



A review of opportunities to recover value from apple and pear pomace



FIGHT FOOD WASTE
Cooperative Research Centre
REDUCE - TRANSFORM - ENGAGE



Government of South Australia



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Industry partner foreword

As the South Australian (SA) Government agency whose role is to promote and facilitate a more circular economy in SA, Green Industries SA (GISA) relies on credible and focused targeted industry-led research.

This makes the work of the Fight Food Waste CRC (and SARDI) invaluable to GISA's evidence-based approach to policy and programme development leading to positive circular economy change.

The Fight Food Waste CRC project 'Options for utilising apple and pear pulp residue' allowed GISA to ascertain, via SARDI desk-top research, more recent overall market conditions and technology updates which encourage possible approaches to upvaluing this particular process residual waste stream.

Important next steps for the industry include providing low-risk options, such as pilot projects, for leading apple and pear growers/processors to explore the feasibility of the concepts presented in the report.

Executive Summary

There are currently more than 550 commercial apple and/or pear growers in Australia producing over 260,000 tonnes of apples and 100,000 tonnes of pears per annum. Whilst most of this fruit is sold fresh, approximately 30% is juiced. These juicing operations produce significant quantities of pomace (residual matter) as a by-product which can create a waste management issue for the operators. Apple and pear pomace are sources of many valuable compounds such as fibres, sugars and phenolics. The wet pomace is however highly perishable and has traditionally been used as a livestock feed supplement or sent to landfill.

In 2016 Green Industries SA commissioned the South Australian Research and Development Institute (SARDI) to review and provide a report on the potential options for use of this pomace to return value to South Australian producers and juicers. This project updates the original report by considering the whole of Australia apple and pear production and juicing sector, and reviews recent developments in end-product applications. Seven potential use categories were identified, namely as a feedstock for biofuels; compost and solid growth substrates; food industry applications; pet food and animal feed; nutraceutical and cosmetic applications; substrate for enzyme and fermentation products; and textiles, biodegradable consumer products and other biomaterials.

An analysis and assessment of various potential end-products was also undertaken to provide an idea of the cost-benefit opportunities that exist in an Australian context. Australian producers grow less than half a percent of the global apple and pear production. Consequently, competing in the production of any commodity-based products from Australian apple and pear pomace by small operators will be economically challenging. A co-operative approach or a stand-alone pomace processing facility fed by several processors may be a viable option for a commodity-based or novel product in growing marketspaces. Economic feasibility assessments are needed to be undertaken prior to considering any valorisation options for commercial developments.

| Objective(s) | Result(s) |
|---|--|
| Objective 1 - Provide an up to date analysis of the possible uses of apple and pear pomace residue. | A literature search has been conducted and seven potential use categories have been identified. |
| Objective 2 - Explore potential value-adding options available to maximise return from the resource. | Valorisation options have been explored and potential options have been assessed. |
| Objective 3 - Inform the state of technology readiness for options available and the relative cost of making that transformation. | State of technology readiness has been assessed and opinion on commercialisation of the product has been provided. |
| Objective 4 - Explore potential target markets. | Target market for each potential use have been identified. |

| Next Step(s) | Timing |
|---|---|
| It is anticipated that discussions will be held with key stakeholders to determine and agree on options for progression of pomace utilisation | As opportunities arise, dates unknown at this stage |

| Project Milestone | Addressed/ Unaddressed |
|--|--|
| Project Milestone 1.1: Update literature review of apple and pear pomace uses and technologies. | Completed |
| Project Milestone 1.2: Update Australian and regional area data on apple and pear production and juicing percentages. | Completed |
| Project Milestone 1.3: Update relative value and size of market of each potential value-adding stream output | Completed |
| Project Milestone 1.4: Insert new information on relative costs of each value-adding processing infrastructure | Completed |
| Strategic Alignment 2.1: Existing waste streams relevant to partner organisations surveyed. Market opportunities and food safety hazards identified. Near-market opportunities reviewed. | Market opportunities identified and reviewed. Some food safety hazards identified. |
| Strategic Alignment 2.3: Further waste streams relevant to partner organisations surveyed for both known and novel products. Further market opportunities and food safety hazards identified and reviewed. Intellectual property for new product solutions registered. | Not addressed/not applicable |
| Strategic Alignment 2.7: Technology needs for different waste streams and products reviewed. Existing technologies surveyed. Market opportunities for technologies identified. | Technology needs and market opportunities included (where known) |
| Strategic Alignment 2.13: Initial data set collated on waste composition, potential hazards and volumes relevant to partner organisations. Review of available relevant technologies delivered. Protocols developed and circulated. | Typical composition of apple and pear pomace identified from literature |
| Strategic Alignment 2.15: Techno-economic analysis of feed/product/process combinations delivered for project regions. | An analysis was undertaken that included the technical feasibility, process complexity and level of investment required to commercialise and manufacture various products, along with an assessment of the state of market, product yield and economic value of the end product. |

Project Impacts

This project will help inform relevant stakeholders (industry, researchers and other bodies) on the potential utilisation options for apple and pear pomace. Uptake of such options may potentially reduce the waste going to landfills and provide economic opportunities for the juicing sector.

Utilisation/Commercialisation Opportunities

Potential use categories for apple and pear pomace identified include:

- Biofuels
- Compost and growth substrate
- Food industry applications: including flours, pectin, aroma and flavour compounds, sweeteners
- Pet food and animal feed
- Nutraceutical and cosmetics
- Substrate for enzyme and fermentation products
- Textile and biodegradable tableware, biomaterials and bio packaging.

This project has not completed a formal techno-economic feasibility or identified if any option is commercially viable for Australian processors

IP

The final report is the only project IP developed - no formal protection has been sought.

Confidentiality

Not confidential

Approved By

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1. BACKGROUND

Commercial apple and/or pear growers in Australia produce over 260,000 tonnes of apples and 100,000 tonnes of pears per annum. Whilst most of this fruit is sold fresh, approximately 30% is juiced. Juicing operations produce significant quantities of pomace (residual solid matter) as a by-product which can create a waste management issue for the operators. In 2016 Green Industries SA commissioned the South Australian Research and Development Institute (SARDI) to produce a report on the potential options for use of this pomace residue to return value to South Australian producers and juicers. The report consisted of a literature review of published papers detailing the various options that Australian and international researchers have explored. It also reviewed the published data on compositional analysis of the pomace, as well as any yields and market value of components from the pomace.

However, new applications/end products for the pomace and initiatives to reduce waste through the supply/value chain has led to an opportunity to update the existing report and provide a whole of Australia apple and pear production/juicing sector context that is missing from the original document.

1.1 Project Objectives

There were four principle objectives to this project, namely:

- Provide an up to date analysis of the possible uses of apple and pear pomace residue
- Explore potential value-adding options available to maximise return from the resource
- Inform the state of technology readiness for options available and the relative cost of making that transformation
- Explore potential target markets.

The future utilisation of the findings from this report, specifically the implementation of food waste transformation strategies, may reduce the amount of apple pomace going to landfill, provide new sources of revenue and help Australia to half its food waste by 2030 in accordance with the United Nations Sustainable Development Goal 12.3.

This project also assisted the Food Waste CRC objectives:

2.1 Commercially Valuable Products from Waste

2.1 Existing waste streams relevant to partner organisations surveyed. Market opportunities and food safety hazards identified. Near-market opportunities reviewed.

2.3 Further waste streams relevant to partner organisations surveyed for both known and novel products. Further market opportunities and food safety hazards identified and reviewed. Intellectual property for new product solutions registered.

2.2 Commercial Prototype Technologies for Waste Transformation

2.7 Technology needs for different waste streams and products reviewed. Existing technologies surveyed. Market opportunities for technologies identified.

2.3 Framework to Optimise Viability of Technology and Waste Input Combinations

2.13 Initial data set collated on waste composition, potential hazards and volumes relevant to partner organisations. Review of available relevant technologies delivered. Protocols developed and circulated.

2.15 Techno-economic analysis of feed/product/process combinations delivered for project regions.

2. METHODOLOGY

A desktop study was undertaken to describe and characterise apple and pear juicing waste residues and identify the various uses and potential uses of the components, including likely target markets and potential monetary values; where possible. Keywords/phrases used in search terms included 'apple pomace', 'pear pomace', and 'valorisation'. Snowball searches were subsequently undertaken from scientific and grey literature.

The review also considered fruit production and juicing statistics in order to identify if Australia had any competitive advantage. Institutes that contained either 'apple pomace' or 'pear pomace' in the title of scientific publications were also identified and these results are summarised in Appendix 1.

Each of the identified potential uses were then evaluated against the scoring criteria outlined in Table 1. The maturity of the technology were gauged against the technology readiness levels using the benchmarking tool in Table 2.

Table 1. Assessment table for potential uses identified. Adapted from Wrap Cymru UK (2017).

| Criteria | Description of criteria |
|--|---|
| Technology Readiness Level | Assessment of the maturity of the technology (as per Table 2) required for each particular end-product/application |
| Process complexity | Assessment (low-medium-high) of the complexity of the processes involved for the production of particular end-product/application |
| State of market | Assessment of the size (low-medium-high) and trajectory of markets in Australia and or globally for each particular end-product/application |
| Product differentiation | Assessment of any likelihood of novelty, differentiation, disruption (cost), or specific benefit derived from any particular by-product utilisation |
| Economic value of end-product | Assessment of the economic value (low-medium-high) of product or ingredient derived from the pomace and potential scale of production from by-product |
| Product yield | Assessment of the yield (low-medium-high) of whole pomace product or ingredient derived from pomace that is or has a potential to be used in another market product |
| Level of investment to manufacture and commercialise a product | Assessment of investment costs (low-medium-high) involved (such as resource input, equipment energy, water, materials, logistics etc.) to manufacture product from pomace and to commercialise it |
| Residues | Assessment of any residue after pomace utilisation and its potential secondary use or destination |

Table 2. Technology readiness levels. Adapted from Wrap Cider Report (Wrap Cymru UK 2017).

| Technology Readiness Level | Basis for score |
|-----------------------------------|---|
| TRL1 | Basic principles observed and reported |
| TRL2 | Technology concept and /or application formulated |
| TRL3 | Analytical and experimental critical function and /or characteristic proof of concept |
| TRL4 | Analytical basic validation in a laboratory environment |
| TRL5 | Technology basic validation in a relevant environment |
| TRL6 | Technology model or prototype demonstration in a relevant environment |
| TRL7 | Technology prototype demonstration in an operational environment |
| TRL8 | Actual technology completed and qualified through test and demonstration |
| TRL 9 | Actual technology qualified through successful mission operations |

3. RESULTS AND DISCUSSION

3.1 Global Apple and Pear Production

Australian apple and pear production accounts for less than 0.5% of the global production. In 2018, Australian apple production in 2018 was approximately 268,000 tonnes compared to global apple production of around 86 million tonnes (FAO 2019). The limited scale of apple and pear production in Australia is apparent by reviewing in Figure 1 and Figure 2, respectively.

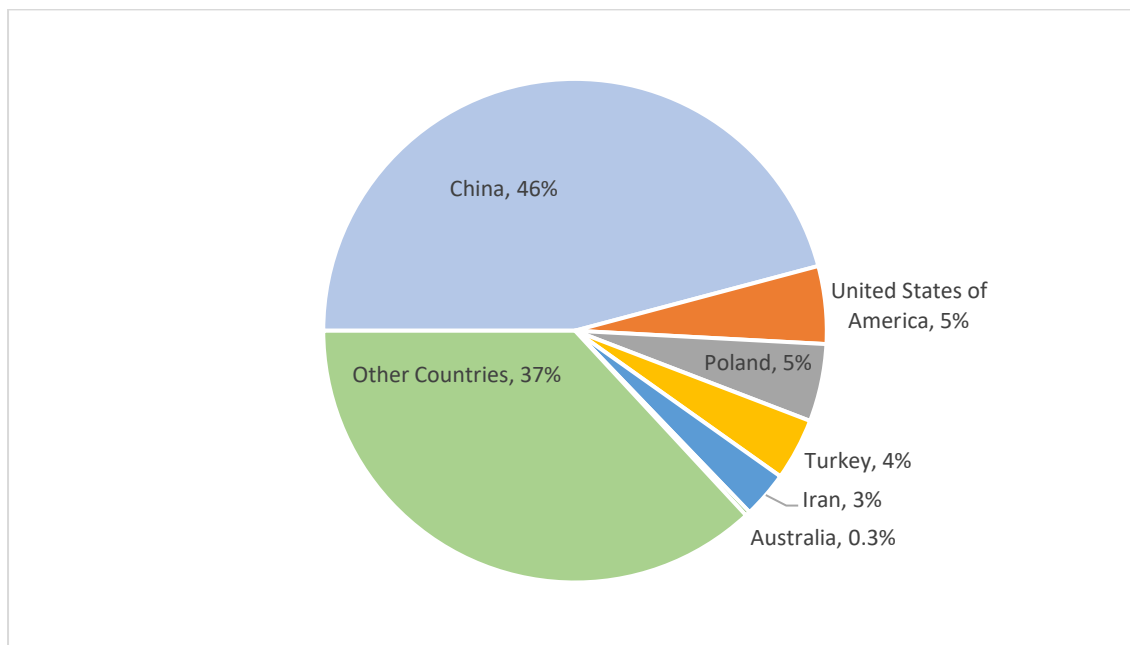


Figure 1. Apple production from top five countries plus Australia; values reported as percent of global production in 2018. Adapted from FAO (2019).

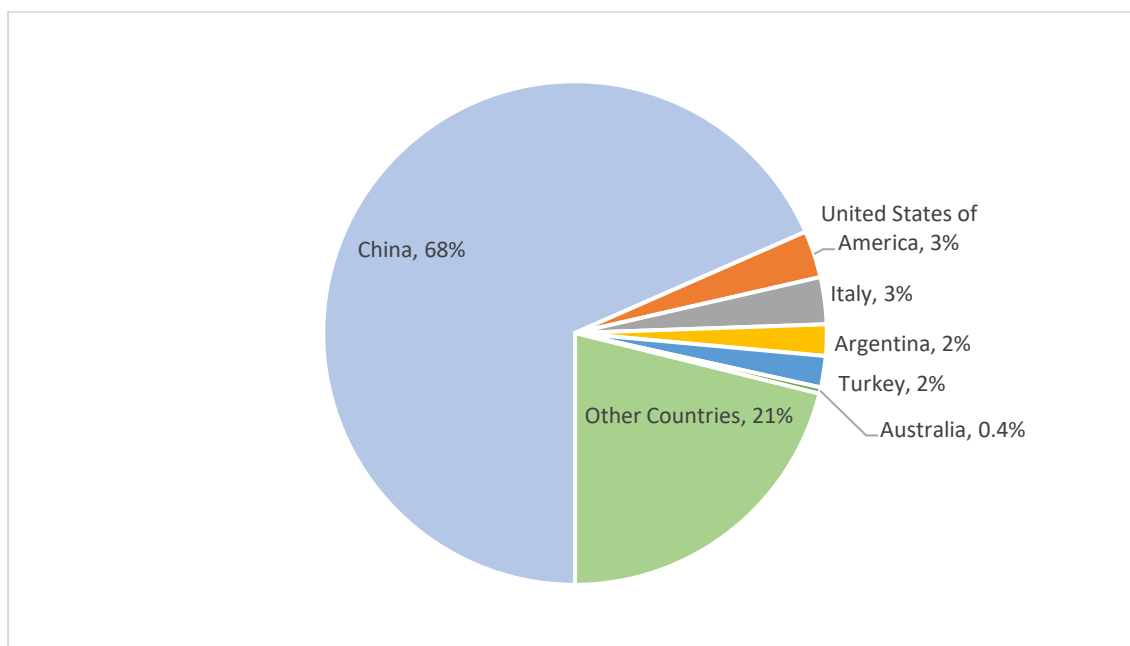


Figure 2. Pear production from top five countries plus Australia; values reported as percent of global production in 2018. Adapted from FAO (2019).

3.2 Production and Juicing Statistics in Australia

Australia apple and pear production and juicing data for the past seven years is shown in Figure 3 and Figure 4, respectively. This data demonstrates that production and juicing levels have been relatively steady over this timeframe.

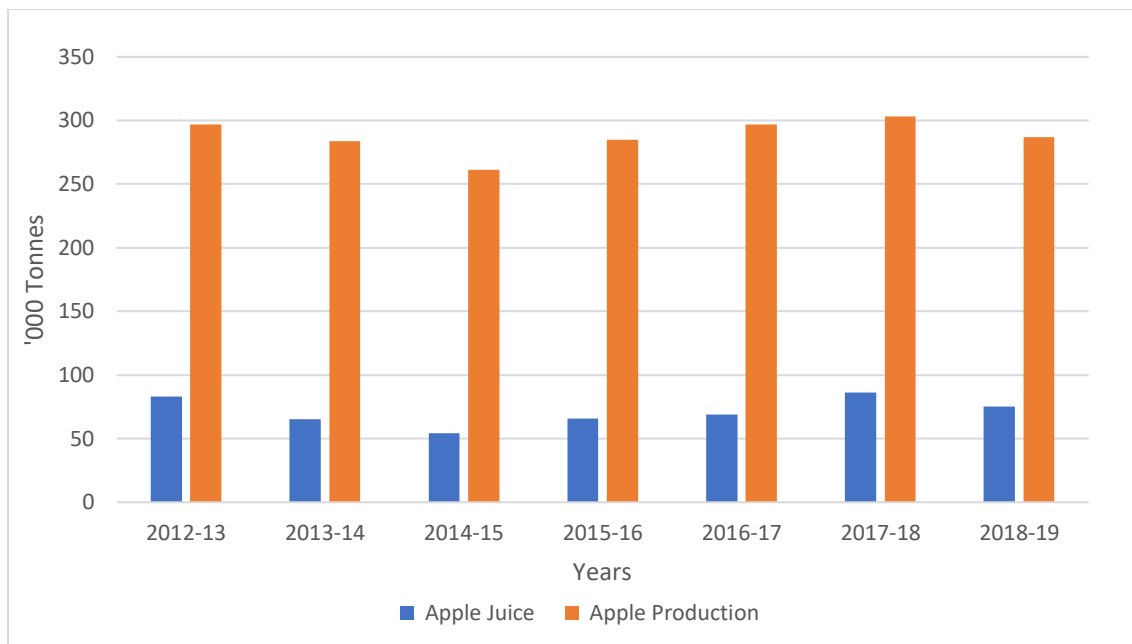


Figure 3. Total Australian apple production and juicing tonnage since 2012/13. Data sources: Department of Agriculture and Water Resources (2018), Department of Agriculture, Water and the Environment (2020).

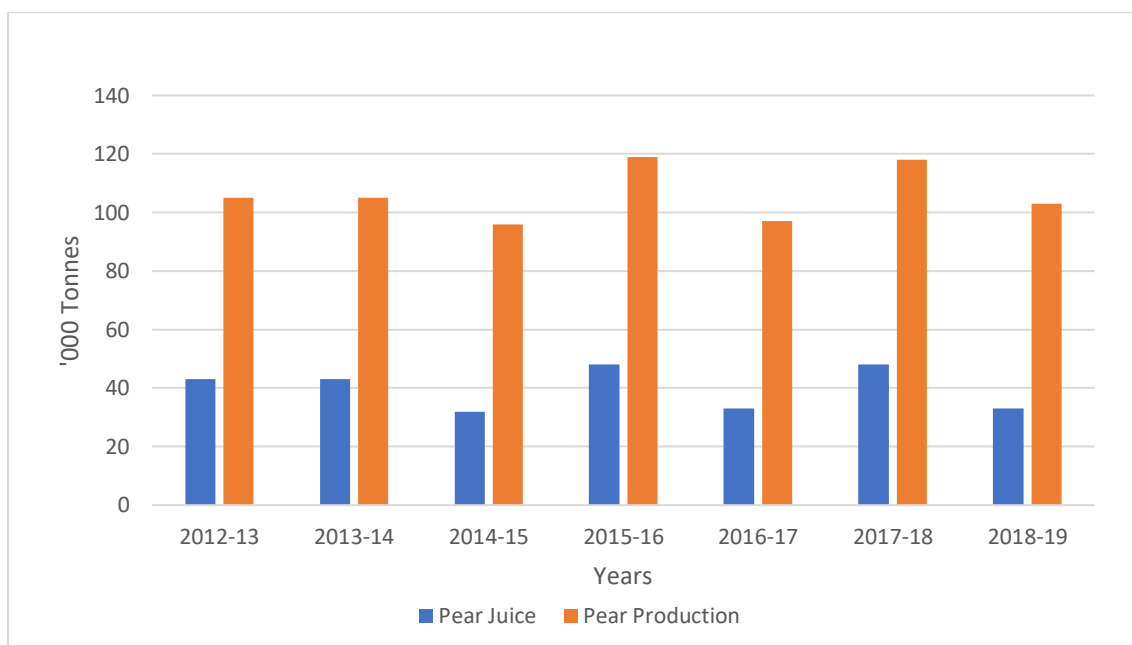


Figure 4. Total Australian pear production and juicing tonnage since 2012/13. Data sources: Department of Agriculture and Water Resources (2018), Department of Agriculture, Water and the Environment (2020).

It is noted that the production data from different sources (including Apple and Pear Australia Limited (APAL), Food and Agriculture Organisation of the United Nations (FAO) and the Australian Bureau of Agricultural and Resource Economics (ABARES)) have some discrepancies in absolute values. For example, in 2018/19 the Australian apple production was approximately 287,000 tonnes (Department of Agriculture, Water and the Environment (2020); see Figure 3), whereas Hort Innovation (2020) reported that approximately 310,000 tonnes were produced, valued at \$513M farm-gate. Discrepancies in volume and value are due to how the information is obtained by the respective bodies.

In Australia, most of the apples and pears are consumed domestically as fresh produce. Approximately 30% of the Australian apple and 34% of Australian pear production is processed into juice and ciders and other processing outlets such as jams, jellies and other confectionary-based products, and a small proportion (approximately 1% apples and 8% of pear production) is exported (APAL 2019).

3.3 Geographical Distribution of Apple and Pear Production in Australia

There are approximately 563 commercial apple and pear growers in Australia (Hort Innovation 2017). Different varieties of apples and pears are grown in different states of Australia. The ripening times for different varieties grown in different parts of the country and use of cold-storage and other controlled atmosphere technologies facilities enables the supply of fresh apples and pears throughout the year. The major apple and pear growing regions in Australia are shown in Figure 5. Apples are harvested typically between the months of February and May.

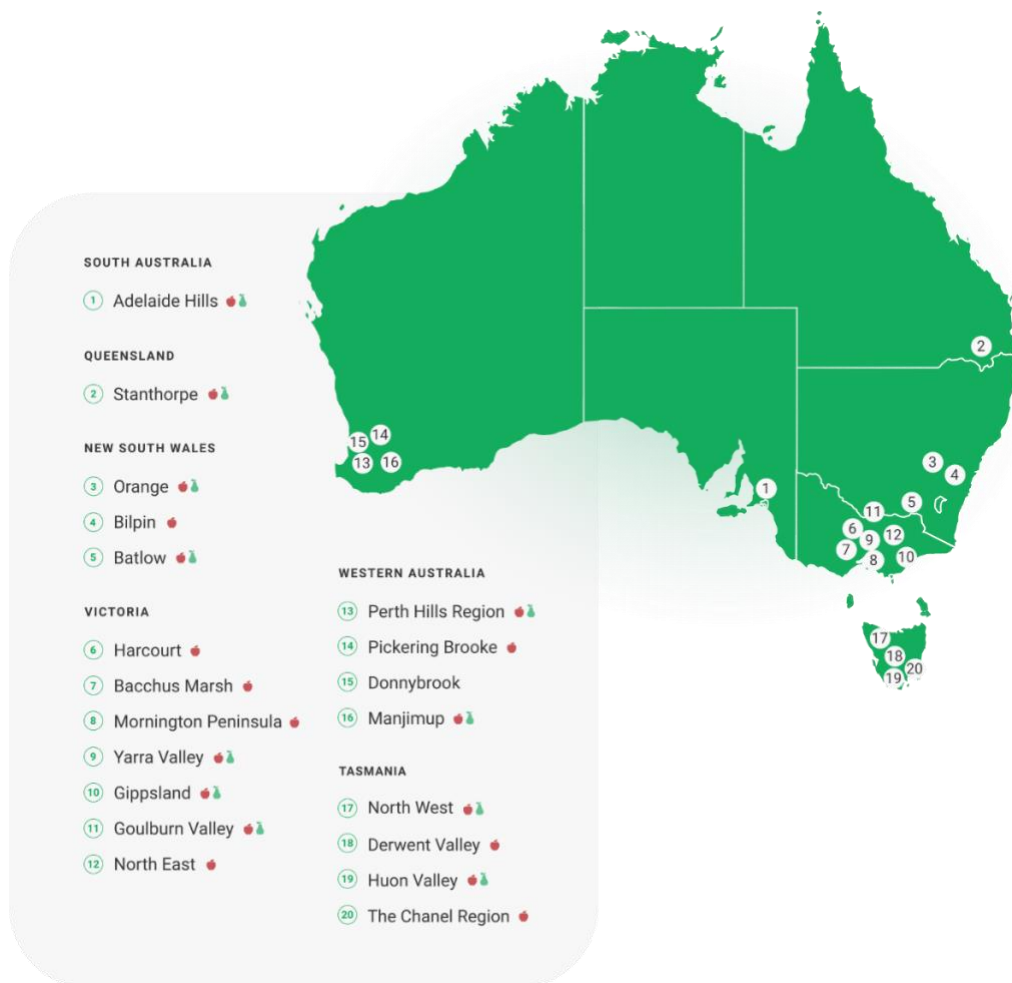


Figure 5. Major apple and pear growing areas in Australia. Reproduced from APAL (2019).

3.4 Statewide Production Statistics for Apples and Pears in Australia

There are many apple varieties grown across Australia, but Pink Lady, Gala and Granny Smith dominate the fresh market. The national breakdown in apple production for 2018/19 is shown in Figure 6. Victoria is the largest producer, accounting for nearly 50% of the nation's apple production, followed by NSW at 14%.

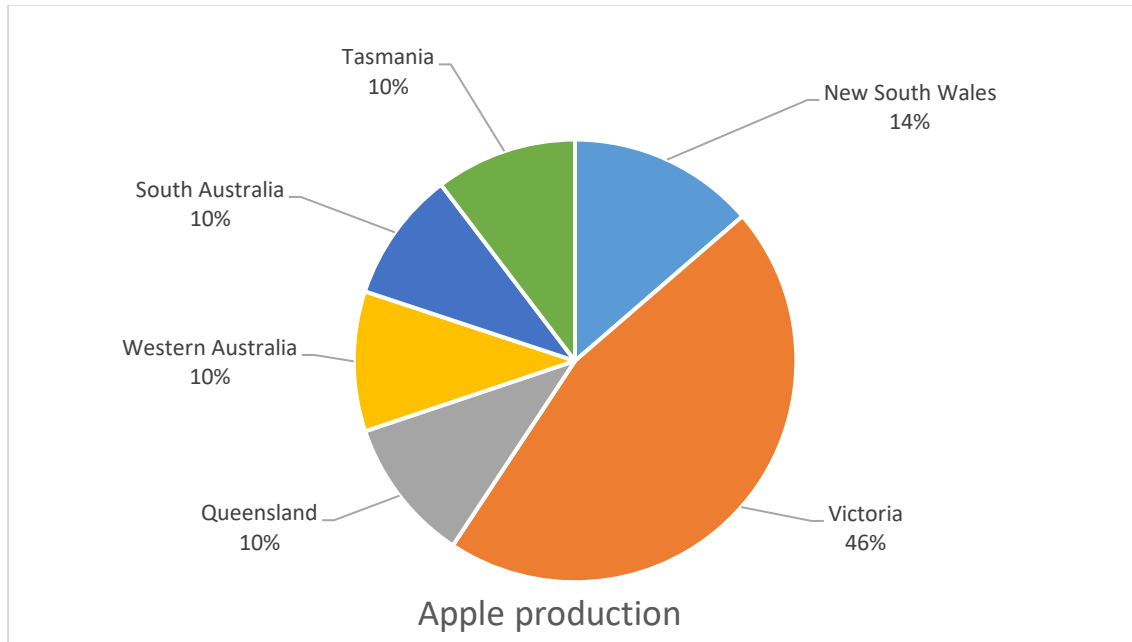


Figure 6. Apple production in Australia 2018/19 by each state. Data source: Hort Innovation (2020).

Pear production (excluding nashi) was 114,446 tonnes in 2018/19, with Victoria producing 90% of the total Australian production. The Australian Nashi Growers Association reports that around 4,500 tonnes of Nashi are produced in Australia (ANGA, 2000). The national breakdown for 2018/19 is shown in Figure 7.

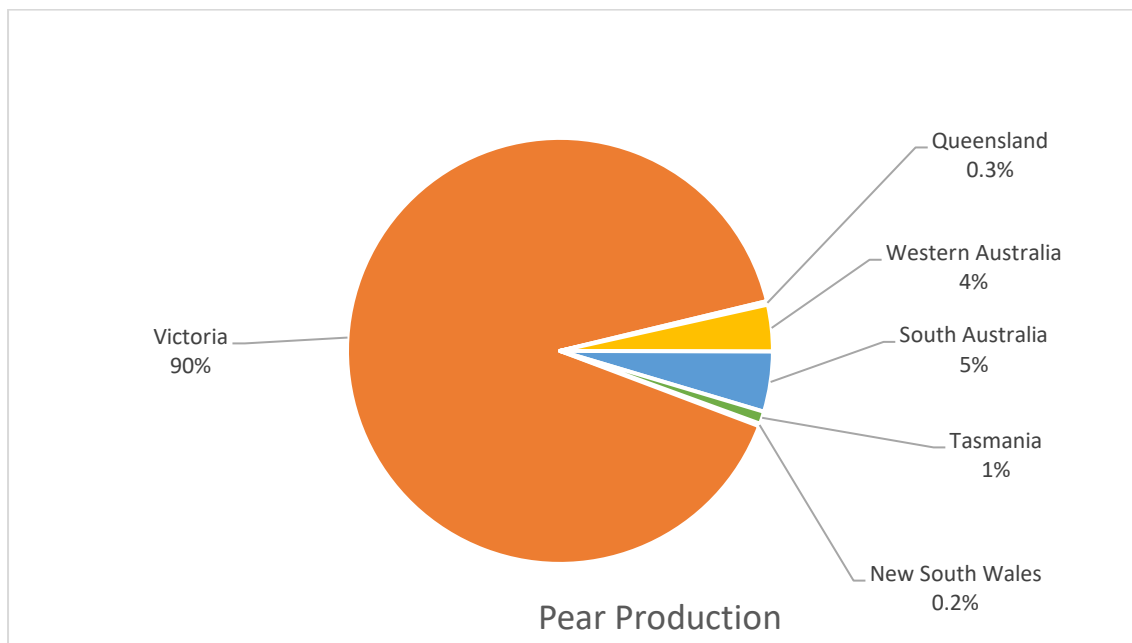


Figure 7. Pear production (excluding Nashi) in Australia 2018/19 by each state. Data source: Hort Innovation (2020).

3.5 Proximate Composition of Apple and Pear Pomace

The pomace is heterogeneous as it contains peel, core, seed, calyx, stem, residual juice and soft tissues (see Figure 8). Whilst there is limited information available regarding the composition of apple and pear pomace from Australian grown produce, the composition and characteristics of apple pomace has been reported in numerous overseas studies.



Figure 8. Typical image of apple pomace showing the heterogeneous nature. Reproduced from Orchard Groundcare (2019).

Even though global pear production is of the same order of magnitude as apple production, very few published studies were readily available that report on the composition of pear pomace.

Numerous studies have been conducted on the chemical composition of whole apples across the globe which point to a difference in the composition for different varieties and cultivars (Carbone, Giannini et al. 2011, Kalkisim, Ozdes et al. 2016, Zivkovic, Savikin et al. 2016, Oszmiański, Lachowicz et al. 2018, Tarko, Kostrz et al. 2018, Kim, Ku et al. 2019). Aside from varietal differences the composition of apple pomace is also influenced by the juicing process and technology (Kapoor, Panwar et al. 2016). An 'average' composition of apple pomace collated from various studies is shown in Figure 9. The composition of apple pomace from several other studies is reported in Table 3 and Table 4. Apple pomace is generally rich in carbohydrates, minerals, vitamins, dietary fibre and contains polyphenols which have antioxidant properties.

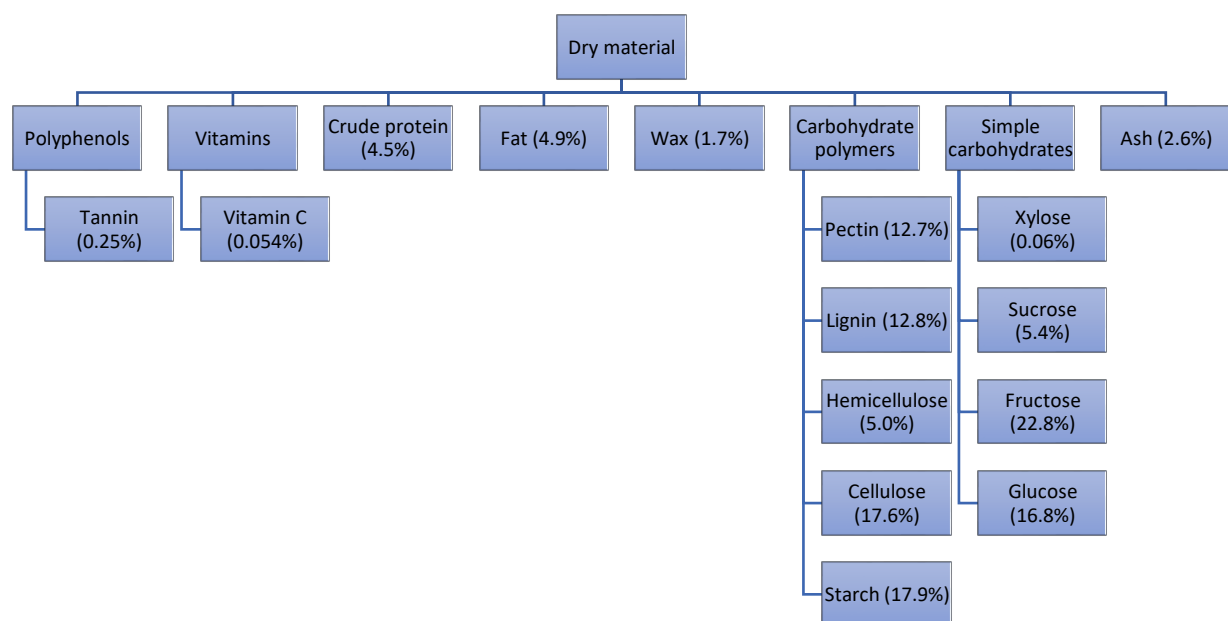


Figure 9. Summary of average composition of apple pomace. Summation of all components equate to 125%¹. Adapted from Kennedy, List et al. (1999).

¹ "The most likely source of error is the starch, fructose and glucose contents which vary widely depending on apple ripeness and cultivar. Another potential source of error is confusion related to reporting data on an "as dried" basis (24% water) or a "bone dry" basis (0% water). The data above is, however, a useful proximate summary of apple pomace" (Kennedy, List et al. 1999)

Table 3. Composition of apple pomace on wet weight basis. Adapted from Jewell and Cummings (1984).

| Water | Dry Matter | Carbohydrates | Proteins | Pectin | Fat | Fibre |
|------------|------------|---------------|----------|----------|----------|-------|
| 66.4-78.2% | 21.1% | 9.5-22% | 1.0-1.8% | 1.5-2.5% | 0.8-1.4% | 3.7% |

Table 4. Composition of apple pomace from Spain. Data reported on dry weight basis. Adapted from Hijosa-Valsero, Paniagua-Garcia et al. (2017).

| Carbohydrates | Cellulose | Klason lignin | Fats | Moisture | Protein | Ash | Phenolic compounds |
|---------------|-----------|---------------|------|----------|---------|------|--------------------|
| 55.9% | 21.2% | 18.5% | 1.4% | 6.6% | 4.9% | 1.3% | 3.5mg/g |

Table 5. Chemical and nutritional composition of apple and pear pomaces from Korea. Reproduced from Rebetika, Bachir, Aguedo, et al. (2014).

| | Apple pomace | Pear pomace |
|-------------------------------------|--------------|-------------|
| Chemical composition | | |
| Moisture (%) | 8.1±0.2 | 8.3±0.1 |
| Ash (g/100 g DM) | 1.4±0.1 | 0.9±0.1 |
| Protein (g/100 g DM) | 6.0±0.3 | 5.7±0.2 |
| Fat (g/100 g DM) | 2.5±0.1 | 3.7±0.1 |
| Free sugar (g/100 g DM) | 1.1±0.1 | 0.3±0.1 |
| Nutritional composition | | |
| Fibre, total (g/100 g DM) | 82.0±0.5 | 90.7±1.1 |
| Insoluble fibre, total (g/100 g DM) | 77.8±0.5 | 89.2±0.5 |
| Hemicelluloses | 16.4±0.5 | 28.5±1.2 |
| Cellulose | 42.4±1.2 | 38.8±1.1 |
| Lignin | 19.0±0.2 | 21.9±0.5 |
| Soluble fibre, pectens (g/100 g DM) | 4.2±0.1 | 1.5±0.1 |

The composition of apple and pear pomaces are similar; however, pear pomace generally contains more insoluble fibre and less soluble fibre. An alternative study found that total dietary fibre of pear pomace on dry weight basis was 43.9% and it was mainly contributed by pectin (7% DW) and lignin (5.2% DW), and protein content was found to be 3.8% and 5.4% ash (Martin- Cabrejas, Esteban et al. 1995).

Dietary fibres are often categorised as either soluble or insoluble fibres. Soluble fibres, such as hemicellulose, dissolve in water forming a gel that slows down movement of food in the digestive tract, helping the digestion process. Insoluble fibres, including cellulose, pectin and lignin, do not dissolve in water and rather provide physical bulk which helps speed up the removal of wastes from the bowel (Bhushan, Kalia et al. 2008, Varney 2016).

Apples are a rich source of polyphenolic compounds and phenolic compounds in apples are more concentrated in the skin (epidermal and subepidermal layers) than the whole fruit (Candrawinata, Golding et al. 2013).

The total phenolic content and antioxidant capacities of fat and water soluble extracts from apple, pear and grape marc (as a comparison) are reported in Table 6 and Table 7, respectively. These values from apple and pears are relatively low compared to some other commodities.

REFRESH is an EU led research program that is aiming to halve per capita food waste at retail and customer level and reducing food losses along production and supply chain by 2030 (REFRESH 2020). The research program has developed an online database to explore food waste streams including those from apple and pear production and processing. The database (available from www.foodwasteexplorer.eu) lists possible side streams with proximate and specific compositional data, and in some cases levels of undesirable components (i.e. pesticide residues, microbiological organisms, toxins, and other contaminants) and the original data sources.

Table 6. Total phenolic content of peel and seeds from various fruits (wet basis). Adapted from Deng, Shen et al. (2012).

| | Total phenolic content of peel (mg gallic acid equivalent/g) | | | Total phenolic content of seeds (mg gallic acid equivalent/g) | | |
|----------------|---|---------------------------|-----------|--|---------------------------|------------|
| | Fat-soluble fraction | Water-soluble fraction | Total | Fat-soluble fraction | Water-soluble fraction | Total |
| Apple, green | 2.8 ± 0.1 | 1.1 ± 0.0 | 3.9 ± 0.1 | 3.1 ± 0.4 | 0.5 ± 0.1 | 3.6 ± 0.5 |
| Apple, red | 3.0 ± 0.2 | 1.3 ± 0.2 | 4.4 ± 0.4 | 3.4 ± 0.2 | 1.1 ± 0.1 | 4.5 ± 0.2 |
| Pear, fragrant | 2.8 ± 0.1 | 0.9 ± 0.1 | 3.7 ± 0.1 | 2.8 ± 0.2 | 0.6 ± 0.0 | 3.4 ± 0.2 |
| Pear, crystal | 3.0 ± 0.2 | 0.6 ± 0.0 | 3.6 ± 0.2 | 4.2 ± 0.1 | 1.0 ± 0.1 | 5.2 ± 0.2 |
| Grape, USA | 5.9 ± 0.3 | 2.3 ± 0.1 | 8.2 ± 0.4 | 12.1 ± 0.1 | 10.8 ± 0.9 | 23.0 ± 1.0 |

Table 7. Antioxidant capacity of peel and seeds from various fruits (wet basis). Adapted from Deng, Shen et al. (2012).

| | Antioxidant capacity of peel (ferric-reducing antioxidant power; µmol Fe (II)/g) | | | Antioxidant capacity of seeds (ferric-reducing antioxidant power; µmol Fe (II)/g) | | |
|----------------|--|---------------------------|------------|---|---------------------------|-------------|
| | Fat-soluble fraction | Water-soluble fraction | Total | Fat-soluble fraction | Water-soluble fraction | Total |
| Apple-green | 4.3 ± 0.2 | 6.2 ± 0.3 | 10.5 ± 0.4 | 3.2 ± 0.1 | 2.3 ± 0.2 | 5.5 ± 0.3 |
| Apple-red | 4.5 ± 0.4 | 6.9 ± 0.7 | 11.3 ± 1.1 | 4.1 ± 0.6 | 3.9 ± 0.2 | 8.0 ± 0.7 |
| Pear -fragrant | 8.1 ± 0.2 | 7.1 ± 0.2 | 15.2 ± 0.5 | 4.4 ± 0.2 | 4.5 ± 0.4 | 8.9 ± 0.6 |
| Pear -crystal | 5.0 ± 0.2 | 4.7 ± 0.4 | 9.6 ± 0.6 | 16.3 ± 0.6 | 6.9 ± 0.7 | 23.2 ± 1.3 |
| Grape -USA | 21.3 ± 2.2 | 13.7 ± 0.5 | 35.0 ± 2.7 | 85.4 ± 2.1 | 96.0 ± 4.9 | 181.4 ± 6.9 |

Apple seeds constitute 2-3% of pomace weight (Kennedy, List et al. 1999). Whilst there is no information readily available on the fraction of pear seeds in pear pomace, it is expected to be of a similar magnitude to apple pomace (Kennedy, List et al. 1999, Seberry, McCaffery et al. 2017, Yukui, Wenya et al. 2009).

3.6 Potential Uses

Globally, apple pomace has traditionally been fed to farm animals or used in composting as a way of ridding this waste. After juicing the pomace is moist and is prone to rapid spoilage (Shalini and Gupta 2010). Pomace is often considered to be a poor animal feed supplement because of its relative low protein and vitamin levels and high carbohydrate content (Vendruscolo, Albuquerque et al. 2008, Ajila, Sarma et al. 2015).

Numerous studies (see Kosseva 2013, Dedenaro, Costa et al. 2016, Perussello, Zhang et al. 2017, Yates, Gomez et al. 2017, Kumar, Bhardwaj et al. 2020) have been published on the potential valorisation and utilisation of apple pomace, however, very few applications have been commercialised, and many of those are limited in scale. Functional properties such as pectin gel encapsulation (Miceli-Garcia 2014), antioxidant properties of phenolic compounds (Candrawinata, Golding et al. 2014) etc. have led to the development of many nutraceutical and value-added products worldwide.

In 2017, WRAP (the Waste and Resources Action Programme in the UK) reviewed the opportunities to get more value from apple pomace and cider lees. WRAP research suggested that no pomace from the UK was sent to landfill, with the majority (31,000 tonnes) sent for animal feed and anaerobic digestion (Wrap Cymru UK 2017). WRAP subsequently identified five high priority opportunities for apple pomace, namely ciderkin (a weak alcoholic cider), flavour/aroma compounds, pet food ingredients, fruit tea ingredients and high valued chemicals (pectin). No direct comparison can be made with Australian pomace due to lack of data. Apple and pear pomace can be used for various products and applications as shown in Table 8.

High levels of moisture (approximately 80%) in fresh pomace make it prone to microbial and enzymatic deterioration, demanding either onsite operations, stabilisation (such as dehydration) and/or refrigerated storage and transport, or rapidly transported from its origin for further processing. For small scale juicing operators, processing the pomace for some value-added products may not be a viable option. A cooperative type approach within regions or a larger-scale resource recovery and processing facility may be an alternative option where the small- to large-scale juicing operators can manage their pomace more economically. Due to long distances between regions (see Figure 5) the transport of pomace between regions is unlikely to be economically viable.

Table 8. Summary of potential use assessment for apple and/or pear pomace products.

| Potential use | Technology Readiness Level | Process complexity | State of market | Product differentiation | Economic value of the end-product | Product yield | Level of investment to commercialise and manufacture and product | Residue remaining and potential secondary use |
|--|----------------------------|--------------------|-----------------|-------------------------|-----------------------------------|---------------|--|---|
| Biofuels | | | | | | | | |
| Bio-alcohols | TRL4 | High | Growing | Unlikely | Low | Low | Medium to high | Yes, compost or landfill |
| Biomethane | TRL9 | Medium | Growing | Unlikely | Low | Low | Medium to high | Yes, compost or landfill |
| Compost and solid growth substrate | | | | | | | | |
| | TRL9 | Low | Growing | Unlikely | Low | Low | Low to medium | None |
| Food industry applications | | | | | | | | |
| Aroma compounds/Flavour compounds/Seed oil | TRL9 | High | Low to medium | Likely | High | Low | Low to high | Yes, compost or landfill |
| Pectin | TRL9 | Medium | Low to medium | Likely | High | Medium | Medium | Yes, compost or landfill |
| Flours (including fermented flour) | TRL9 | Low to medium | Low to medium | Likely | Medium to high | High | Low to high | None for flour Yes, compost or landfill for fermented flours |
| Pet food and animal feed | | | | | | | | |
| Animal feed | TRL9 | Low | Steady | Unlikely | Low | High | Low | None |
| Pet feed and diet formulations | TRL9 | Medium to high | Growing | Unlikely | Medium to high | Variable | Low to medium | No residue in most cases |
| Nutraceutical and cosmetic applications | | | | | | | | |
| | TRL9 | High | Growing | Yes | High | Low | Medium to high | Yes, compost, animal feed or landfill |

| Potential use | Technology Readiness Level | Process complexity | State of market | Product differentiation | Economic value of the end-product | Product yield | Level of investment to commercialise and manufacture and product | Residue remaining and potential secondary use |
|--|----------------------------|--------------------|-----------------|-------------------------|-------------------------------------|---------------|--|---|
| Substrate for enzyme and fermentation products | TRL3&4 | Low to high | Growing | Unlikely | Variable depending upon the product | Low to medium | Variable depending upon the product | Yes, compost, animal feed or landfill |
| Textile, biodegradable consumer products and other biomaterials | | | | | | | | |
| Biodegradable and biomaterials | TRL6 | Medium to high | Growing | Likely | Low to medium | Low to medium | Medium | No |
| Textile based products | TRL9 | High | Growing | Yes | High | Low to medium | Medium -High | Yes, compost, animal feed or landfill |

3.6.1 Biofuels

Apple pomace contains simple sugars that can be fermented to produce various alcohols such as ethanol (Hang, Lee et al. 1981, Vendruscolo, Albuquerque et al. 2008). Ethanol is considered a renewable and sustainable biofuel that is usually blended with petrol (United Petroleum 2020). Manildra Group (uses livestock grains (Manildra Group 2020), CSR Limited (uses sugarcane production biomass (CSR Limited 2020) and Dalby Bio refinery of United Petroleum (uses grains-sorghum (United Petroleum 2020) are the major ethanol producers in Australia.

The Australian Renewable Energy Agency recently funded a pilot project with New South Wales based Ethanol Technologies Ltd to demonstrate ethanol production using waste or low value products including sugarcane bagasse, forestry residues and cotton gin trash (Australian Renewable Energy Agency 2017, Ethtec 2019). The largest challenge for the refining sector that is intending to use waste materials is often logistics. Most juicing operations in Australia are relatively small and will be unlikely to sustain refinery operations on their own. Wet pomace will need to be either dried, pelleted, cold stored and/or transported to a centralised facility (Hang, Lee et al. 1981, Joshi and Devrajan 2008, Edwards and Doran-Peterson 2012, Magyar, Costa Sousa et al. 2016, Bioenergy Insight 2020).

Biobutanol is another biofuel that can be produced from apple pomace. However, biobutanol production processes are complex, and yields are low compared to petrochemical-based processes (Voget, Mignone et al. 1985, Hijosa-Valseo, Paniagua-Garcia et al. 2017, Maiti, Gallastegui et al. 2018).

High moisture and sugar levels in the apple pomace also make it a suitable feedstock for anaerobic digestion to produce methane gas (Jewell and Cummings 1984, Kalia, Kumar et al. 1992). Whilst this methane can be captured and sold as a commodity, for smaller processors it is often used on-site to reduce other energy costs. Biomethane is recognised as a renewable energy source and can be used for the same end consumer applications as natural gas. It is possible to also combine domestic and agricultural wastes (including waste from various fruit industries) as feedstock for anaerobic digestion systems (Bhatia, Ramadoss et al. 2020).

Some of the current biofuel prices are reported in Table 9 and the potential use assessment of bio-alcohols and biomethane are reported in Table 10 and Table 11, respectively.

Table 9. Examples of bioethanol and butanol available in markets and prices.

| Product | Company | Product format | Price | Link |
|------------|--------------------|---------------------------------|------------|---|
| Bioethanol | Biolume, Australia | Denatured ethanol | 20.0 AUD/L | https://www.biolume.com.au/ |
| Bioethanol | e-NRG, Australia | Fuel for 'vent-less' fireplaces | 4.75 AUD/L | https://e-nrg.com.au/ |
| Butanol | Echemi.com, USA | Industrial grade | 0.79 USD/L | https://www.echemi.com/products/Information/pid_Seven2824-butanol.html |

Table 10. Potential use assessment of bio-alcohols (i.e. ethanol and butanol) from apple and/or pear pomace.

| Criteria | Assessment |
|--|---|
| Technology Readiness Level | TRL-4. Apple pomace has been demonstrated as a feedstock for raw materials required for biofuel production |
| Process complexity | High complexity – requires optimization of fermentation/enzyme and often used in a mix with other feedstocks |
| State of market | Bioenergy is trending globally to reduce environmental footprint from fossil fuels but needs to be economically competitive |
| Product differentiation | Unlikely to exhibit any differentiation in the marketplace |
| Economic value of end-product | Medium value and low production volumes from apple pomace when compared to other available feedstocks |
| Product yield | Low |
| Level of investment to manufacture and commercialise a product | Medium to high |
| Residue | Residues most likely only suitable for compost or landfill |

Table 11. Potential use assessment of biomethane from apple and/or pear pomace.

| Criteria | Assessment |
|--|--|
| Technology Readiness Level | TRL-9. Apple pomace combined with other feedstocks is currently used to produce methane through anaerobic digestion processes. |
| Process complexity | Medium complexity – pomace can be used without pre-treatment but needs to be combined with other feedstocks to achieve a suitable C/N ratio. |
| State of market | Bioenergy is trending globally to reduce environmental footprint from fossil fuels but needs to be economically competitive |
| Product differentiation | Unlikely to exhibit any differentiation in the marketplace |
| Economic value of end-product | Low value and low production volumes from apple pomace when compared to other available feedstocks |
| Product yield | Low |
| Level of investment to manufacture and commercialise a product | Medium to high |
| Residue | Some biosolids for compost or landfill |

3.6.2 Compost and solid growth substrates

Apple pomace is organic material and has been used in composting as way of ridding this waste (Vendruscolo, Albuquerque et al. 2008, Ajila, Sarma et al. 2015). Compost is a low valued product that often retails for between \$0.10-\$0.36/kg. Apple pomace is also considered to be a suitable feedstock for earthworms (Hanc and Chadimova 2014). Soil amendments using apple pomace have shown positive impact on soil fertility by improving the total organic matter, total nitrogen and some minerals in the soil (Yilmaz and Alagoz 2009). The utilisation of apple pomace as a key substrate for the growth of Shitake and oyster mushroom has also received some attention (Worrall and Yang 1992). The production of mushrooms through this solid substrate fermentation can enhance the nutritional value of the spent materials by improving lignocellulose digestibility (Mahesh and Mohini

2013). The potential use assessment of compost and solid growth substrates are reported in Table 12.

Table 12. Potential use assessment of compost and solid growth substrates from apple and/or pear pomace.

| Criteria | Assessment |
|--|--|
| Technology Readiness Level | TRL 9. Composting is well established technology and uses mixed feedstocks |
| Process complexity | Low |
| State of market | Demand for compost products is dominated by urban amenities/home gardeners. Expected to grow. |
| Product differentiation | Nil - Compost is made from a mixture of organic materials |
| Economic value of end-product | Low |
| Product yield | Low production volumes from apple pomace when compared to other available feedstocks |
| Level of investment to manufacture and commercialise a product | Low – apple pomace could be directed to existing facilities. Requires transport and logistics. |
| Residue | None |

3.6.3 Food industry applications

Apple pomace is a potential source of dietary fibres consisting approximately 45-60 % of wet weight including 5.5-11.7 % pectin (Bhushan and Gupta 2013). Apple fibre can have several functional properties including enhancing water and oil retention, to improve emulsion or oxidative stabilities, improve the viscosity, texture, sensory characteristics and shelf-life of the food product (Elleuch, Bedigian et al. 2011). Fibres from cooked apple pomace can be used as textural ingredients due to enhanced physicochemical properties such as water holding capacity or as functional foods (Rabetafika, Bchir et al. 2014). Besides food technological properties increasing the fibre content in foods can also improve their healthiness (Wu, Sanguansri et al. 2014).

Pomace can be dried and used as a crude ingredient or undergo further processing to improve its physical and textural properties. The extraction of fibre generally involves a leaching step to remove soluble sugars. The fibre can undergo additional processing to decolourise, however, unbleached pomace fibre can also be utilised as a food ingredient. A study has shown that apple pomace fibre can be used to reduce fat content from 30 to 20 % in uncured chicken sausages providing healthier alternative to fat (Choi, Kim et al. 2016).

Main manufacturers of apple fibre ingredients include:

- EZ Organic Shop (Australia)
- J. Rettenmaier Söhne (Germany)
- Herbafood Ingredients GmbH (Germany)
- Tree Top Ingredients (USA)
- Hawkins Watts Australia Ltd (Mulgrave, Vic) are the national distributors for Herbafood Ingredients GmbH (www.herbafood.de). The range of ingredients includes:
 - The Herbasweet range of Apple sweeteners (high fructose)
 - The Herbarom range of apple (high polyphenol content)
 - The Herbacel range of fibre-rich apple extracts

Pectin is a family of complex variable polysaccharides extracted from the primary cell wall of higher plants and traditionally used in jam, jelly and confectionary making (Canteri-Schemin, Fertoni et al. 2005). It is widely used in yogurts, bakery products, mayonnaise, salad dressings, tomato ketchups, protein foams, and beverages. Using apple pomace for pectin extraction is considered the most practical and economical solution to utilise this by product (Bhushan, Kalia et al. 2008, Miceli-Garcia 2014).

Botanical Innovations based in Orange, NSW Australia, has developed several value-added products including an Apple Sweetener from whole apples (see Figure 10), an apple cider vinegar and apple peel extract (Botanical Innovations 2020).



Figure 10. Award winning apple extract sweetener from Botanical Innovations.

Ethanol can be produced from the apple pomace and used in beverages (Magyar, Costa Sousa et al. 2016). Processing of one tonne of dry pomace will produce about 135kg of ethanol (Magyar, Costa Sousa et al. 2016).

A recent study by Juodeikiene et al (2019) investigated gel encapsulation properties in food and found that apple pomace-pectin hydrogels can be used as a carrier of probiotic bacterial cells as a functional ingredient for food (Catana, Catana et al. 2018, Juodeikiene, Zadeike et al. 2020).

Sensory Mill from Forbidden Foods collaborated with Bellevue Orchards, Victoria and Australian Dehydrated Food to initiate production of apple fibre from pomace in a patented process to promote and introduce Australia's first apple flour in Jan 2020 (Figure 11) to the market (Foodmag 2020, Forbidden Foods 2020, Sensory Mill 2020). It is anticipated that 800,000 kg waste produced each year will be converted into premium product for market instead of costly redistribution to farmers for feed or move to landfill. There is very limited information available regarding the retail cost of apple flour, however a gourmet retail supplier in the United States sells it for US\$40/kg and Sensory Mill sells it for AUD\$43/kg.

Apple flour can be blended with wheat flour and used for cookie, cake and muffin formulations (Sudha, V. et al. 2007, Zlatanovic, Kalusevic et al. 2019). Addition of 5-10% of apple pomace in raw noodles resulted in acceptable sensory qualities with high fibre content (Xu, Bock et al. 2020). Blends of apple and wheat flour have been shown to have poor bread baking quality whereas incorporation of fresh fibre concentrate from apple, pear and date pomaces enhanced the bread quality (Bchir, Rabetafika et al. 2014). A Danish apple juicing company produces dried apple granules from its residual pomace. These granules are sold commercially and can be used in various applications including baking, cereals and yogurts (Vesterhavsmost 2020).

Researchers at the University of Auckland, New Zealand have developed a low-calorie apple flour prototype by fermenting apple pomace (The University of Auckland 2015). The product, Ample Apple, is reportedly nutrient rich; high in protein, vitamins, dietary fibre, gluten free and low in cholesterol, fat and sugar and has the potential to replace wheat. The incorporation of an apple powder from pre-harvest dropped apples has also been shown to reduce the oil absorption index of apple/wheat flour blends (Kim, Kim et al. 2013).

A team of New Zealand scientists have successfully demonstrated a prototype hydrothermal treatment system to produce a creamed apple pomace that can then be used in various applications including a source of fibre, or as a spray-drying encapsulant. The hydrothermal treatment was demonstrated to kill microorganisms and deactivated enzymes, as well as solubilises pectins and soften cell walls. This process was recently showcased at the 13th International Congress of

Engineering and Food in Melbourne in 2019. An international engineering company (Aurecon) has been engaged to help commercialise the concept (Yedro, Eblaghi et al. 2018, Archer, Eblaghi et al. 2019).

Extrusion is high temperature and short time cooking technology which is widely used in grain-based food and feed products. Inclusion of apple pomace in grain-based cereals has also been successfully demonstrated as an option to utilise this nutritious waste (Singha and Muthukumarappan 2018, O'Shea, Arendt et al. 2013).

Apple and pear seeds can be separated from pomace by flotation or sieving and the oil recovered through traditional extraction techniques. A recent patent (Bhushan, Gupta et al. 2013) reports an apparatus for the separation of seeds from pomace through agitation and sedimentation techniques. The fatty acid content of apple and pear seed is higher than in soybean and can be used as edible oil (Yu, Li et al. 2005). The free radical scavenging activity and antimicrobial properties of apple seed oil can be used in pharmaceutical and food industry (Tian, Zhan et al. 2010).



Figure 11. Apple flour produced in Australian apple orchard by Sensory Mill.

More recently, apple seed oil been shown to exhibit cytotoxic activity and has potential as an anticancer agent (Walia, Rawat et al. 2013). Apple and pear seeds also contain amygdalin which if metabolised in the stomach and can produce hydrogen cyanide. The amygdalin content of apple and pear seeds are relatively low; typically, 3.0 mg/g and 1.3 mg/g, respectively (Bolarinwa, Orfila et al. 2014) and it is poorly metabolised from intact seeds. The effect of amygdalin is not cumulative and the lethal dose of amygdalin in humans is reported to be in the range of 9.15-59.5 mg/kg body weight (Solomonson 1981). Therefore, an individual would need to consume a significant quantify of apple seeds before any toxic effects are observed.

Flavourtech (www.flavourtech.com) have expertise in the recovery of apple essence through use of spinning cone counter-current liquid-gas contacting columns. Whilst apple and pear aroma compounds are used in cosmetics and as a natural food flavouring, the yields from apple pomace are very small (Kennedy, List et al. 1999). Several synthetic apple and pear fragrances are commercially available, and the scale of market demand of such natural compounds is unknown. Some food ingredients derived from apples are shown in Table 13 and the potential use assessment for food industry applications are reported in Table 14.

Table 13. Apple products available in market as food ingredients.

| Product | Company | Product format | Price (AUD) | Source |
|--------------------------|-----------------------------|-----------------|---------------|---|
| Apple Flour | Sensory Mill | Flour | \$43/kg | https://www.sensorymill.com.au/pages/apple-flour?gclid=EAlaIQobChMixoLb3Ori7AIVwX4rCh29HwUoEAAAYASAAEgL56_D_BwE |
| Apple seed oil | Botanical Innovations | Oil | Not available | https://botanicalinnovations.com.au/phenolic-and-nutrient-rich-cold-pressed-oils/cold-pressed-apple-seed-oil-2/ |
| Apple extract sweetener | Botanical Innovations | Food Ingredient | Not available | https://botanicalinnovations.com.au/plant-extracts/apple-syrup-flavour-sweetner/ |
| Apple pectin | Melbourne Food Depot | Powder | \$51/200g | https://www.melbournefooddepot.com/buy/pectin-apple-jam-powder-200g/F00789 |
| Apple natural flavouring | Baking Pleasures, Australia | Essence | \$7.95/50ml | https://bakingpleasures.com.au/s/apple-essence |
| Apple fragrance oil | Natures Flavors, USA | Oil | \$19.0/50ml | https://www.naturesflavors.com/organic-fragrance-oils/68358-apple-spice-fragrance-oil-oil-soluble-organic.html |

Table 14. Potential use assessment for food industry application from apple and/or pear pomace.

| Criteria | Assessment |
|--|---|
| Technology Readiness Level | TRL-9. Various ingredients derived from apple pomace are commercially produced in Australia and elsewhere |
| Process complexity | Aroma compounds/flavour compounds/seed oil – medium to high Pectin – high Flours - medium |
| State of market | Low to medium volume market – high amount of competition from mainstream and other alternative products |
| Product differentiation | Some products can be differentiated in the marketplace, potential to market as naturally derived or organic (if certified) |
| Economic value of end-product | Aroma compounds/flavour compounds/seed oil – high Pectin – high Flours – medium-high |
| Product yield | Aroma compounds/flavour compounds/seed oil –low Pectin – medium Flours – high |
| Level of investment to manufacture and commercialise a product | Low to high, depending on product type Aroma compounds – high capital investment but may be able to utilise existing facilities depending on logistical constraints. |
| Residue | De-pectinised waste and oilcake can be used as a feedstock/compost. No/minimal residue in flour production |

3.6.4 Pet food and animal feed

Wet pomace is often used directly as supplemental feed for various livestock. Redistribution of wet pomace to the farmers can be a costly option for juicing businesses (Foodmag 2020). Wet pomace is prone to rapid spoilage (Shalini and Gupta 2010) and is often considered to be a poor animal feed supplement because of its relatively low protein and vitamin levels and high carbohydrate content (Vendruscolo, Albuquerque et al. 2008, Ajila, Sarma et al. 2015).

Fermenting apple pomace will reduce its sugar content and increase the protein content. Fermented apple pomace (FAP) can replace 11% of alfa hay and soybean meal in sheep diet and it has been shown to improve meat quality in terms of pH, colour and less oxidation during storage (Alarcon-Rojo, Lucero et al. 2019). Protein enrichment of apple pomace by solid state fermentation has demonstrated a potential for its use as dietary supplement in pig feed. Inclusion of 5% w/w FAP in an experimental pig diet increased the protein content by 36% improving the animal performance (Ajila, Sarma et al. 2015). There is also a growing demand for more non-traditional feed sources including the use of fermented apple pomace to support the production of animal-based proteins in developing countries (Song, Xu et al. 2005).

Not only animal feed but the pet food industry has also explored uses of apple pomace. Inclusion of apple pomace up to 20% in a cat diet can reduce the energy content making it suitable for obese cats (Fekete, Hullar et al. 2001, Prest 2020). Apple fibre derived from freshly harvested and dried apples is used in an Australian pet food supplement to support digestive system (Natures Goodness 2020).



Figure 12. Apple pomace used in poultry feed mix sold online at Aussie Chook Supplies.

Pelleted animal feed is becoming a preferred option when it comes to stability, quality, handling and transport. A study on three model feeds has shown that adding 10 and 20% of apple pomace increased the pellet quality in term of durability, hardness and percentage of fine and bulk density (Maslovaric, Vukmirovic et al. 2017). Pelleted apple pomace is available in the international market and is currently imported to Australia for various feed formulations (Global Sources 2020, Trade Korea 2020). Apple pomace has been marketed as a source of prebiotic fibre which have been claimed to help improve egg production, shell quality and improves gut health of chooks (Aussie Chook Supplies 2020,

Figure 12). Examples of stabilised animal feed products that contain a high proportion of apple pomace are shown in Table 15 and the potential use assessments for pet and animal feeds are reported in Table 16.

Table 15. Example of stabilised apple pomace products for animal and pet feed that are available in the market.

| Product | Company | Product format | Price (AUD)/kg |
|----------------------------|---------------------------------------|-------------------------|----------------|
| Apple pomace and spice mix | Suburban Chooks (Australia) | Feed Ingredient | 40.0 |
| Apple pomace pellets | Shijizhang Yinniu Feed Company, China | Animal feed constituent | 0.30 |
| Dried apple pomace | Sanimax, US and Canada | Pet feed ingredient | No information |

Table 16. Potential use assessment pet food and animal feed applications from apple and/or pear pomace.

| Criteria | Assessment |
|--|---|
| TRL | TRL 9- Products available in the market |
| Process complexity | Pet foods and animal feed formulations – Medium to high Livestock feed – Low |
| State of market | The world population and growth of middle class in developing countries has led to an increase in global demand for animal products (e.g. milk, meat). Alternative to grain-based animal feed are in growing demand. Pet food and special pet diets are in increasing demand in developed countries. |
| Product differentiation | Not likely. Existing food sources are natural. May be differentiated as alternative or organic (if organic certified apples) |
| Economic value of end-product | Pet Foods and animal feed formulations – Medium to high Livestock feed – Low |
| Product yield | Variable- dried pomace applications (e.g. Pellets) and feed supplement – Low Direct consumption as livestock feed- High |
| Level of investment to manufacture and commercialise a product | Low to medium (most products require dried apple pomace) |
| Residue | No residue in most cases, fermented feed formulations will leave residue that can be used as compost or landfill |

3.6.5 Nutraceutical and cosmetic applications

Apples are amongst the biggest contributors of polyphenolic compounds in the human diet with significant benefits to health such as prevention of cancers and cardiovascular diseases (Boyer and Liu 2004, Scalbert, Johnson et al. 2005). Polyphenols responsible for antioxidant activity are present in the pomace and can be extracted for food fortification and use in nutraceutical products (Bhushan and Gupta 2013, Deng, Shen et al. 2012).

Most of these phenolic compounds are in the peel and don't make it into the juice when crushed. This makes fresh apple pomace a good source for these high quality and valuable compounds (Price, Prosser et al. 1999). Various chemical solvents such as methanol, ethanol and acetone have been used to separate the phenolics which carries an expense and environmental burden hindering industrial scale success (Ajila, Brar et al. 2011, Candrawinata, Golding et al. 2014, Candrawinata, Golding et al. 2015). Researchers from the University of Newcastle, NSW and co funded by NSW Primary Industries and Hort Innovation, developed an alternative and patented technology to separate phenolics from apple using water (Candrawinata, Golding et al. 2014). Examples of various products made with apple phenolics in Australia (shown in Figure 13) are available online and in Woolworth supermarket and also exported to Singapore, Malaysia and Hong Kong. It was reported that the main aim the University of Newcastle study was to not only find a better way to extract phenolics from apple but provide apple producers with an option to use rejected produce other than landfill or compost.



Figure 13. Apple phenolics rich Renovatio products sold online and at Woolworths food supermarket.

It is expected that similar nutraceutical and cosmeceutical products could be derived from pear pomace; however, there is significantly less information readily available in the public domain. Similar to apples, pear peels contain most of the phenolic compounds, however the concentration of phenolic compounds diminish as the fruit matures, and it has been reported that pear pomace from juicing operations becomes less suitable for phenolic compound extraction (Zhang, Koo et al. 2006)..



Figure 14. Example of apple pectin based dietary supplement. Product sold online at iHerb.com.

Pears have high levels of insoluble fibres and a water-based extract from pear pomace has been reported to potentially be used as part of prevention or treatment strategy for obesity and weight loss. However, no commercial products have currently on the market (Burgos 2017, You, Kim et al. 2017, You, Rhuy et al. 2017). Dietary fibres impart several protective effects on cardiovascular diseases, colorectal cancer, obesity and diabetes. An example of an apple pectin is used as a dietary supplement as shown in Figure 14. Although used at a comparatively smaller scale, pectins are also used for various purposes in pharmaceutical industry such as specific drug delivery systems and emulsions (Miceli-Garcia 2014).

Several studies (Hang and Woodams 1984, Shojaosadati and Babaeipour 2002, Kumar, Verma et al. 2010, Dhillon, Brar et al. 2011, Dhillon, Brar et al. 2011, Dhillon, Brar et al. 2013, Sekoai, Ayeni et al. 2018) have used apple pomace as a substrate for fermentation in citric acid production. However,

recoveries are variable and no information on commercial uptake could be found. Citric acid is commonly used in food, cosmetic and pharmaceutical industry and mainly produced by the fermentation cane and beet molasses (Berovic and Legisa 2007).

Ethanol is a valuable ingredient used in cosmetics such as perfumes, pharmaceuticals such as antiseptics and hand sanitiser gels, and a natural product to extract flavours and aromas (Epure 2020). As discussed in the sections above, apple pomace has the potential to be used as substrate in ethanol production for use as a bioethanol or in food/drinks.

Some apple based pharmaceutical, nutraceutical and cosmetic products with their market price are shown in Table 17 and the potential use assessments are reported in Table 18.

Table 17. Apple based, nutraceutical and cosmetic products available in market.

| Product | Company | Product format | Price (AUD) | Source |
|--------------------------|------------------------|------------------------|----------------------|---|
| Face Cream | Renovatio | Skin Cream | \$38.50/ 100g | https://renovatio.com.au/ |
| Activated Phenolics | Renovatio | Dietary antioxidant | \$ 20, \$ 26 / 100 g | https://renovatio.com.au/ |
| Apple Cider Gummies | Various | Nutraceutical | \$ 20 for 65 pack | https://www.woolworths.com.au/shop/search/products?searchTerm=apple%20cider%20vinegar |
| Apple cider vinegar diet | Various | Nutraceutical | \$ 30 for 60 pack | |
| Shampoo and scalp rub | dpHue, Pure | Cosmetics | \$ 16 for 354 ml | https://www.allure.com/gallery/apple-cider-vinegar-hair-products |
| Apple pectin | Mr Vitamins | Dietary Fibre | \$20/ 200g | https://www.mrvitamins.com.au/morlife-apple-pectin-200g |
| Apple pectin | Solgar | Dietary supplement | \$37/100g | https://www.megavitamins.com.au/ |
| Ethanol | Sydney Solvents | Denatured ethanol | \$4.0 /L | https://www.sydney-solvents.com.au/ |
| Ethanol | Green Living Australia | Soap making ingredient | \$20.0/L | https://www.greenlivingaustralia.com.au/ethanol-1-l |
| Apple Seed oil | Kokoskin | Nutraceutical/cosmetic | \$18/ 150ml | https://kokoskin.com.au |

Table 18. Potential use assessment of nutraceutical and cosmetic applications from apple and/or pear pomace.

| Criteria | Assessment |
|--|--|
| Technology Readiness Level | TRL 9. Products are available in the market |
| Process complexity | High |
| State of market | Natural ingredient-based products are in growing demand |
| Product differentiation | Yes- Natural ingredient-based cosmetics and all nutraceutical products are favoured over chemical based products |
| Economic value of end-product | High (low volumes of ingredients required, and high value products manufactured) |
| Product yield | Low (Note: Low levels of ingredient from apple / pear pomace may be required in the formulations) |
| Level of investment to manufacture and commercialise a product | Medium to high level of investment required for start-ups but low to medium level investment may be required to provide apple pomace-based ingredients |
| Residue | Yes, depending upon the compound extracted, residues may need to be reutilized in compost, animal feed or land fill |

3.6.6 Substrate for enzymes and fermentation products

Enzymes are mainly used in manufacturing of food, feed, cosmetics, paper, textiles, biofuels and pharmaceuticals. Enzyme use is growing in animal nutrition as well. Global market for industrial enzymes was expected to grow to USD\$10.5 billion by 2024 (Binod, Palkhiwala et al. 2013, Kosseva 2013, Ahuja and Rawat 2019). Enzyme production using apple pomace as a substrate for microbial enzyme production has been widely explored (Vendruscolo, Albuquerque et al. 2008). Xylanase, cellulase and pectinases produced from apple pomace have shown to have commercial uptake potential due to cheap substrate and simple processes involved in production (Dhillon, Kaur et al. 2012, Walia, Mehta et al. 2013, Kapoor, Panwar et al. 2016). Prices of such enzymes were not readily available through web searches. Approximately 75% of all enzymes currently available are produced by three companies, namely Denmark based Novozymes, US Based DuPont and Switzerland based Roche. Global enzyme market is highly competitive and technology intensive with small profit margins. In addition, China and India have been increasing their import and export of enzymes (Li, Yang et al. 2012, Binod, Palkhiwala et al. 2013).

Apple pomace has been utilised as a substrate for the fermentation and production of a number of chemicals including organic acids (acetic acid, citric acid, lactic acid), alcohol, protein enriched feeds and enzymes (including cellulase, hemicellulase, ligninolytic, amylase, chitinase, chitosonase and pectinase) (Dhillon, Kaur et al. 2013, Kosseva 2013, Miceli-Garcia 2014).

Polylactic acid is an important polymer that has gained attention due to its use in environmentally friendly, biodegradable products such as bioplastics (John, Nampoothiri et al. 2007). L-Lactic acid is used in the production of polylactic acid. A laboratory-scale study (Dedenaro, Costa et al. 2016), produced L-Lactic acid by fermenting a mixture of pear pomace and cheese whey.

Acetic acid is used in products such as dyes, perfumes, synthetic fibre, textiles, inks, soft drink bottles, rubbers, plastics, pesticides, wood glues, food additive and solvent in many industrial processes (PR Newswire 2017). A study by Vashisht et al (2019) has developed an eco-friendly method which is reportedly simpler than more traditionally used commercial methods that rely on the use of expensive enzymes and chemicals. This method by Vashisht et al (2019) uses a strain of bacteria (*Acetobacter pasteurianus*) which grows on the pomace. The process (outlined in Figure 15)

involves initially inoculating the pomace with yeast to produce bioethanol which is further subjected to this bacterium to produce acetic acid (Vashisht, Thakur et al. 2019).

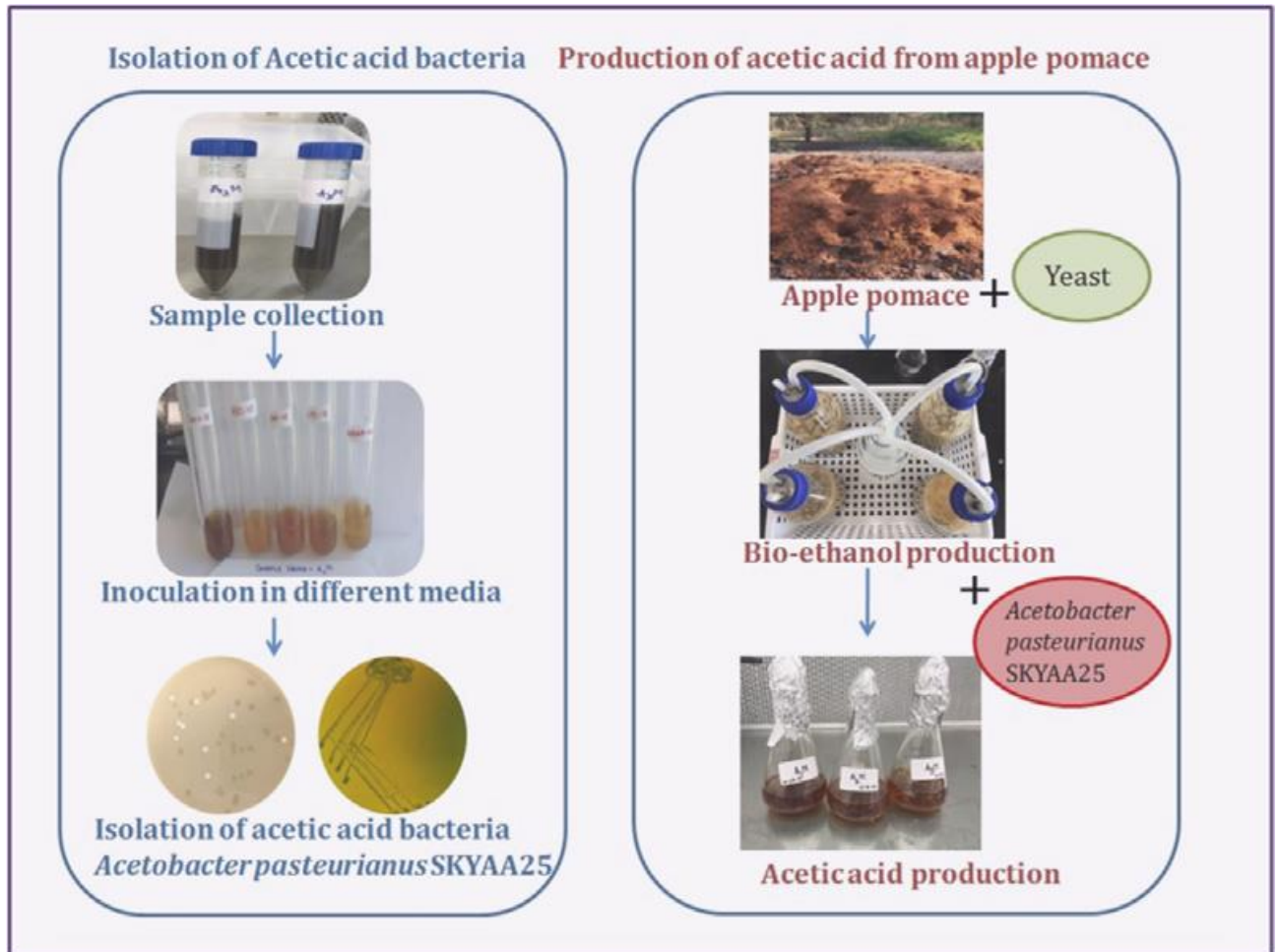


Figure 15. Bioconversion of apple pomace to acetic acid. Reproduced from Vashisht et al. (2019).

Some apple fermentation products available and their prices indications are shown in Table 19 and the potential use assessment is reported in Table 20.

Table 19. Fermentation products available in market.

| Product | Company | Product format | Price (AUD) | Source |
|---------------------|----------------------|-----------------|-------------|---|
| Apple cider vinegar | Various | Food ingredient | \$3-\$11/L | https://www.woolworths.com.au/shop/productdetails/325452/bragg-apple-cider-vinegar-organic |
| Acetic acid | Cleaners Supermarket | Cleaning | \$185/20kg | https://www.cleaningshop.com.au/contents/en-us/p19061-Acetic-Acid-75-Food-Grade.html |
| Citric acid | N- essentials | Cosmetic | \$9/kg | https://n-essentials.com.au/product/citric-acid-anhydrous/ |

Table 20. Potential use assessment of substrate for enzyme and fermentation products from apple and/or pear pomace.

| Criteria | Assessment |
|--|---|
| Technology Readiness Level | TRL 3 &4: All potential uses above have been shown as a feasible option through experimental demonstrations |
| Process complexity | Low to medium complexity in production of the raw compounds but further purification can add to the complexity of operations |
| State of market | Constantly growing markets except for enzymes where demand for commercial manufacturing is increasing and global demand is on the rise |
| Product differentiation | None likely |
| Economic value of end-product | Enzymes- high Others- low to medium |
| Product yield | Low to medium |
| Level of investment to manufacture and commercialise a product | Low to medium except for enzymes which requires high level of investment |
| Residue | Yes, may be used in compost or animal feed and some cases land fill as the pomace will be unfit for any other purpose such as enzyme production process may leave unusable pomace after chemical processing |

3.6.7 Textiles, biodegradable consumer products and other biomaterials

Apple peel contains cellulosic fibres that can be used to make alternative leather materials for various applications. An Italian based company Apple Peel Skin (PAQ Leather, 2020) manufactures a vegan certified Vegan AppleSkin leather using a power derived from apple peels. The apple peel is reportedly sourced from apple pomace.

A Canadian furnishing company Gus Modern manufactures leather furniture using Vegan AppleSkin leather (Kaja 2020, Ledoux 2020). This AppleSkin leather is also used to make various travel and fashion accessories (Mochni 2019, Veggani 2020). Example products that utilise the Vegan AppleSkin leather are shown in Figure 16. Apple pomace can also be used to produce bioplastic films and 3D products for edible packaging and tableware (Gustafsson, Landberg et al. 2019) and de-pectinised pomace can be used to make recyclable packaging materials for food items as well (Barrett 2020).



Figure 16. Apple skin products available in market to replace leather products. Reproduced from Kaja (2020), Ledoux (2020) and Mochni.com (2019).

Lithium ion rechargeable batteries are most suitable option for modern technology needs such as phones and laptops. Lithium is expensive and limited resource and that's why researchers have been looking for a sustainable alternative (Nayak, Yang et al. 2018). Sodium ion batteries have shown potential to replace lithium ion batteries (Slater, Kim et al. 2013). However, the graphite in sodium ion batteries has poor electrochemical performance and consequently there is high interest to find alternative. A Chinese study has recently demonstrated that pectin-free apple pomace waste can be converted to a hard carbon that has the potential to replace the graphite in sodium-ion batteries (Dou, Geng et al. 2018, Fu, Xu et al. 2018).

The potential use assessment for consumer products and textiles from apple pomace are reported Table 21 and Table 22, respectively.

Table 21. Potential use assessment of biodegradable tableware, biomaterials and bio packaging.

| Criteria | Assessment |
|--|--|
| Technology Readiness Level | TRL6- biodegradable tableware, biomaterials, 3D objects |
| Process complexity | Medium to high |
| State of market | Demand for affordable biobased products is increasing globally |
| Product differentiation | Plant based/ biodegradable/renewable source products are preferred over traditional petrochemical products or taken from limited natural resource through mining |
| Economic value of end-product | Low to medium |
| Product yield | Low to medium |
| Level of investment to manufacture and commercialise a product | Medium |
| Residue | Mostly no residue remains |

Table 22. Potential use assessment of textiles products from apple and/or pear pomace.

| Criteria | Assessment |
|--|---|
| Technology Readiness Level | TRL 9- Furniture and other fashion accessories are in market |
| Process complexity | High |
| State of market | Plant based and other synthetic or recyclable alternatives in the market are gaining popularity over traditional leather products |
| Product differentiation | Plant based textiles are gain popularity for cruelty free status compared to natural leather products |
| Economic value of end-product | High |
| Product yield | Low to medium (fibre component of apple pomace) |
| Level of investment to manufacture and commercialise a product | Initial level of investment is high to produce such textiles, but this textile can be used by existing consumer product manufacturers |
| Residue | Yes, compost or landfill |

4. CONCLUSION AND RECOMMENDATIONS

Apple and pear pomace are sources of many valuable compounds such as fibres, sugars and phenolics. The high moisture content of pomace makes it highly perishable, and as a consequence it often currently used as a livestock feed supplement or disposed in landfills. Greater awareness to reduce waste and the development of biobased and circular economies have led to the exploration of pomace valorisation options worldwide. Very few readily available published studies have been conducted in Australia.

The list of products derived from apple pomace are now available in the global market is growing and includes products such as apple seed oil, pet diets containing pomace, textiles, nutraceutical and cosmetics. Some product may also have the potential to be differentiated as novel, organic or alternative to non-renewable/ petrochemical or animal products such as biofuels and plant-based textiles. The availability and quantities of pomace, minimum economic scale, level of investment required in existing and new technology, and product yield to compete with the existing product markets are important considerations for the commercialisation potential of any pomace valorisation option. A clear understanding of these factors are needed and would be a logical next step. However, given Australia's small apple and pear production volumes (when compared on a global scale), the valorisation into commodity-based chemicals are unlikely to be economically competitive. Comprehensive data on Australian apple and pear pomace composition, geographical locations of juicing operations, costs in transport, market availability and consumer demand are needed for any cost benefit analysis prior to commercial investment. From an environmental footprint, waste reduction and waste valorisation perspective the production and management of any secondary residues would be another important consideration.

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7. APPENDIX 1 - SCIENTIFIC PUBLICATION TRENDS

A search for ‘apple pomace’ in the title, abstract or keywords of the Web of Science and Scopus databases² on 25 June 2020 revealed that 1,615 and 946 articles have been published, respectively. The top 10 organisations based on number of publications for apple pomace in the Scopus database is reported in Table 23. Only 17 of these articles contained authors from Australia institutions.

A similar search for ‘pear pomace’ revealed that only 59 and 40 documents have been published in the Web of Science and Scopus databases respectively. The top three organisations based on number of publications for pear pomace in the Scopus database is reported in Table 24. None of these articles contained authors from Australian institutions.

Table 23. Top 10 organisations in Scopus database which contain ‘apple pomace’ in the title, abstract or keywords.

| Affiliation | Number of publications | Country |
|---|------------------------|---------------|
| INRS- Research Centre on Water, Earth, and the Environment | 34 | Canada |
| Dr. Yashwant Singh Parmar University of Horticulture and Forestry | 31 | India |
| University of Quebec | 29 | Canada |
| Cornell University | 26 | United States |
| Northwest A & F University | 18 | China |
| IRDA Research and Development Institute for the Agri-Environment | 18 | Canada |
| Federal University of Santa Catarina | 17 | Brazil |
| Ponta Grossa State University | 16 | Brazil |
| Institute of Himalayan Bioresource Technology | 16 | India |
| Lodz University of Technology | 15 | Poland |

Table 24. Top three organisations in Scopus database which contain ‘pear pomace’ in the title, abstract or keywords.

| Affiliation | Number of publications | Country |
|---------------------------|------------------------|-------------|
| Mokpo National University | 6 | South Korea |
| University of Liege | 4 | Belgium |
| University of Calabria | 2 | Italy |

² Web of Science and Scopus are bibliographic databases for academic and scientific articles.

