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INDUSTRIAL APPLE POMACE BY-PRODUCTS AS A POTENTIAL SOURCE OF PRO-HEALTH COMPOUNDS IN FUNCTIONAL FOOD

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ABSTRACT

Apples are widely consumed in all countries. Poland is one of the biggest apple producing country in world and this amount grows from year to year increase. More than half of produced apples is processed which cause occur solid residue called apple pomace. Apple pomace contains may pro-health compounds. Most recent interest has focused on the bioactive phenolic compounds in apple pomace. Several studies have demonstrated that apple pomace compounds possess many biological activities, such as antioxidant and anti-inflammation properties. Therefore apple pomace can be a potential source for health food preparations. The purpose of this paper is to review the most recent literature regarding the health benefits of apple pomace.

Keywords: fruit residues, novel food, phloridzin, dietary fibre

INTRODUCTION

Apples are the most popular fruits in the world and widely grown in all temperature regions. Poland with production of apple up to 4 million tons is third apple producer on a globe scale. About 58% of produced apple in Poland is processed into clear apple juice concentrate, cider, canned as fresh slices/cubes, baby foods, apple butter, jelly, vinegar etc. (**Sudha *et al.*, 2016**). About 65% of processed apple rely on juice pressing causes occurring the residues, which the biggest part is apple pomace (**Wichrowska & Żary-Sikorska, 2015**). Apple pomace is left-over solid residue resulting of extraction of juice from apple in: apple juice concentrate, cider, jams etc. and accounts for ~25% of total apple weight. The by-product could be easy to dispose of, but because it is still a part of fruit it has great potential for conversing into edible products. The apple pomace is characterized by a high content of pro-health compounds like dietary fibre and many phytochemicals, including phenolics, like quercetin, catechin, phloretin/ phloridzin, gallic acid and chlorogenic acid, all of them can reduce chronic disease risk (Fig 1) (**Fronc and Nawirska, 1994; Downing, 1995; Boyer and Liu, 2004**).

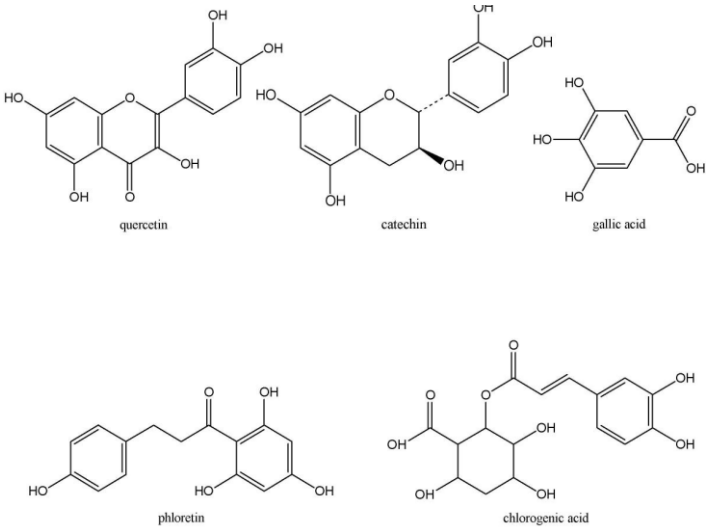

Figure 1 Structures of selected apple antioxidants (**Boyer & Liu, 2004**)

However different varieties of apples could have different phytochemical composition and the maturation and ripening of the fruit at harvest could affect also changes in that composition (**Boyer & Liu, 2004**). Storage has only little effect on apple phytochemicals, but processing can greatly affect the amount of those compounds in juice, but not as much in apple pomace, which are still rich source of pro-health phytochemicals. Apple pomace has more pro-health ingredients than processed products, like juice, nectar and other drinks which are often clarification or diluted (**Kruczek *et al.*, 2016**). Fresh apple pomace has high moisture content and is susceptible to microbial degradation markered often, therefore needs to be dehydrated during drying and then ground into powder shown on Pic. 1 (**Lavelli and Corti, 2011**).

Picture 1 Dried apple pomace: whole and ground (own picture)

NUTRITIONAL PROFILE OF APPLE POMACE

Apple pomace is a rich source of nutrients phytochemicals, such as carbohydrates, vitamins and minerals (Table 1) (**Bhushan, *et al.*, 2008)**. It consist of high amount of carbohydrate, of which about 70% are simple sugars, which provide energy for the body, brain and nervous system. Simple sugars are quickly converted into blood glucose, which is converting directly into energy. Fructose which amount is the highest from simple sugars in apple pomace is the sweetness sugar relative to its weight. Fructose metabolism in human body is mainly caused by an enzyme called fructokinase, found mostly in the liver. The muscles and brain do not contain fructokinase, therefore do not have a high affinity for fructose, which is making a less efficient source of fuel for nonliver tissues. Apple pomace contain from 10 to 12% glucose (dry weight basis), which is a main fuel source for most tissues throughout human body (**Bhushan, *et al.*, 2008)**.). Apple pomace is also a high source of arabinose and rhamnose which are a component of biopolymers such as hemicellulose. Alcohol- insoluble fraction of carbohydrate in apple pomace mainly is a part of an unavailable for human body fraction. Besides carbohydrates, apple pomace is also a source of proteins (from 3 to almost 6%), what makes apple pomace a poor source of this important nutrient. Therefore apple pomace is an unfavourable feed supplement. Aspartic and glutamic acids are the predominant amino acids in fresh apple (**Downing, 1995**). Apple pomace is rich source of many minerals, which are of interest from the human nutritional point of view. Potassium represents the main portion of the total mineral content of apple pomace and provides 20% of Recommended Dietary Allowances (RDA) after consumption 100g of apple pomace (**National Institutes of Health, 2017)**. Potassium is important for lowering blood pressure. A high-potassium diet reduces cardiovascular disease or renal disease and decrease the risk of osteoporosis (**He and MacGregor, 2008**). Sodium and phosphorus are the next most widespread minerals in apple pomace and provides respectively 13% and 11% of RDA (**Bhushan, *et al.*, 2008; National Institutes of Health, 2017)**. Consumption 100g of apple pomace per day provides also 48% RDA of iron. Iron deficiency is one of the most popular in humans. Even small deficiency of these element causes decreasing of physical activity and could damage psychomotor activity (**Asghari-Varzaneh, *et al.*, 2017)**. Apple pomace is also rich source of copper and zinc. Copper is request in correct superoxide dismutase working, which causes neutralization of free radicals in human body (**Chu, *et al.*, 2005)**. Zinc is essential trace element for humans, and other organisms, after iron is second most abundant transition metal in organisms. Children, adolescents pregnant and lactation women have increased requirements for zinc. Diagnosis of marginal Zn deficiency in humans remains problematic. Deficiency of zinc causes results problems with epidermal, gastrointestinal, central nervous, immune, skeletal, and reproductive systems. Therefore the supplementation of zinc is important (**Roohani, 2013**). However, it should be noted that there were found some variation in ash content of minerals among different geographic growing regions of apple. This variability is supposed to be due to the different mineral availability of the soils of different globe regions (**Downing, 1995)**. Apple contains also vitamin C- ascorbic acid, but like in case of mineral content there are differences in content depends of cultivars, cultivation and geographical location. Research shows that apple pomace contains 0,35 mg ascorbic acid/ 100g fresh weight (**Lu and Foo, 2000)**.

Table 1 Proximate nutritious composition of apple pomace (**Bhushan, *et al.*, 2008)**

Constituents	Composition (dry weight basis)	Constituents	Composition (dry weight basis)
Moisture (%)	3.90–10.80	**Alcohol-soluble fraction of carbohydrate**	
Protein (%)	2.94–5.67	Saccharose (%)	3.80–5.80
Total carbohydrate (%)	48.0–62.0	Glucose (%)	19.50–19.70
Fibre (%)	4.70–51.10	Fructose (%)	48.30
Insoluble fibre	36.50	Xylose, mannose and galactose (%)	1.20–4.40
Soluble fibre	14.60	L-malic acid (%)	2.60–3.20
Fat (ether extract, %)	1.20–3.90	Arabinose and rhamnose (%)	7.90–6.0
Pectin (%)	3.50–14.32	Glucooligosaccharides (%)	3.40–3.80
Ash (%)	0.50–6.10	Xylooligosaccharides (%)	3.0–3.70
Minerals		Arabinooligosaccharides (%)	0.20–0.40
Phosphorus (%)	0.07–0.076	Uronic acid (%)	2.70–3.40
Potassium (%)	0.43–0.95	**Alcohol-insoluble fraction of carbohydrate**	
Calcium (%)	0.06–0.10	Glucan (%)	41.90–42.90
Sodium (%)	0.20	Starch (%)	14.40–17.10
Magnesium (%)	0.02–0.36	Cellulose (%)	7.20–43.60
Copper (mg/kg)	1.10	Polysaccharides of xylose, mannose and galactose (%)	13.0–13.90
Zinc (mg/kg)	15.00	Polysaccharide of arabinose and rhamnose (%)	8.10–9.0
Manganese (mg/kg)	3.96–9.00	Acid detergent lignin (%)	15.20–20.40
Iron (mg/kg)	31.80–38.30	Uronic acid (%)	15.30

DIETARY FIBRE

Dietary fibre is portion of food deliver from plants, which is not digested in the human small intestine. Dietary fibre can be classified in a number of different ways. The two main components are soluble and insoluble fibre. Insoluble fibre includes lignin, cellulose and hemicelluloses, soluble fibre pectin, β-glucans, galactomannan gums, and a large range of non-digestible oligosaccharides, including inulin. Dietary fibre has many health benefits and could help in the treatment of obesity, arthrosclerosis, coronary heart diseases, large intestine cancer and diabetes- by decreasing blood glucose level. It could binds hydrochloric acid, metal ions and cholesterol in stomach, dietary fibre could also stimulate growth of probiotic microflora in intestines. Dietary fibre intake in Western countries achieves value 18g per person per day while population's fibre intake should increase to 30g a day, according World Health Organization (**British nutrition fundation, 2015**). This undertake should be supplement by different functional food intakes. Apple pomace contains significantly high content of dietary fibre (~55% of dry weight) and hence it can be a potential source for health food preparations (**Kołodziejczyk *et al.*, 2007**).

Apple pomace is good source not only of total dietary fibre but also contains a big amount of soluble dietary fibre, which comprises of pectin (**Sharma and Gupta, 2016**). Pectin is structural hydropolisaccharide contained in the primary cell walls. Apple pectin presents a high degree of esterification and a particularly high content of branched side chains. It shows prebiotic effects in human body and is fermented by the microflora in the large intestine. During fermentation of pectin they arise the short chain fatty acids (SCFA), which are absorbed and metabolised in the colonic mucosa, liver, or peripheral tissues. A recent study have shown a relationship between the consumption of pectin and maintenance of normal blood cholesterol concentrations or a reduction of post-prandial glycaemic responses (**Ferretti, *et al.*, 2014**). The proportion between soluble and insoluble fractions of dietary fibre in apple pomace is well-balanced (1:2). Fruit fibre have better oil holding capacity and colonic fermentability than more popular cereal ones. Therefore the apple pomace dietary fibre have better quality to compared to other dietary fibres, and lower caloric value (**Wichrowska & Żary-Sikorska, 2015**).Researchers are suggested that pulp and peel should be a predominant part of raw material for commercial preparation of dietary fibre (after removal of seeds and hard parts) (**Kołodziejczyk *et al.*, 2007**).. Commercial apple dietary fibre is characterized by low caloric value, natural

flavour and taste, and low content of lipids. The production of apple fibre by separation of seeds and hard parts is because its bitter taste. The removal of seeds for the preparation dietary fibre is characterized by higher content of total dietary fibre and soluble dietary fibre. Some researcher found that undesired sensory properties of apple fibre can be eliminate by the extraction of phenolics (**Kołodziejczyk *et al.*, 2007**).

POLYPHENOLS

It has been estimated that every day in humans there are 10,000 oxidative hits to DNA per cell. But oxidative stress caused by free radicals can damage not only DNA but also lipids, proteins, enzymes, carbohydrates, this process can led to membrane damage, damage of structural proteins, enzymes and finally cause cell death. Because our environment is highly oxidative, and many processes involved in metabolism oxidation, the antioxidant defence system is not effective (**Boyer & Liu, 2004**). One of the most useful role of the polyphenols present in apple pomace is protection against free radicals. Several studies have shown that these phytochemicals can inhibit proliferation of cancer cells, regulate inflammatory and immune system and protect against oxidation, so they could help in protecting against chronic disease and slow aging.

Apples are a significant source of antioxidants in people's diet. In the United States more than 20% of the polyphenols consumed from fruits come from apple, what makes apples the largest source of polyphenols. In a Finish study, apples were the main source of dietary flavonoids, which shows the strongest pro-health properties in human's diet. (**Boyer & Liu, 2004**). Apple pomace as a part of apple contain significant amounts of polyphenols. The apple pomace is big source of flavonoids (flavanols and flavonols), which consist of quercetin 3-O-rutinoside, quercetin 3-O-galactoside, quercetin 3-O-glucoside, quercetin 3-O-xyloside, quercetin 3-O-arabinoside and quercetin 3-O-rhamnoside (Tab. 2.) Other phytochemicals present in apple pomace are anthocyanins (cyanidin-3-galactoside), coumaric acid, chlorogenic acid, gallic acid, and certain dihydrochalcones only found in apples (phloridzin and phloretin) (**Ferretti, *et al.*, 2014**).

Table 2 Average polyphenols content in apple (mg per 100g fresh weight) (**Ferretti, *et al.*, 2014**).

Constituents	Contents [mg]
Total polyphenols	111
Flavanols	96.3
Flavonols	5.66
Dihydrochalcones	4.18
Anthocyanins	1.62
Hydroxycynnamic acids	14.21

There are several studies which linked apple consumption with a reduced risk of cancer, especially lung cancer. **Feskanich et al. (2000)** shows that 1 apple per day significantly lower risk of lung cancer for women. Very few of examined fruit or vegetables had such a significant effect on lung cancer risk in women like apple. Probably that effect is related with higher flavonoid intake (especially quercetin). This point was confirmed by Finish study (**Boyer & Liu, 2004**), showing also the reduce risk of cardiovascular disease and cardiovascular events associated with apple consumption by woman (from 13 to 22%) (**Sesso, et al., 2003)**.

Only few plant species contains significant quantities of phloridzin (the 2'-glucoside of phloretin), which belongs to polyphenols compounds and more specifically to dihydrochalcones (Fig 2). Apples are unique in Rosaseous plants due to fact the presence of such high amounts of phloridzin which is the major phenolic compound in commercially grown varieties of apple (**Lavelli and Corti, 2011**). Over past last decade different studies showed the beneficial effects of phloridzin for human health (**Gosch, *et al.*, 2009; Najafian, *et al.*, 2012; Zhang, *et. al.*, 2016**). The study have examinaed positive respect for the treatment of diabetes, metabolic syndrome and neurological diseases. Phloridzin could be applicate as natural sweeting agents, additive in foods, beverages, pharmaceuticals or cosmetics. The physiological function of phloridzin in plants is still unclear, probably it is responsible for pathogen defence (**Gosch, *et al.*, 2009**). Phloridzin is recognised as anti-diabetic agent- by binding of the glucose moiety to the Na+/glucose cotransporter. Therefore phlorizin was studied as a potential pharmaceutical treatment for type II diabetes, but has since been superseded by more selective and more promising synthetic analogues, such as canagliflozin and dapagliflozin. Orally intake phloridzin is converted into phloretin by hydrolytic enzymes in the small intestine.

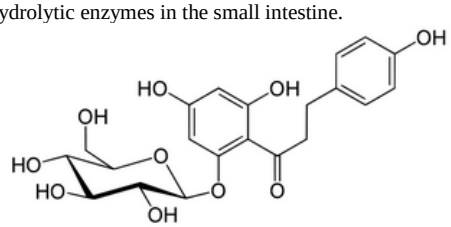

Figure 2 Structures of phloridzin

Other strong antioxidant present in apple pomace is quercetin. This compound has protective effects against breast and colon cancer and heart diseases. Quercetin can also protect the liver from oxidative damage (**Boyer & Liu, 2004**). A recent study showed positively association between consumption af apples and decreasinng risk of asthma and a decrease in bronchial hypersensitivity (**Woods, *et al.*, 2003).**

The commercial preparation of apple phytochemicals "Pomactiv HFV®" contains 40% of apple phenolics in dry weight of which 15-20% is quercetin. The polyphenols could be easy extracted from apple pomace by already published method by Kołodziejczyk et al., 2007: ground pomace is extracted in three ethanolic batches- first extract is rejected and the second and third were joined. Ethanol is evaporated and water extract is concentrated. Authors suggested that these phytocomponents could be used as an additive to food products etc. drinks of special nutrition design or in cosmetics for skin and hair care, anti-decay and anti-cellulite products (**Kołodziejczyk, *et al.*, 2007**).

However, it is important to emphasize that it is not always clear whether the effects in animals can be extrapolated to humans. Further, studies in cell culture *in vitro* must be conducted before getting to know how that phytochemicals work *in vivo* and how they are absorbed and metabolized in the body. Some phytochemicals are fermented and digested by colonic bacteria and the original phytochemical may not even be detectable in the blood (**Del Rio, *et al.*, 2013**). Table 2 shows different molecular mechanism which explain the protective effect created by apple pomace components.

Table 2 Potential disease-preventive mechanisms of apple and their active constituents as identified in human dietary studies (**Ferretti, *et al.*, 2014**)

Potential disease-preventive mechanisms	Key active components
Antioxidant activity (ROS and RNS)	Flavonoids, Ascorbic acid, Pronthocyanidins
Blood pressure reduction	Flavonoids
Modifications of plasma lipids and lipoprotein levels	Fibres (Pectin), Polyphenols
Modulation of endothelial cells	Flavonoids
Anti-inflammatory properties	Flavonoids, Proanthocyanidins

Many studies showed that apple pomace polyphenols have been identified as potential radical scavenger, antioxidant and anti-inflammatory molecules and apple fibre offers many health benefits.

UNSATURATED FATTY ACIDS

Apple pomace contains about 5% of seeds, which contain from 27.5 to 28% lipids, and could be a good source of oil. The oil from apple seeds can be obtained by cold-pressing or hot-extracting. Additionally apple seeds oil contains high levels of linoleic acid (49%) and other dominant fatty acids as oleic, palmitic and stearic acids (**Tab 3)**. The unsaturated fatty acids highly present in apple seed oil are considered to have positive effects on lowering the LDL cholesterol and reduce risks of heart diseases. The protein content of apple seed is significant- 34%. Apple seed proteins are rich in sulfuramino acids and seems to be fairly balanced, with only tyrosine being in low quantity. Compared to pattern for whole egg protein, the lysine content of apple seed proteins can make it useful for complementary cereal proteins. The apple seeds also contain significant amounts of primary elements and certain trace elements like phosphorus, potassium, magnesium, calcium and iron (**Yu, *et al.*, 2007**).

Table 3 Fatty acid composition (%) of the oil extracted from apple seed (**Yu, *et al.*, 2007**).

Fatty Acid	Apple Seed Oil
Palmitic	7.1±0.3
Stearic	2.4±0.2
Oleic	39.7±0.0
Linoleic	49.6±0.2
Linolenic	-
Saturated	9.5
Unsaturated	89.3

AMYGDALIN

Apple tree belong to the family *Rosaceae* and contains the toxic cyanogenic glycoside- amygdalin (D-mandelonitrile-β-D-gentiobioside), which could be metabolized in toxic hydrogen cyanide there it is important to focus on this compounds . Although amygdalin itself is not toxic, it became toxic when enzymes β-glucosidase and α-hydroxynitrile lyases, present in plants after tissue damages, come into contact with amygdalin. Enzymes cleaving the carbohydrate moiety of the cyanogenic glicoside yield the corresponding cyanohydrins, which are metabolized into hydrogen cyanide (HCN) and the aldehyde or ketone. However not only plant enzymes shows that action but also enzymes from the gut microflora could generate the hydrogen cyanide (**Bolarinwa, *et. al.*, 2014**). The relationships between cyanide concentrations in blood and the symptoms are as

follow: levels of 0.5–1 mg/L mild, 1–2 mg/L moderate, 2–3 mg/L severe, and greater than 3 mg/L generally result in death (**Anseeuw, *et. al.*, 2013).** Amygdalin is the major component of apple seeds, which contains 2,96 mg/g of amygdalin. Of course there are differences between amounts of amygdalin in seeds depending on cultivars (**Michalcová, *et al.*, 2016**). Apple juice (100% pressed) contain 0,09mg/g of amygdalin, so it is much lower than observed in apple seeds. There are no evidence about the amygdalin content in apple pomace; however, on the assumption that apple pomace contain about 7% of seeds the amygdalin content could be estimated as 0,21 mg/g which is low and it is unlikely to cause any health problems if consumed normally (**Kołodziejczyk *et al.*, 2007**). However, there is no evidence that amygdalin, administered in "therapeutic" dosage, causes toxicity. Therefore it is also important to mention about researcher reported antitumor activity of amygdalin. **Makarevića et al. (2016)** showed positive effect of amygdalin on the growth capacity and molecular machinery in tree prostate cancer cell lines without any toxity. They showed also that highly purified amygdalin applied in "therapeutic" concentrations, probably does not cause toxicity. Even the maximum dosage of 100 mg/kg term body waight purified amygdalin in mouse diet does not lead to any toxicity (**Makarevića, *et al.*, 2016**). **Luo et al. (2016)** showed also the antifibrotic potential of amygdalin in liver fibrosis. Amygdalin significantly inhibited HSC-T6 cells (kind of hepatic stellate cells) proliferation which may have therapeutic potential for patients (**Luo, *et al.*, 2016)**. A recent report has shown *in vitro* that amygdalin inhibits metastatic spread in the cultured renal cell carcinoma. In those cells amygdalin caused significant reductions in chemotactic activity, invasion and adhesion to endothelium, collagen and fibronectin (**Juengel, *et al.*, 2016)**. It was also shown that amygdalin inhibits angiogenesis which is sausing growth and repairing of blood vessels. Angiogenesis could also contribute to several malignant, ischemic, inflammatory, immune and infectious disorders likes diabetic retinopathy. **Mirmiranpour et al. (2012)** showed first time the antiangiogenic properties of amygdalin on the cultured endothelial cells derived from the aortic rings of diabetic rats (**Mirmiranpour, *et al.*, 2012**). Further studies confirmed that amygdalin had analgesic effects in mouse BV2 microglial cells probably by inhibiting prostaglandins E2 and nitric oxide synthesis (**Song and Xu, 2014)**. Amygdalin may play also a protective role in hyperoxia-induced lung injury, by stimulating the proliferation alveolar epithelial cells (**Huaping, *et al.*, 2004).** Multiple aspects of amygdalin administration have not been adequately explore, making further investigation particular *in vitro*necessary to evaluate its actual therapeutic potential.

CONCLUSION

Apple pomace contains many compounds with pro-health action like micro and macroelements, dietary fibre, polyphenols and unsaturated fatty. Apple pomace showed high antioxidant activity mostly from polyphenol group. Consequently has also high radical-scavenging activity and antiglycation activity what help prevent oxidative stress, and may therefore help prevent chronic disease. It is also high source of phloridzin, which has anti-diabetic potential. Amygdalin has a clear pharmacological activity, but there are still need to conduct in-depth research on the pharmacological mechanism of the compound. To sum up, still many human and animal studies are needed in normal and pathological conditions to confirm the hypothesized about protective against diseases effects of apple pomace.

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