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REVIEW

Utilization of pomace from apple processing industries: a review

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Abstract In large scale apple juice industry, about 75% of apple is utilized for juice and the remaining 25% is the by- product, apple pomace. In India, total production of apple pomace is about 1 million tons per annum and only approximately 10,000 tons of apple pomace is being utilized. Generally, apple pomace is thrown away, which causes environmental pollution. As the pomace is a part of fruit, it has potential for being converted into edible products. Apple pomace is a rich source of carbohydrate, pectin, crude fiber, and minerals, and as such is a good source of nutrients. This paper reviews the work done to utilize this precious resource, which can prove useful for setting up of small scale industries.

Keywords Apple pomace · Waste utilization · Apple processing industries · Nutritional aspects · Edible products

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Introduction

Apple (*Malus domestica* Borkh.) is the most favoured fruit of millions of people and is a widely grown fruit in temperate regions of the globe (Kaushal and Joshi 1995, Kaushal et al. 2002, Agrahari and Khurdiya 2003). The world production of apple is about 58 million tons from an area of about 5.26 million ha (FAO 2005). Presently, India is the 9th largest producer of apples in the world contributing about one-third of total apple production of the world with an annual production of 1.42 million tons from an area of 0.25 million ha (Anon 2004). It is the 4th major fruit crop of India (GOI 2004). About 71% of apple is consumed as fresh apple while about 20% is processed into value added products of which 65% are processed into apple juice concentrate (AJC) and the balance quantity into other products which include packed natural ready-to-serve (RTS) apple juice, apple cider, wine and vermouth, apple purees and jams and dried apple products (Downing 1989, Joshi et al. 1991, Joshi 1997, Kaushal et al. 2002).

The major apple growing states in India are Jammu and Kashmir, Himachal Pradesh and Uttaranchal (Sharma 1994). It is a major horticultural produce and is the backbone of the rural economy of these States (Agrahari and Khurdiya 2003). However, during the last 4–5 years, cultivation of apples has been extended to North East Himalayan States also. Most of the production of this fruit is used for table purposes but a portion is being processed into various products (Kaushal and Joshi 1995). A conventional process removes 75% of fresh weight of apple as juice and 25% is the pomace (Wang and Thomas 1989, Shah and Masoodi 1994, Kaushal et al. 2002).

In large scale apple processing industries, the wastes can be categorized into 2 types. The first type is the fruit discarded into the sorting belt due to its partially bruised/ spoiled nature and named as belt rejection. The second type is the apple pomace obtained after juice extraction.

The belt rejection apples are also dumped along with apple pomace as waste. Safe disposal of processing waste is very important to prevent environmental pollution. Apple pomace contains large amounts of water and is in a wet and easily fermentable form therefore causes serious disposable problems. A substantial cost is involved for disposal of such wastes. Pomace can be treated as an excellent example of waste food resource (Shah and Masoodi 1994).

In India, total production of apple pomace is about 1 million tons per annum and only approximately 10,000 tons of apple pomace is being utilized (Manimehalai 2007). The large scale processing plants are located in Jammu and Kashmir and Himachal Pradesh, which produce huge quantum of apple pomace and is not being utilized at present but is dumped in the fields creating pollution problems because of fermentation and high chemical oxygen demand (COD) of 250–300 g/kg. Apple pomace being biodegradable in nature with high bio-chemical oxygen demand (BOD), disposal of apple pomace into the environment causes pollution, necessitating the efforts to find out the appropriate solution to this problem. The commercial utilization of pomace shall ultimately be determined by economics of products and the cost of waste disposal coupled with pressure from environment protection agencies in implementing the laws (Kaushal et al. 2002).

Apple pomace, though traditionally utilized as cattle feed, only a fraction of apple pomace is used due to rapid spoilage of the wet pomace (Bates and Roberts 2001). Being a rich source of carbohydrate, pectin, crude fiber and minerals, it is the good source of nutrients. Shah and Masoodi (1994) estimated that Rs 50,000 per month was being paid for waste disposal at the apple juice concentrate plants. It is reported that in United States, the disposal fee for apple pomace exceeds $ 10 million per year. The large quantity of apple pomace produced (Table 1) during apple processing suggests that the preparation of single product would not be economically feasible and production of all possible products needs to be explored (Kaushal et al. 2002).

Taking this into consideration, in this paper, the research work carried out on the utilization of apple pomace from apple processing industries for the development of various products is reviewed, along with the scope for the setting up of small scale industries.

Nutritive value of apple pomace

Apple pomace is the main by-product of apple cider and juice processing industries and accounts for about 25% of the original fruit mass at 85% (wb) moisture content (Sun et al. 2007). Apple pomace typically contains 66.4–78.2% (wb) moisture and 9.5–22.0% carbohydrates (Sun et al. 2007). Apple pomace contains 26.4% dry matter (DM), 4.0% proteins, 3.6% sugars, 6.8% cellulose, 0.38% ash, 0.42% acid and calcium, 8.7 mg/100 g of wet apple pomace (Vasil'ev et al. 1976).

Fuel purposes

Dried apple pomace can be utilized as fuel for steam generation in processing plants which will help to make a significant contribution to the energy budget (Fischer 1984). Sargent et al. (1986) studied the economic feasibility of in-plant combustion of apple processing wastes. They suggested that reductions in fossil fuel and waste disposal costs could be achieved by apple processors through in-plant combustion of apple pomace.

Food products

Efforts have been made to utilize apple pomace in the preparation of edible products like apple pomace jam and sauce (Kaushal and Joshi 1995, Joshi et al. 1996) or to make citric acid (Sharma and Joshi 2001, Kaushal et al. 2002). Pomace *papad*, a form of high value low volume product has also been prepared from apple pomace (Kaushal et al. 2002). Rotova (1983) worked out a technology for preparation of apple powder from apple press cake which involves moulding, drying, crushing and fractionation. Several recipes of confectionaries containing this powder were also worked out. Estimated consumption of apple powder by the Ukranian confectionery industry was reported to be 2000 tons. Apple pomace powder was substituted for soy meal in two types of blended toffees without having any adverse effect on their quality (Eingor et al. 1984).

Table 1 Processing wastes recorded at an apple processing plant

Period, month	Fruit supplied for processing, MT	Quantity of wastes discarded, MT			Percentage of wastes discarded		
		Apple	Pomace	Total	Apple	Pomace	Total
1	450	9.5	114.6	124.1	2.1	25.5	27.6
2	489	6.0	111.3	117.3	1.2	22.8	24.0
3	629	8.9	162.3	171.2	1.4	25.8	27.2
4	481	6.1	120.3	126.4	1.3	25.0	26.3
5	259	3.5	71.2	74.7	1.4	27.5	28.9
Total	2308.0	34.0	579.7	613.7	5.3	101.1	134.0
Average	461.6	6.8	115.9	122.7	1.5	25.3	26.8

Source: Shah and Masoodi (1994)

Walter et al. (1985) conducted studies on the edible fibers from apple pomace. They subjected apple pomace to a mild alkaline degradation that yielded an α-cellulosic fraction of approximately 26% of the untreated dry matter. They extracted fiber by various aqueous solvents which yielded water dispersible, uronide fractions comprising of 10-18% of the untreated dry matter which had a different viscometric characteristics, depending on the extractant (aqueous solvents) used. All the fibers had the potential to provide non-nutritive bulk to low-fiber fabricated foods. Additionally, they provided a high concentration of solid matter to an aqueous, food system without significantly altering the viscosity of the system. Direct use of apple pomace in bakery products was investigated by Wang and Thomas (1989). They examined the drum-dried apple pomace (DDAP), an edible by-product from single pass metallic membrane ultra filtration of apple puree for composition and utilization as a source of sugar and dietary fiber in bakery products. Total dietary fiber (TDF) of freeze-dried apple pomace (FDAP) and DDAP was 35.3% and 33.2%, respectively. Total sugar content of the apple pomace concentrate (APC), FDAP and DDAP was 54.3, 46.3 and 36.7%, respectively. A sensory evaluation result of the experimental muffins with 50% (w/w) of the plain wheat bran substituted by powdered apple pomace was more desirable than control bran muffins. In addition, experimental moon cookies with flaked apple pomace substituted for 40% (w/w) of the quick-cooking oats in the filling were significantly ($p<0.01$) more desirable than the control moon cookies.

Shah and Masoodi (1994) conducted studies on the utilization of wastes from apple processing plants. They reported that in large scale apple processing plants about 25% apple pomace and 1.5% apples are discarded as processing wastes. Such industrially discarded apples were converted to homogenous pulp after autoclaving. The pulp when preserved with potassium metabisulphite (KMS) @ 1.0 g/kg of pulp stored well for over one year at 20 °C. Beverages prepared from pulp were highly acceptable. Joshi et al. (1996) utilized apple pomace from 3 stages of apple maturity (August, September and October) and 3 levels of sugar (per kg of pulp) with final total soluble solids (TSS) of 15 (T_1), 20 (T_2) and 25 (T_3) °B for the development of apple pomace sauce. They found that sugars (reducing and non-reducing), Brix/acid ratio, starch, proteins and crude fiber increased, but ascorbic acid content decreased from stage T_1 to T_3. Apple pomace sauce from T_2 was found to be the best on the basis of sensory qualities. All the quality parameters showed increase except for starch, pectin, crude fiber and ascorbic acid, which reduced from T_1 to T_3. The TSS, sugars (reducing and total), titrable acidity and standard plate counts increased significantly during 6 months storage, whereas non-reducing sugars, starch, pectin, crude fiber and ascorbic acid content decreased during storage. The changes during storage in general were similar to any other sauce and were not specific for apple pomace sauce. The product remained acceptable for 6 months storage at room temperature.

Kaushal and Joshi (1995) prepared cookies by incorporating different amounts (10–50%) of apple pomace powder in dough. Sensory evaluation of prepared cookies showed that 30% of apple pomace powder could be incorporated in the preparation of cookies of good quality. Utilization of apple pomace as a press aid in fruit juice preparation was studied by Bates and Roberts (2001). Drying kinetics of apple pomace was also investigated. The apple pomace was dried at 70°C in a drying chamber, milled and added to raspberries, strawberries, blueberries and grapes prior to pressing. The juice was evaluated for yield and flavour and compared with juice pressed with rice hulls and paper. Desorption isotherms of the pomace were measured at 25, 35 and 45°C. The results showed that the juice yield by pressing with apple pomace was comparable with the juice yield with rice hulls and paper. Pressing with apple pomace resulted in a more favorable flavour for the juice than from the juice pressed with hulls.

Pectin extraction

Apple pomace is being utilized for extraction of pectin since long. Efforts have been made in the past to extract pectin from apple pomace (Sharma et al. 1985). Gentschen (1988) used a multistep countercurrent method for extraction of pectin from apple pomace and suggested that processing should be carried out without mixing the batches of raw material and after determining optimum processing conditions. It was reported that during countercurrent extraction of pectin with short residence time in the plant, back extraction was observed i.e., exchange of material from pectin rich extract with liquid phase of the feed. Pectin yield of more than 90% and high pectin concentration in the extract were achieved even from low pectin pomace with double extraction. However, countercurrent extraction of pectin adversely affected its gelling power.

Ihl et al. (1992) studied the recovery of pectin from apple pomace (*cv.* Pippin) and precipitated pectin from crude extract by ethanol or with 2–4% $AlCl_3$. Pectin yield was 7.2% with ethanol, 1.11% with 2% $AlCl_3$, 2.38% with 3% $AlCl_3$ and 2.8% with 4% $AlCl_3$. Degree of esterification (reaction of aldehyde and ketone forms ester which has sweet and fruity smell and the process is called esterification) as highest for pectin precipitation with 4% $AlCl_3$. Samples precipitated with 3% $AlCl_3$ had the highest gel strength but had high residual aluminium content. Overall precipitation with ethanol was recommended because of high yield and acceptable properties of pectin.

Ezhov et al. (1993) patented a method for extraction of pectin from apple pomace under acid conditions. The method involves the separations of pressings into solid and liquid phases, precipitation of pectin from liquid phase and subsequent drying. Following removal of pectin, solid and liquid phases can support microbial growth. Pectin yield and microbial growth on solid phase was reported to be enhanced by additional extraction using equimolar amounts of NH_4OH.

Cattle feed

Apple pomace had been traditionally utilized as cattle feed. An innovative approach for the recovery of the ethanol and the production of animal feed concomitantly has also been advocated (Joshi and Sandhu 1994, 1996). Narang and Lal (1985) while evaluating some agro industrial wastes as feed of 'Jersy' calves on the basis of body weight gains, live body measurements and metabolic trials, concluded that apple pomace can safely be included in the ration of animals.

Bae et al. (1994) compared a total mixed ration (AP-TMR) containing 39% apple pomace with conventional feeds (control). They observed that cows fed AP-TMR showed increased protein content but decreased lactose content in milk, when compared with cows fed the control diet. Milk fat and Solid not fat (SNF) were similar for both diets. Body weight of cows fed AP-TMR was also better as compared to control fed cows. The feed cost per kg milk production was higher with AP-TMR but the gross income (calculated as total milk cost minus total feed cost) was higher with AP-TMR than the control.

Biotransformation

Different microbial transformation of apple pomace have been proposed for obtaining valuable products like biogas (Lane 1979), ethanol (Hang et al. 1982), butanol (Voget et al. 1985), citric acid (Hang and Woodams 1986) and pectinases (Hours et al. 1988). Fermentable sugars in apple pomace such as glucose, fructose and sucrose can be converted to ethanol using yeast (Hang et al. 1981, Miller et al. 1982, Hang 1987). Ethanol is considered a possible alternative fuel source to supplement or totally replace petroleum (Coote 1983).

Kranzler and Davis (1981) studied the potential for recovering energy from apple and grape juice processing wastes by means of biomass conversion technologies. Results indicated that thermo chemical conversion and anaerobic digestion could provide all or a substantial portion of the plant produced by micronization of the pomace and by adding SO_2 (60 ppm) and vitamin C (500 ppm), thereby synergistically counteracting oxidation of phenolic compounds, which is a limiting factor in bioconversion. A solid state fermentation system for production of ethanol from apple pomace with a strain of *Saccharomyces cerevisiae* was described by Hang et al. (1982). Yield of ethanol varied from about 29 to 40 g/kg pomace, depending on samples fermented. Separation of up to 99% of ethanol from spent apple pomace was achieved with a rotary vacuum evaporator. Results indicated that alcoholic fermentation of apple pomace might be an efficient method of alleviating waste disposal problems with a concomitant production of ethanol.

Jewell and Cummings (1984) identified 2 processing systems for converting apple processing wastes into a beneficial resource. The first process involves the anaerobic digestion of pomace producing energy as biogas. Batch and pilot scale testing indicated that nearly 80% of the pomace organics could be converted into a substitute natural gas. The second process called "bio-drying" combined a high rate composting reactor with a low energy consuming dryer. They reported that operation of a full scale bio-drying system achieved wet pomace mass and volume reductions greater than 70% and produced a dried, stable, odourless product in less than 5 days.

Almosnino and Belin (1991) examined the possibility of obtaining C-6 (hexanal) and C-18 (2, 4-Decadienal) volatile aldehydes by degradation of linoleic acid (C-18 : 2, 9-12) under the action of intrinsic enzyme systems found in apple pomace. Crude β-fructofuranosidase homogenate was purified by ultrafiltration and gel filtration by chromatography. *Aspergillus foetidus* gave highest β-fructofuranosidase activity of 3 species examined. *A. foetidus* enzyme was stable over a pH range of 3.4–6.0 but lost 37 and 39% of its activity after 20 min at pH 3.0 and 6.6, respectively. Optimal enzyme activity was reported at pH 4.0 and 55°C.

Ngadi and Correia (1992) studied the solid fermentation of apple pomace with moisture contents of 77 and 85% (wet basis), mixing speed of 2, 20 and 40 rpm and *Saccharomyces cerevisae* (microorganism). Mean maximum ethanol concentration of 18.1 and 19.3% (dry basis) were obtained at 85 and 77% weight basis pomace moisture levels, respectively. Mean ethanol concentration of 10.8, 10.3 and 9.3% dry basis were obtained at bioreactor mixing speeds of 2, 20 and 40 rpm, respectively. Maximum ethanol concentrations were attained earlier at 2 and 20 rpm than at 40 rpm. A regression model for fermentation efficiency was fitted as a function of initial glucose and moisture content.

Bhalla and Joshi (1994) reported an increase in the nutritional value of apple pomace by co-culture of cellulytic fungi and yeasts in solid state fermentation and liquid state fermentation. Coculture of *Candida utilis* and *A. niger* was reported to be best out of several combinations on the basis of increased protein content of dried apple pomace and pectin extracted from apple pomace under solid state fermentation conditions.

The potential of apple pomace as a substrate for the production of β-fructofuranosidase synthesis by *A. fumigatus*, *A. foetidus* and *A. niger* was studied by Hang and Woodams (1994). *A. foetidus* produced more β-glucosidase on pomace than other 2 species yielding more than 900 units of β-glucosidase/kg of apple pomace fermented whereas *A. fumigatus* and *A. niger* produced only 48 and 73 units, respectively. The enzymes were purified by ultrafiltration and gel filtration with a yield of 480 g/kg. The purified enzyme was more active at 65°C and pH 4.6.

Hang and Woodams (1995) investigated the potential of apple pomace as a substrate for β-fructofuranosidase synthesis by *A. foetidus and A. niger* process heat requirements. Fermentation was reported to have minimal applicability. Rahmat et al. (1995) fermented apple pomace under solid state fermentation conditions by using the yeast *Kloeckera* *apicualta* or *Candida utilis* for increasing its protein content. A total crude protein content of 7.5% (w/w) was achieved after 72 h using either yeast. The concentration of essential amino acids in the modified apple pomace was 2 times that of the control.

Source of fiber

Chemical analysis of apple pomace has revealed that it is not only a good source of total dietary fiber but contains a significant amount of soluble dietary fiber which comprises of pectin (Shah and Masoodi 1994). Bielig et al. (1984) described a procedure for manufacture of bakery products with reduced energy content and increased fiber content. Dried and ground residue from juice extraction was added at levels up to 20% of finished product weight. Apple or its combination with pear is most commonly used for juice extraction. Pulps from stone fruits or berries may be used in certain products to achieve special flavours. The sugar content of pulp accelerated fermentation of dough resulting in reduction in the sour dough. Shelf life of bread was increased by at least 6 days. However, the brown colour of the pulp restricted its use in fine bakery products to a maximum of 5%.

Patt et al. (1984) added apple pomace powder at 5–10% to bread (wheat, rye and mixed) to reduce energy content. Baking tests showed that apple powder, which is not as expensive as flour, can be used to enrich bread with fiber and for acidity control as a sugar substitute in the bread formulations using rye or mixtures of rye and wheat flour. Walter et al. (1985) subjected apple pomace to a mild alkaline degradation which yielded an alfa-cellulose fraction of approximately 26% of the untreated dry matter. Extraction by various aqueous solvents yielded water dispersible, uronide fractions comprising 10–18% of the untreated dry matter. The latter fibers had a viscometric character, depending on the extractant used. All the fibers have the potential to provide non-nutritive bulk to low fiber, fabricated foods. Additionally, they may provide a high concentration of solid matter to an aqueous, food system without significantly altering the viscosity of the system.

Caprez et al. (1987) incubated yellow pea hulls and ground pomace for 4 h at 40°C with cellucast (5 or 10 g/kg) combined with either pectinex (for 2 g/kg) for pomace or pectinex ultra SP-L (1, 3 or 5 g/kg) for pea hulls. The material was then autoclaved to inactivate enzyme. Enzyme treatment increased the soluble fiber content by 100% or more, decreased total fiber content by approximately 20% and lowered the water uptake and water binding capacity. The treatment also improved sensory properties of pomace. The treated hulls and pomace can be used for increasing the dietary fiber content of various foods including pastry.

Chen et al. (1988a) added varying amounts of apple fiber and cellulose to wheat gluten and determined water-holding capacities (WHC) of different mixtures. A linear relationship between concentrations of 2 kinds of fiber and WHC was not observed, indicating a possible interaction between fiber and gluten which reduced the WHC of the mixture. Mixograph studies of wheat flour and fiber mixtures demonstrated that the dilution of gluten by fiber could not account for all the observed changes in mixing properties of the wheat flour/fibers blends. This is further evidence for a possible interaction of fiber and gluten which may explain the poor baking properties of apple fiber bread. Chen et al. (1988b) in another study characterized apple fiber by chemical and physical methods and reported that it is a good dietary fiber source and superior water binder to wheat and oat brans. Addition of 4% hydrated apple fiber to bread was reported to reduce loaf volume by 14%. Apple fiber could be added to cookies and muffins at 4% level without causing any adverse effect on the quality of cookies and muffins.

Wang and Thomas (1989) reported that sensory properties of muffins with 50% of the plain wheat bran substituted by powdered apple pomace were significantly more desirable than the control bran muffins. In addition, experimental moon cookies with flaked apple pomace substituted for 40% (w/w) of the all purpose flour in the crust and 40% (w/w) of the quick cooking oats in the filling were significantly more desirable than the control moon cookies. Carson et al. (1994) used pomace as an ingredient in pie fillings and oat meal cookies.

Miscellaneous use

Waugh (1981) identified potential uses of apple pomace as filler, extender and bulking agent and substitute of micro crystalline cellulose. Hinsch and Simon (1992) patented a process for utilization of wastes from apple peeling plants. Fresh apple peel and cores from apple peeling plants were comminuted to a pumpable pulp. This pulp may be stored under refrigeration for 8 days. The pulp was pressed to yield a juice which could be used for manufacture of apple concentrate and aroma.

Ramm et al. (1994) while conducting studies on extraction of waxes from dried apple pomace reported that yield of waxes was greater with solvents than with CO_2 and was increased further by depectinization and grinding with 90% ethanol but necessitated subsequent removal of water soluble components. Regardless of extraction method, all the waxes contained triterpenoids.

Conclusion

After processing apple into juice or juice concentrate, the left over material is pomace which is discarded causing environmental pollution. Since, apple pomace is a part of the fruit, it has potential for conversion into edible products. Being rich source of carbohydrate, pectin, crude fiber and minerals, it is a good source of nutrients. Efforts have been made in the past to utilize pomace in one or the other form but the problem of its utilization still persists. The large quantity of apple pomace produced suggests that the preparation of single product would not be economically feasible and production of alternative products should be explored.

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