of dietary fiber, polyphenols and other phytochemicals. One such commodity is apple pomace, which is rich in health promoting constituents such as pectin, phlorizin, quercetin, chlorogenic acid etc. These constituents contribute towards treating diabetes and its associated complications such as diabetic peripheral neuropathy (DPN), extended injury restoration (EIR), depression and high blood pressure. Several fortified products have been developed using apple pomace which have the ability to treat diabetes. Some of them are fortified breads, cookies, yoghurt and noodles. All of these developed products can treat diabetes mainly because of their good phlorizin and dietary fiber content, along with rich overall antioxidant profile.

Keywords: Antidiabetic potential, apple pomace, phlorizin

Introduction
Biotic pressures thrusted upon nature due to growing amounts of agricultural wastes is gigantic (Othman *et al*., 2020) [1]. In present circumstances, sustainable usage of agricultural wastes in order to produce nutraceuticals is the need of the hour, both from environmental as well as economic point of view (Bhat *et al*., 2019) [2] in order to achieve "sustainable development goals". Also, as per United Nations Food and Agriculture Organisation (UNFAO), almost one-third of the food is either lost or wasted on an annual basis and this waste mainly comprises of fruit and vegetable waste (https://www.fao.org/3/i4068e/i4068e.pdf).
Apples are one such commodity which produces immense quantity of waste, primarily in the form of "apple pomace" (Puric *et al*., 2020) [4] and the depressing fact is that this is suppose to increase in the coming years (Spengler *et al*., 2019) [5]. Apple pomace is primarily derived from juice and cider industry and comprises of almost 20% - 30% of the whole fruit (Canteri *et al*., 2012) [6]. The major portion of apple pomace consists of dietary fiber (65%) and the next primary components present are proteins (49%) and lipids (24%) (Rupasinghe *et al*., 2008) [7]. The seeds and peels of apple pomace are affluent in phenolic compounds such as phlorizin and chlorogenic acid (Rabetafika *et al*., 2014) [8].
Phlorizin has various health promoting benefits, especially in diabetes, due to its capability to change the levels of glucose absorbed and discharged by the body (Taborskey *et al*., 2021) [9]. Moreover, sodium/glucose cotransporters in the intestinal system and kidney are such regulated that by phlorizin that it contributes well towards treating diabetes (Najafian *et al*., 2012) [10]. Furthermore, research shows that when streptozotocin-induced diabetic rats were fed with diet comprising of 0.5% phlorizin, it notably enhances the aggravated alterations in blood glucose levels (Kamdi *et al*., 2021) [11]. Chlorogenic acid is present in the peel and pulp of apples as compared to their seeds. It is a potential antioxidant which has the ability to combat pathogens arising due to free radical reactions, thus contributing towards treating diabetes (Fang *et al*., 2002) [12].

Detailed analysis of the constituents of apple pomace
Apple pomace encompasses apple pulp, kernels and peduncle. Elevated water activity levels, browning reactions and existence of kernels are three primary obstacles in clarification and usage of apple pomace (Bhushan *et al*., 2013) [13]. The dehydrated apple pomace consists of overwhelming quantities of carbohydrates, proteins, fats, pectin and total phenols. Also, small amounts of minerals such as phosphorus, potassium, calcium, manganese, magnesium and iron are also present.

The main carbohydrates present are galacturonic acid (approx. 64%), arabinose (approx. 23%), galactose (approx. 15%) while the minute ones are rhamnose, glucose and xylose. 60% - 65% dietary fiber in apple pomace consists of pectin (around 11.7%), cellulose (around 43.6%), hemicellulose (around 24.4%), lignin (around 23.5%) and gum. Apple pomace is a very superior derivative of various antioxidants and the predominant polyphenols present are flavanols, cinnamic acids and dihydrochalcones. Overall, the aggregated production of polyphenols from apple pomace extends from 200-300 mg/100 g (Garcia *et al*., 2009) [14].

Pectin as anti-diabetic agent

Research reports that pectin extracted from different plant derivatives possess anti-diabetic properties (Kumar *et al*., 2021) [15]. Diabetes mellitus (DM) is an anabolism-catabolism related dysfunction wherein carbohydrate, protein and lipid absorption is disarrayed, thus disrupting balanced calorie usage by the cells. Study conducted by Liu *et al*. (2016) [16] shows that citrus pectin can be used very effectively in the treatment of type 2 diabetes (Liu *et al*., 2016) [16]. Research outcomes demonstrated that fasting blood glucose magnitudes were remarkably reduced 28 days time period of citrus pectin dispensation. Citrus pectin significantly ameliorated blood sugar tolerance levels, liver glycogen amount and blood lipid proportions in diabetes induced rats. Moreover, it notably lessened insulin resistance thus contributing directly towards treating diabetes. The entire framework of anti-diabetic effect operated on the basis of P13K/Akt signalling mechanism, as pectin administration was followed by stimulation of phosphorylated Akt pronounciation while GSK3ß assertion decreased. Another study based on passion fruit (*Passiflora glandulosa* Cav.) extracted pectin showed that the polysaccharide can be very useful in lowering blood glucose levels in alloxan-administered mice (Sousa *et al*., 2014) [19]. The isolated pectin exhibited the capability to treat diabetes when administered in quantities of 200, 400 and 600 mg/kg for a time period of half month. Amidst this, the most effective concentration that was reported of dose administration was that of 200 mg/kg due to its blood sugar lowering potential, wherein no side effects such as kidney or liver lethalities were reported. On similar lines, pectin was extracted from a different variety of passion fruit i.e. *Passiflora edulis* and doses ranging from 0.5 mg/kg to 25 mg/kg were fed to alloxan-effectuated rats through oral administration for a time period of 5 days (Silva *et al*., 2011) [18]. Glibenclamide and metformin were referred to as comparative medicines. It was concluded that pectin from this variety can be very effectively used to cure type 2 diabetes, based on the blood levels ascertained prior to and after the 5-day time period of pectin administration. Pectin has immense potential to treat type 2 diabetes, even in a way better than popular antidiabetic drugs (glibenclamide and metformin). Corroborating this statement is a fact that pectin (dosage levels: 2,10,25 mg/kg) restored blood sugar levels by upto 65% when compared to glibenclamide (5 mg/kg) and metformin (50 mg/kg), which lowered blood sugar levels by upto 80%. Low dosage levels but greater anti-diabetic activity has been remarkably achieved by this wonder polysaccharide named “pectin”. Such promising results can be achieved using apple pomace pectin as well. Similar studies should be conducted in the case of apple pomace pectin, so that waste valorization can serve as promising option in the form of anti-diabetic drug.

Phlorizin as anti-diabetic agent

As the problem of diabetes mellitus is constantly increasing at an alarming rate, there is an urgent requirement of natural edible substances which can lessen down glucose absorption in the intestinal region in order to ward off spike in plasma glucose and insulin levels (Schulze *et al*., 2014) [19]. In this context, a study was conducted to depict that decoction and independent phytochemicals harnessed from apple cut down glucose assimilation regulated via the sodium-coupled glucose transporter 1 (SGLT1) molecule. Decrease in glucose uptake was demonstrated in xenopus blastocysts and jejunal fragments of mice. The highest intensity of decrease was achieved by phlorizin (showcasing IC_{50} values of 0.46 and 4.1 in blastocysts and jejunal fragments, respectively) when measured using membrane gradient plotting method. Moreover, homogeneous outcomes were obtained as human participants consumed apple decoction. Such studies can be conducted using apple pomace extracts. Phlorizin (harnessed from apple peel extract) also has the capability to ameliorate the associated complications of diabetes, such as diabetic peripheral neuropathy (DPN) and extended injury restoration (EIR) (Kamdi *et al*., 2021) [11]. Sometimes, diabetes is identified with symptoms of depression in patients due to several factors such as insulin resistance, free radical as well as neural induced damages in body (Kamdi *et al*., 2021) [11]. Phlorizin can even treat this category of depression. A study was carried out on similar lines by the same group, wherein rats thriving on high-fat diet were subjected to streptozotocin in order to instigate diabetes. As the rats were segregated into different categories, each of them were given a mixture of salt solution (0.25 ml) and phlorizin (around 20 mg/kg) for a time period of 28 days. It was concluded that analgesic effects related to curing depression of phlorizin were very evident when enzyme-regulating framework of the body modulated itself in order to achieve antidepressant targets. Furthermore, one very common problem linked with diabetes is increased blood pressure (Osorio *et al*., 2010) [22] which can be sorted using phlorizin. A research proves that SGLT2, regulated particularly by phlorizin, averts high blood pressure formation in rats. In this study, animals were categorized into control group and streptozotocin-administered group, so that SGLT2 mechanism can be explored in brush lined laminated cavities designed using quick filtration method. Another set of rats were segregated into normal and high salt diet, wherein further categorization was done, leading to control group, (control + phlorizin) group, diabetes group and (diabetes + phlorizin) group. After evaluating activity of systolic blood pressure in all these groups for a period of one month, SGLT2 significantly prevented the initiation of high blood pressure in diabetic rats (Osorio *et al*., 2010) [22].

Fortified products

Many products have been enhanced in terms of antioxidant activity using apple pomace. Some examples are that of apple pomace enriched breads, cookies, yoghurt etc. Gluten deficient breads lack goodness of nutrients, so, they need to be fortified with certain naturally existing nutraceuticals like apple pomace (Gumul *et al*., 2021) [23]. Results showed that gluten-free breads fortified with 5% apple pomace exhibited good phenolic activity, with phlorizin content upto 21 times greater than the control samples. Similarly, gluten lacking cookies were enhanced in phenolic content using apple pomace (Kruczek *et al*., 2023) [24]. Antioxidant profile significantly improved and dietary fiber greatly enhanced. All developed variants (control (gluten lacking cookies) + 15%

apple pomace, control + 30% apple pomace, control + 45% apple pomace, control + 60% apple pomace) showcased greater levels of phlorizin along with quercetin, which together contribute towards treating type 2 diabetes (Randhawa *et al*., 2013) [25]. Next in line is the development of apple pomace flour fortified yoghurt, which demonstrated the capability to treat diet-controlled type 2 diabetes and its associated complications like obesity, if consumed in the quantity of 100 ml everyday (Jovanovic *et al*., 2020) [26]. Apple pomace enriched noodles exhibited good dietary fiber content since the value almost doubled once apple pomace powder was added into the noodles.

Conclusion

Future studies are needed to explore the antidiabetic potential of apple pomace. Similar studies using other sources of pectin should be used as a role model and implemented in the case of apple pomace. Taking such step will help us to widen the scope of antidiabetic study, thus providing us the opportunity to utilize food waste. More studies should be conducted to study the effect of phlorizin on SGLT transporters as they play a vital role in regulating glucose absorption.

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