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Underutilized by-product streams from the Canadian horticulture value chain

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Executive summary

The current research focused on examining underutilized by-product streams from the top seven Canadian fruits and vegetables by production volume. These include: potatoes, apples, field tomatoes, greenhouse tomatoes, greenhouse cucumbers, onions and carrots.

The study involved interviews with representatives of over 40 companies from across the horticulture value chain and food industry. These interviews aimed to identify underutilized by-products generated on farms, at packing houses and during processing. Additionally, a number of consumer packaged goods and food ingredient companies were interviewed to better understand current trends driving product formulation and to identify gaps in the ingredient market that can be filled by transformation of underutilized fruit and vegetable by-product streams.

It was reported that field crops (e.g. carrots, potatoes, onions, field tomatoes) and apple production result in limited amounts of waste as nearly all edible grade-outs are sold for further processing. In some cases (e.g. carrots) a smaller proportion of the crop that is severely misshappen or damaged is given to livestock farms. During harvesting, defective, such as severely misshappen or insect damaged product, is left in the field to decompose and add nutrients back to the soil. After harvest, product that is sorted out for rot or other damage is returned to a field to decompose, buried in a hole, or diverted to a biodigester. Although all of the above solutions are not highly profitable (and in some cases have an associated cost), these waste streams are generally diverted from landfills and in many cases provide at least break-even returns to growers and distributors. This was not the case in other investigated sectors, thus although there is an opportunity to convert some of the field crop production by-product streams to higher value products, these streams were not identified as the highest priority for change.

The situation is different in greenhouse production. There is currently no processing market for greenhouse tomatoes and cucumbers, so any product that does not meet the criteria for the fresh market is discarded (landfilled or allowed to decompose in a pile near the greenhouse). This presents a large untapped opportunity as virtually all of the discarded product is whole and edible with only cosmetic defects. In Leamington, Ontario, the greenhouse capital of North America, approximately 15 million pounds of edible tomato and 12 million pounds of cucumber grade-outs are discarded annually.

The other area with substantial untapped opportunity is the processing sector. Large volumes of unavoidable waste (e.g. peels, cores, pomace) is generated when potatoes, apples, field tomatoes, carrots and onions are processed into chopped or sliced frozen, fried or fresh products, juice or purees. Among the interviewed organizations, on average a single large processing facility generated approximately 3 million pounds of carrot by-product, 4.5 million pounds of apple by-product or 8.5 million pounds of tomato peels annually. In Manitoba and Alberta, it was estimated that roughly 133 and 114 million pounds of potato peels are generated annually from all potato processing in the province, respectively.

With the exception of potato processing waste in Atlantic Canada, all other produce processing waste across the country is typically either distributed to livestock farms, spread out on fields to decompose, sold to pet food companies at low cost or landfilled.

The current report outlines a range of options for landfill diversion of these by-product streams. Established popular solutions involve the direct use of raw material for land amendment, shipping to livestock farms or to biodigesters. These solutions produce minimal or negative returns however they are simple to execute, carry minimal risk and do not require a great deal of capital investment. For those producers and processors seeking higher returns and willing to invest in by-product processing, there are many other options to consider.

Fruit and vegetable by-product streams are rich in nutritional and functional compounds that may be of interest to the food industry (e.g. pectin/starch, antioxidants, colours, enzymes) or agricultural industry (e.g. organic matter and minerals). The by-product streams have the potential to be converted by various means including drying and milling to produce powders, dehydration to produce concentrates, extrusion to produce dried pellets or snacks, and extraction of valuable components, among others.

Clean label, the reformulation of food products to have fewer, more easily-recognizable ingredients with fewer allergens or additives, is a major trend driving current food product reformulations. Fruit and vegetable by-product-derived food ingredients have the potential to bring many different functionalities to products (e.g. shelf-life extension, natural colour, thickening, sweetening) while fitting within clean label constraints.

Alternatively, these by-product streams may be converted for use in the cosmetics industry (e.g. skin creams), materials engineering (e.g. car tires, packaging films), and for agricultural applications (e.g. compost, substrate mixes, biofertilizer).

Many organizations that are currently diverting their by-product streams to direct use options expressed interest in finding more beneficial alternatives for their by-product streams. Setting up in-house processing of by-product streams to generate new value-added products requires significant capital and R&D investment and may be too far outside the scope of many organizations' core businesses. Therefore there is an opportunity for a new category of processors that purchase by-product streams from the horticulture value chain for transformation to value-added products. Although a limited number of such organizations already exist in Canada, many more are needed to match the demand.

Overall, high volumes of production and processing by-products are generated across the horticulture value chain. In particular, the greenhouse tomato and cucumber growing sector as well as fruit and vegetable processing sectors were identified as higher priority areas with ample volumes of underutilized by-product streams. These by-product streams have a great deal of potential to not only be managed differently to help organizations reach environmental sustainability targets but also to produce value-added products that bring better returns to Canadian producers and processors.

1. Introduction

Approximately one-third of the food produced in the world for human consumption is wasted. Among these, fruits and vegetables have the highest wastage rates with 40 to 50 per cent of products produced being thrown away (Food and Agricultural Organization of the United Nations, 2010).

In Canada, approximately 74 per cent of produce waste occurs before it reaches consumers. This totals nearly six million metric tonnes (13,227 million pounds) of fruit and vegetable waste before reaching the consumer (Gooch et al., 2019). Two-thirds of this produce waste is categorized as avoidable waste occurring due to operational or market factors such as a breakdown in seller-buyer relationships, an oversupply or excess food not donated due to a vendor agreement. These massive amounts of wasted, potentially edible products could be reduced or eliminated by improving efficiencies or policies in the value chain. Meanwhile, the other third of fruit and vegetable waste occurring from farm to retail, is planned or unavoidable food waste. It is estimated that these unavoidable waste streams generate nearly two million metric tonnes of waste (Gooch et al., 2019) and include inevitable losses as they are by-products of processing such as the removal of husks, peels and cores.

These by-product streams from unavoidable food waste pose a problem for producers and processors, many of whom must pay to dispose of this waste at landfills or allow the by-products to decompose on unused plots of land. Besides the economic factor, the increasing focus on environmental sustainability in many organizations as well as in changing local regulations are driving an interest to find new solutions to managing by-product streams.

Many of these fruit and vegetable by-products are edible and contain valuable nutritional and functional components. The by-product streams are continuously and predictably generated in large volumes, a feature that makes them attractive for further processing to value-added products.

The idea of converting fruit and vegetable by-product streams to value-added products is not new and there are many examples of such endeavours such as selling dried grape skins from wine production as a source of flavonoids (e.g. Bioflavia™) or converting spent grains into cookies, granola and flours (e.g. Still Good). However, these efforts were often approached based on chance awareness or accessibility of the by-product stream rather than a strategic evaluation of all available by-product streams and targeted selection. Although such efforts are individually important for landfill diversion and for increased profitability of the horticulture value chain, a greater impact could be achieved if the Canadian agriculture and food industries have access to more information regarding by-product stream availability.

The lack of publicly available information on current sources of unavoidable horticultural waste in Canada is a barrier to tackling this problem. A systematic evaluation of the sources of underutilized by-product streams was identified as a gap on the path to determine the areas with the greatest need and opportunity. Thus, the current report will focus on unavoidable waste streams and identify the major sources of underutilized by-product streams occurring at different points in the Canadian horticulture value chain. These waste streams will then be described according to their nutritional and functional components and potential approaches for waste management or conversion to value-added products.

The report is intended to enable the horticulture sector, government and research organizations to tackle this issue more strategically by investing time, effort and money in the areas with greatest needs and opportunities for by-product stream utilization.

2. Approach

The horticulture sector encompasses the production of fruits, vegetables, flowers, shrubs and trees. The current report is part of a larger project examining the utilization of by-product streams from both edible and ornamental (tree nursery sector) horticulture. In order to maintain focus, the reporting on by-product streams from the edible and ornamental sectors was separated into two parallel reports and the present report focuses only on edible horticulture. The report on waste streams and composting opportunities in the tree nursery sector can be found on the Vineland website https://www.vinelandresearch.com/wp-content/uploads/2020/02/Identifying-Opportunities-for-Waste-Conversion-within-the-Ontario-Tree-Nursery-Sector.pdf.

Canada produces a long list of edible horticultural products including crops such as apples, raspberries, strawberries, tomatoes, carrots, asparagus and ginseng. Since it would take considerable time to capture the whole range of edible horticultural products produced in Canada, the current study was limited to the value chains of the top seven Canadian horticultural crops by marketed production volume in 2020. These include (in order of production volume):

- Potatoes (4,728 million tonnes)
- Field tomatoes (492 thousand tonnes)
- Apples (387 thousand tonnes)
- Carrots (355 thousand tonnes)
- Greenhouse tomatoes (256 thousand tonnes)
- Onions (247 thousand tonnes)
- Greenhouse cucumbers (244 thousand tonnes)

Interviews were conducted with representatives from 41 organizations spanning the range of growers, packers, processors, consumer packaged goods (CPG) companies and ingredient suppliers from across Canada. Although interviews included 41 organizations, a higher number of individual interviews were completed. In several cases where a company was vertically integrated, interviews were conducted with individuals that could speak to by-product stream handling as well as with others that could speak to food industry trends from the perspective of a CPG.

Following the identification of the major by-product streams, a literature and online media search was conducted to supplement the report with information regarding composition and potential uses of the by-product streams.

The table below describes the organizations that were interviewed for the purposes of this study.

Table 1. Categories of organizations interviewed for the purposes of this report.

Produce type		
(Only applies to producers, packers and processors)	**Potato**	5
	Field tomato	3
	Apple	11
	Carrot	4
	Greenhouse tomato	5
	Onion	5
	Greenhouse cucumber	5
Region		
Note: Many organizations fell into more than one category as they had facilities in multiple provinces	**Atlantic**	7
	Quebec	9
	Ontario	26
	Prairies	10
	British-Columbia	6
Organization type*		
Note: Many organizations fell into more than one category as they were vertically integrated	**Producer**	21
	Packer	6
	Processor	16
	CPG	6
	Ingredient supplier	4
	Other	1

***Definitions of organization types**:
Producer: Grows one of the top seven Canadian horticultural crops or subcontracts and manages the cultivation of these crops at subcontracted farms.
Packer: Receives product from multiple local farms for sorting, packing and marketing.
Processor: Processes raw fruits, vegetables or tubers. May also produce consumer packaged goods.
CPG: Produces consumer packaged goods but does not process raw fruits, vegetables or tubers.
Ingredient supplier: Supplies ingredients to the food industry (e.g. flavours, colours).
Other: None of the above (i.e. animal feed supplier).

3. Underutilized by-product streams of the top seven Canadian horticultural crops

The section below will provide key facts about production and processing of the top seven Canadian horticultural crops and present findings from sector interviews that identified by-product streams. Sector interviews detailed the sources and volumes of by-products generated along each crop's value chain and the current status of by-product management by the sector. The ensuing sections (Sections 4 and 5), will dive deeper into opportunities for waste utilization by discussing composition of the identified by-product streams and options for their transformation or direct use.

Potatoes

Canadian potato production

Potatoes can grow successfully in diverse climates and are cultivated in all Canadian provinces. In 2020, 4.7 million metric tonnes of potatoes were produced in Canada. The largest volumes of potatoes are produced in Manitoba, Alberta and Prince Edward Island (P.E.I.) with a little over 20 per cent of Canadian production originating from each one of these provinces. New Brunswick and Quebec are the next highest producers, accounting for 11 per cent and 12 per cent of production, respectively (Agriculture and Agri-Food Canada, 2021a). Overall, 68 per cent of potatoes grown in Canada are destined for processing (mainly French fries and potato chips), however this percentage varies by province. In 2020, 78 to 79 per cent of potatoes grown in Manitoba and Alberta were destined for processing, 64 per cent of P.E.I potatoes were sold for processing and only 40 per cent of Quebec potatoes were sold for processing (Agriculture and Agri-Food Canada, 2020).

Potato by-product streams

Potatoes are harvested using mechanical harvesters. Harvester claws must be set far enough apart to allow small rocks to fall through during collection. However, there is a trade-off as smaller potatoes also fall through and remain unharvested. Additionally, a small amount of larger potatoes are missed during harvesting. As potatoes are harvested, the harvesters remove vines and leave them behind in the field. Thus, potato farming is not considered to generate any by-products as all unharvested potatoes and vines are plowed back into the field and allowed to decompose to contribute organic matter to the soil.

Some farms supply potatoes to potato packers (i.e. distributors) whereas others are contracted to grow potatoes for major processors. Potato packers usually sell potatoes to the fresh market and food service. In Canada, marketable potatoes are graded according to two categories: No. 1 and No. 2. No. 1s typically go to the fresh market whereas No. 2s are marketed to food service and smaller-scale processors that produce refrigerated products such as potato salad.

Most packers, particularly larger ones in Atlantic Canada, sell all potato sizes in the fresh market. However, some potato varieties, such as russet, have an unattractive skin that is not suitable for the baby potato market and these pose a challenge for marketing for both large and small packers. Packers in Atlantic Canada sell as many of the small russets as they can to food service, however a significant proportion as high as 50 per cent are still diverted to a potato dehydrator plant, where they receive the lowest returns.

One packer outside of Atlantic Canada that specializes in premium fresh market potatoes indicated that they have a line of potatoes sold in larger bags at a discounted price (i.e. "ugly produce" category) to the consumer market in a major grocery chain. These usually include smaller russets and mid-size potatoes of other varieties whose sizes do not meet traditional consumer expectations for full size fresh market potatoes nor baby potatoes. However, potatoes sold to the consumer market, even as part of the discounted "ugly produce" line, generally fetch a better price than food service.

Culls are potatoes that are significantly misshappen, too small for the baby potato market, have notable defects, significant rot or bruising. In Atlantic Canada, edible culls (no bruising or rot) are sold to a dehydrator plant to be processed into potato flakes. These potato flakes are marketed to soup manufacturers, bakeries and other consumer packaged goods companies. On average, approximately eight million pounds of potatoes are diverted to be dehydrated by a typical large distributor in Atlantic Canada. Any green or rotten potatoes are either crushed and buried in a hole or given to livestock farmers rather than returned to the field over concerns of disease transmission.

In other parts of Canada there is no dehydrator plant nearby, therefore potato culls are either landfilled, given to livestock farms (cattle or pig) or diverted to an off-site biodigester (at the cost of the packer).

While potato packers typically sell to the fresh market and food service, major potato processors that produce frozen or fresh cut potato products (e.g. French fries, wedges, hash browns) or potato chips, contract local growers and source potatoes directly from these farms. Upon receipt at the processing facility, they first go through a grading and sorting step according to suitability for different processing lines based on dimensions and shape. Grade-outs (e.g. bruising, rot) account for approximately two per cent of the potatoes received at processing facilities. All potatoes that are not rotten are used in one or another processing line.

Larger potatoes are used to produce cut products such as French fries and wedges. These potatoes first go through a pre-heating and steam peeling step and then are cut or sliced. When peeled, the peel loss accounts for approximately seven per cent of the weight of potatoes processed on those lines.

Processing facilities that have both cut and formed potato production lines, use bits and pieces of peeled potato that are cut away as well as potatoes that were too small for French fries and wedges to produce hash browns, nuggets, patties and other formed potato products. Some plants do not have a formed potato product line and therefore the cut away bits and pieces of potato are considered waste.

All of these potato products (both cut products and formed) have low tolerance for discolorations and imperfections to meet consumer acceptance. Additionally formed products must have the skin peeled off. Therefore, when skin-on potato products are cut, the bits and pieces that are cut away from these production lines as well as any pieces with discoloration are not suitable for formed potato production lines.

Therefore, grade-outs (usually potatoes with discolorations, significant defects, very misshappen shape), peels, cooked fries that don't meet quality control standards, as well as any frozen unsold product are considered waste. Similar to packers, processors in Atlantic Canada sell much of their potato by-products that are not discoloured or bruised to a potato dehydrator. Due to the size of these operations and the high energy costs in the region, major potato processors in Atlantic Canada have biodigesters on-site. Any potato by-products that do not meet the potato dehydrator standards are diverted to their on-site biodigesters. The microbial mass inside the biodigesters breaks down the waste product to produce biogas which in turn is used in combustion to heat water to steam. This steam can then be used in potato processing, thus reducing the plant's electricity needs and resulting in substantial cost savings. As is typical in biodigestion, not all of the material decomposes inside the biodigester and the sludge that is left behind in the biodigester is de-watered and removed daily to be spread onto grain or hay fields.

In other provinces, potato processing by-products that are not suitable for formed potato manufacturing (or do not have formed potato product lines on-site) are given to farms for livestock feed or to spread on fields or for biofuel (off-site). For example, in Ontario, potato processors generally sell clean potato by-product to a company that prepares it for animal feed however any by-product that has significant rot or is otherwise unsuitable for animal feed is generally picked up and taken away to an off-site biodigester at the cost of the processor. In the Prairies, potato by-product is generally given away to livestock farms with shipping costs covered by either the farmer or processor depending on the relationship. These by-products add up to significant volumes. In 2020, 79 per cent and 78 per cent of potatoes grown in Manitoba and Alberta, respectively, were destined for processing. If we assume that roughly 90 per cent of processed potatoes are peel-off products, this is equivalent to around 133 million pounds of potato peels generated annually in Manitoba and 114 million pounds in Alberta.

In addition to peels, potato processing also generates a large amount of wash water that contains pieces of potato and solubilized starch. Across most potato processing plants, pieces of potato (i.e. nubbins and slivers) are removed from the wash water and re-introduced into formed potato processing lines (if the plant has such a line). The wash water is diverted to an on-site water treatment facility. Virtually all of the major potato processing facilities across Canada extract starch from the wash water for sale.

Overall, nearly all of the potato by-products generated in Atlantic Canada are used for purposes that provide returns to packers or processors. In the past, many processors gave away their by-products to nearby cattle farms. However, after the Bovine Serum Encephalopathy (BSE) crisis, many cattle farms in the Atlantic provinces shut down and potato processors had to find alternative solutions to manage these waste streams. Additionally, the ban on landfilling of organic waste in Nova Scotia and P.E.I. pushed the potato sector to find alternative solutions to potato waste management.

Energy costs are high in Atlantic Canada, which makes the biodigester option quite attractive. However, this is not the case in other Canadian provinces, particularly in the Prairies where energy costs are notably lower. Another factor that differentiates the potato market in Atlantic Canada from the rest of the country is the high volumes of potatoes that are produced in the region. The scale of potato production in a concentrated area makes it possible to profitably operate a potato dehydrator plant in the region. Even with these high volumes of potato production, it can be challenging to obtain enough potato supply for dehydrator operations depending on the season. It was reported that a major challenge with operating a potato dehydrator plant is that product sales must be forward contracted. Therefore, in years where there is a crop failure, it is very difficult to obtain sufficient product to meet contract commitments. In the past when there have been crop failures, potato dehydrators have had to purchase potatoes from Idaho. The shipping costs and currency conversion rates have reportedly resulted in highly unanticipated costs that eventually lead some dehydrator operations to bankruptcy. All of these combined factors, make the potato waste management strategy unique in Atlantic Canada and solutions used in this region are unlikely to be transferrable to other Canadian provinces such as Ontario. However, considering that Alberta and Manitoba both have significant potato production, it may be worthwhile to investigate the economic feasibility of operating a potato dehydrator plant in a central location with access to various potato processors in both provinces.

Potato packers and processors in Atlantic Canada indicated they were generally satisfied with their by-product handling options. However, packers and processors in other regions of Canada largely rely on options that come at a cost and therefore were more likely to express an interest in alternative solutions.

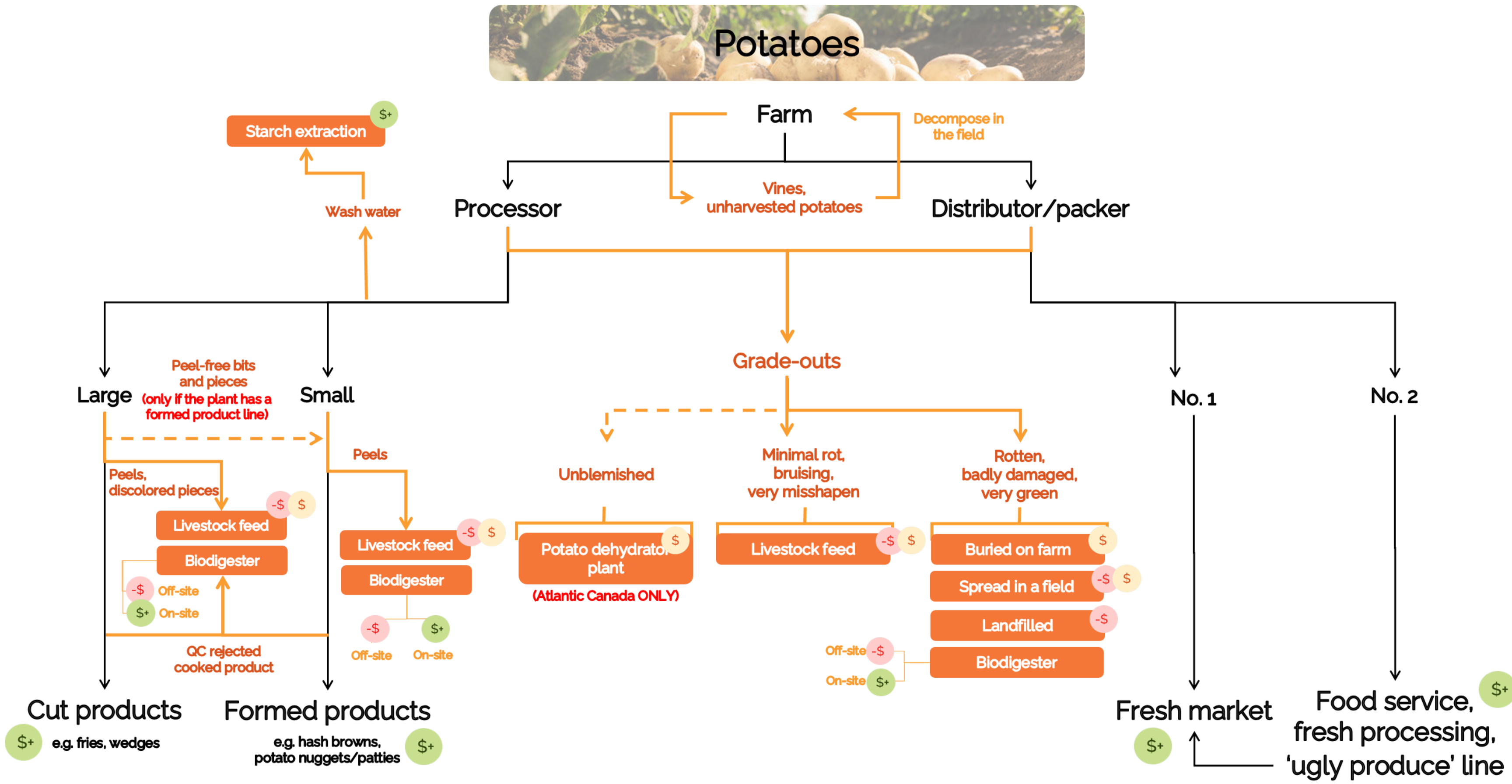

Figure 1. Sources of potato by-products in the value chain.

Field tomatoes

Canadian field tomato production

In 2020, 479,648 metric tonnes of tomatoes were produced in Canada, with 98 per cent of this production in Ontario (Statistics Canada, 2021b). Since field tomatoes are almost exclusively grown in Ontario, the discussion in this section will be limited to this province.

The vast majority (91 per cent) of field tomatoes in Ontario are grown for the tomato processing sector (Agriculture and Agri-Food Canada, 2021b). Of note is that the minority of field tomato growers that grow for the fresh market, grow different varieties of tomatoes than those who grow for processing. Although both grow field tomatoes, they operate in different markets, different industry groups and have different needs. Processing tomatoes have thicker skin than fresh market tomatoes to help them withstand the rigours of mechanical harvesting. Processing tomatoes are selected for their high Brix, characteristic red colour after processing and other attributes that make them suitable for different applications such as a desirable post-processing viscosity (Ontario Processing Vegetable Growers, 2021).

Processing tomatoes are harvested from mid-August to early October. Approximately 20 per cent of the tomatoes are processed into whole peeled tomatoes, another 20 per cent into tomato juice and 80 per cent are processed into tomato paste (Ontario Processing Vegetable Growers, 2021). Tomato paste is stored in large totes and throughout the year, companies draw on these totes of paste to produce consumer packaged goods (e.g. seasoned sauces, ketchups, soups, small cans of tomato paste).

Field tomato by-product streams

Like many field vegetable crops, field tomato harvesting is automated. Mechanical harvesters collect up whole vines and shake off the tomatoes into a collection bin. After tomatoes are shaken off, vines and green tomatoes are left in the field and plowed back into the soil. There is little to no waste generated during grading. Thus, field tomato production is considered to not create any organic by-product waste streams.

Because tomatoes are used for processing, there is very little whole fruit waste as any tomatoes without rot can be used regardless of shape or surface blemishes. As mentioned previously, tomatoes used in processing are converted to whole canned tomatoes, tomato paste or tomato juice. For all of these applications, tomato skins must be removed and these constitute the largest source of by-product in the processing tomato value chain. A pet food manufacturer from the U.S.A. reportedly buys these tomato peels and picks them up from all the major tomato processors on every production day. It was found that an average tomato processing plant generated approximately 8.5 million pounds of tomato peels during the processing season (mid-August to early October). Finished products that do not meet quality control standards are dripped into waste water treatment.

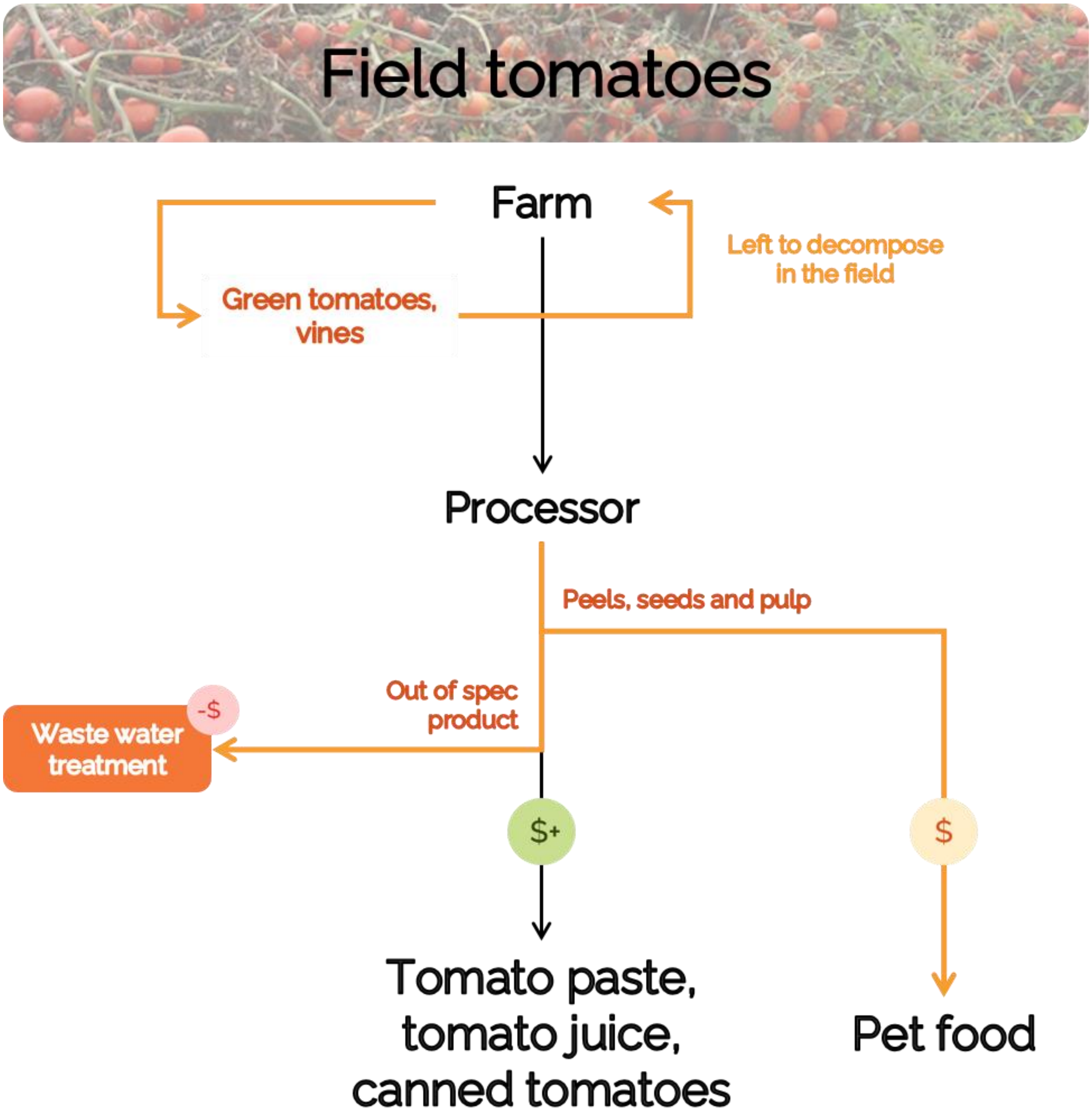

Figure 2. Sources of field tomato by-products in the value chain.

Apples

Canadian apple production

Canadian apple growers produced 386,817 metric tonnes of apples in 2020. Ontario, Quebec and British Columbia produce the bulk of Canada's apples, accounting for 40 per cent, 27 per cent and 24 per cent of production, respectively (Statistics Canada, 2021a).

In 2014, it was reported that 23 per cent of Canadian apples were destined for processing (Makki, 2015). In Ontario, Canada's largest apple producing province, 71 per cent of apples were destined for the fresh market and 29% for processing in 2020 (Ontario Apple Growers, 2021).

Around 25 years ago, it was typical for some growers to cultivate apples for the fresh market while others grew apples for processing (e.g. juicing) or growers kept some combination of dedicated orchard space for each purpose. However, over time, juice manufacturers required lower pricing for processing apples and the low profit margins on apples destined for processing caused a shift in the market. Today, virtually all growers grow with the intention to sell as much of their crop as possible to the fresh market and only apples that do not meet the quality standards needed for the fresh market are sold for processing. As such, it is also not uncommon for major local apple processors to not be able to meet their apple needs with only locally grown apples. Several major Canadian apple processing facilities that we spoke with must supplement their operations with imported apples as locally grown apples of higher quality standards, destined for the fresh market, exceed apple processors' price points.

Apple by-product streams

Considering that the primary objective of apple producers is to sell apples to the fresh market, for the purposes of this report, any apples resulting from apple production that do not meet the needs of the fresh apple market will be considered a by-product.

In Canada, apples are typically harvested from August to late October, with different apple cultivars ripening, and therefore being ready for harvest, at different times within this window. Most growers produce several varieties and therefore harvest throughout these months. Any apples with insect larvae or significant rot are left behind on the trees or on the ground. At some farms, apples that fell off the tree prematurely but are in good condition are picked up from the ground and diverted for processing. Rotting apples on the orchard floor are mowed into the orchard to add back nutrients into the soil. In a typical year, approximately 10 per cent of apples are left behind in the orchard due to rot or other issues that make them unmarketable.

Once harvested, apples are sorted either in a central facility on the farm or shipped to a packer for sorting. Packers, many of whom also have their own orchards, receive apples from several different orchards and then sort, pack and market the apples. In smaller farm operations, sorting and grading is completed manually whereas in larger operations, especially operations that act as packers, sorting and grading is done by scanning each individual apple to create a digital image and then artificial intelligence is used for image analysis to automatically grade and sort apples (i.e. computer sizing and grading). Another 10 per cent of apples are typically culled during packing due to rot, excessive bruising or storage issues. In a bad year, this number is closer to 20 per cent but may be as high as 50 per cent if there is an unusual weather event that year (e.g. early frost). These unmarketable apples are often returned to the orchard and mowed into the ground.

Fallen apples or apple that were graded out during sorting for minor amounts of rot, puncture wounds or storage defects are sometimes returned to the orchard and other times collected and given to local livestock farms for animal feed or sold as deer bait to hunters. When apples are destined for animal feed, most often growers pay for shipping costs. The high moisture content of apples makes them expensive to ship. As a result, apple growers can only use this option if they happen to be located in close proximity to livestock farms.

Apples are graded according to seven grades which can be broadly attributed to three categories: Canada Fancy (Canada Extra Fancy, Canada Fancy), Canada Commercial (Commercial, Hailed, Commercial Cookers) and Peelers (No. 1 Peelers, No. 2 Peelers).

Of the marketable apples, approximately 80 to 90 per cent meet the quality standards for sale to the fresh market (Canada Extra Fancy and Canada Fancy grades). Canada Commercial apples are sold to food service or bakeries (apple chunks) while Peelers are sold for juice processing. All the growers that we spoke with indicated that selling apples for processing generates little to no profit after accounting for handling and shipping costs. However, this option is often used for Peeler grade apples as breaking even is more economically beneficial than paying to ship to local farms or landfills. Ontario is Canada's largest producer of apples and it is estimated that approximately 99 million pounds of apples from this province were diverted for processing in 2021, providing approximately break-even returns to the growers that produced them.

Many of the mid- to large-sized apple growers are also processors and sell apple cider, juice, apple chunks (i.e. for baked goods), puree and/or other apple products. All of these processing operations generate by-product streams consisting of apple peels, cores or apple pomace (the pulp left behind when whole apples are pressed for juice production).

When apples are peeled and cored (e.g. for apple chunks or puree), this by-product typically accounts for around seven per cent of the processed apples. When apples are pressed for juicing or cider, it requires around three pounds of apples to make 1L of juice and the apple pomace accounts for around 20 per cent of the processed apples. Mid-sized Canadian apple processors generate around one million pounds or less of apple by-product annually while the larger ones that were interviewed generated an average of 4.5 million pounds per processing facility annually.

Processors that use only local apples (e.g. many smaller processors), may process for around nine months of the year while apples are available either freshly harvested or from storage. The largest processors that produce year-round, supplement their local apple supply with apples imported from the United States.

Many processors that we spoke with ship their apple processing by-products to nearby livestock farms and give the material away as feed or for spreading in agricultural fields or pastures. However, some processors ship their by-products to landfills either because they produce more by-product than local farms can accept or in some cases they have not developed relationships with local farms who may be willing to accept their by-product material. Giving away by-product to livestock farms is more economical and more environmentally sustainable than landfilling. One of the challenges with finding livestock farmers willing to accept apple by-products, is that eating too many apples causes gassiness in ruminants and livestock farmers become limited with how much apple product they can accept.

As was mentioned earlier, apples are expensive to ship due to their high water content. Because of this, some processors make attempts to remove moisture from these by-products to reduce shipping costs or increase value. For example, one processor indicated that they juice their apple by-product streams and then sell the juice and ship the pulp to a landfill or livestock farms. Another processor indicated that they dry their apple pomace after juicing and then sell it to a pet food manufacturer. Yet another indicated that they convert some of their apple by-product into a value-added product, whereby apple peels from their organic apples are dried and milled into a powder for sale as a nutraceutical with high polyphenol content.

A number of growers and processors indicated that they have been considering composting but were not sure about the feasibility and did not feel they had the knowledge to move forward. Vineland Research and Innovation Centre recently completed a research study evaluating apple pomace as compost feed and the results will be published in the near future.

Finally, another potential source of waste comes from juice manufacturing. When apple juice processors produce juice, the juice may be sold as apple cider or it may be clarified to remove larger particles from the juice to produce a clear apple juice. Juice clarification typically involves a filtration step which separates the clarified juice from a retentate sludge (i.e. what is filtered out). Currently this sludge is typically sent to waste water treatment or an on-site biodigester. A larger apple juice processor may send as much as two million litres of apple juice retentate to waste water treatment annually.

Sustainability was a theme that frequently came up in interviews, as many producers were concerned about the environmental impact of landfilling by-products. However, because apple production and processing by-products are high in water content, this makes it expensive to truck the material long distances. As such, how these streams are handled by processors typically depends on what options they have available within a reasonably close range of their facility. Only a small number of apple growers/processors have invested in further processing of their by-product streams to increase profitability.

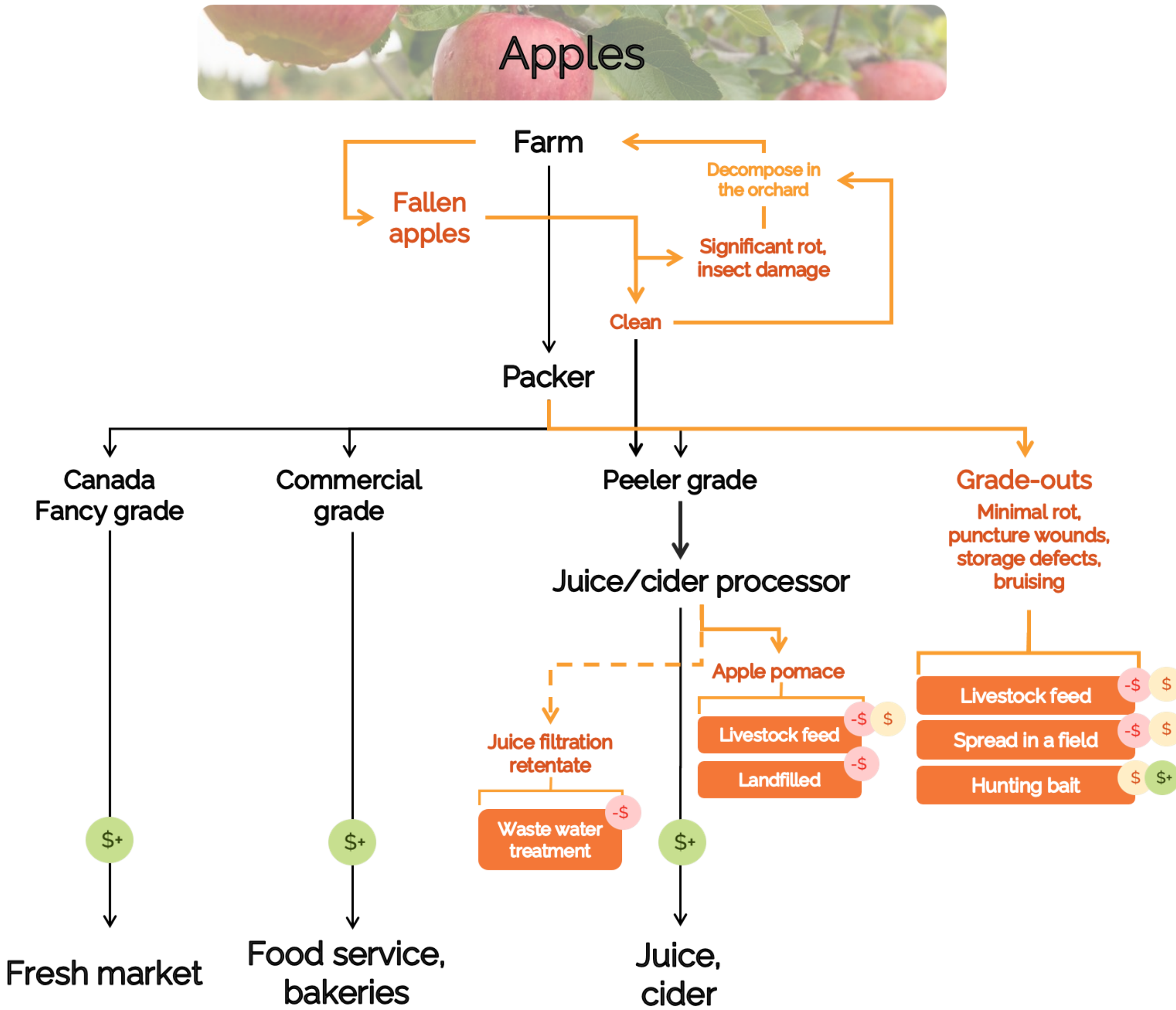

Figure 3. Sources of apple by-products in the value chain.

Carrots

Canadian carrot production

Across Canada, 354,640 metric tonnes of carrots were produced in 2020. Ontario and Quebec are the major Canadian carrot growing regions, accounting for 49 per cent and 28 per cent of production, respectively (Statistics Canada, 2021b).

In Ontario, approximately 28 per cent of carrots are exported, 54 per cent are sold domestically to the fresh market and 18 per cent is sold domestically for processing (e.g. canning, freezing) (Golden horseshoe food and farming alliance, 2020).

Carrot by-product streams

When carrots are mechanically harvested, carrots that are too small fall through the harvester claws and are left behind in the field. However, this accounts for only a small proportion of the carrots produced and the ones left behind decompose and add nutrients back to the soil. Green carrot tops are cut off during harvesting and are also left behind in the field to decompose.

Harvested carrots are kept in wooden crates and placed into storage until they are ready to be shipped to a packer. At the packing house, carrots are graded and sorted. No. 1s are well shaped with a specific minimum size, are free of blemishes or marks and are not cracked or broken. No. 1s are sold to the fresh market and often to processors as many processors require carrots to be a minimum size with a straight shape and specific dimensions to be compatible with their automated processing equipment. Other processors or food service operations can handle some broken, cracked and slightly or very oddly shaped carrots and can therefore use No. 2s for processing. The prices that processors pay to the growers for carrots depend on the amount of non-conformity that their processing operation can handle in terms of carrot shapes and sizes. It was reported that approximately 80 per cent of carrots qualify as No. 1s. Carrots that are very deformed or otherwise unsuitable for No. 2 grade account for approximately 2,500 pounds per acre (approximately 5 per cent) in a season. Ontario is the top carrot-producing province in Canada and around 50 per cent of Ontario carrots are produced in the Holland Marsh (incorporating Simcoe and York regions). Considering that there are over 4,000 acres of carrot production in the Holland Marsh, this area alone generates around 11 million pounds of carrot grade-outs annually. These carrots are sold for the lowest prices either to select processors, livestock farmers, hunters or pet food manufacturers. Some growers indicated interest in finding new purposes for these carrots in particular as the returns on these are minimal even though they are edible. Furthermore, when carrots are put into storage, storage loss due to rot can be as high as 10,000 pounds per acre of harvested carrots (approximately 20 per cent) in a bad year. Although these carrots are not edible, they may have acceptable in non-food applications.

When carrots are processed into diced pieces, the waste generated includes peels, tops, decay, discoloured carrots and in some processing operations, pulp from steam peeling. Large processing facilities generate an average of three million pounds of carrot by-product annually. This waste is often given away to livestock farmers or farmers who spread the waste on their pastures to decompose. Processors typically pay for the costs of transport to the farms.

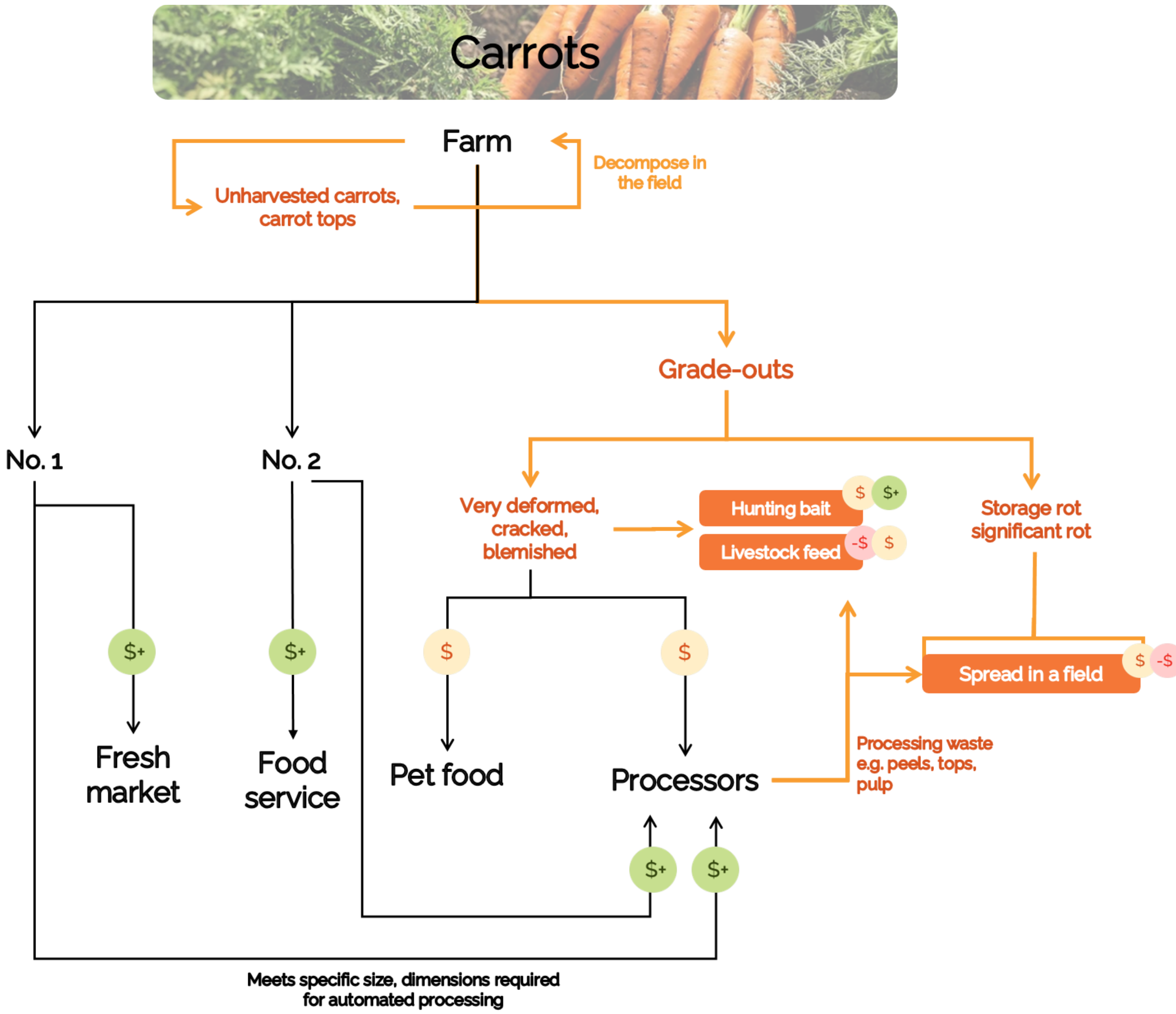

Figure 4. Sources of carrot by-products in the value chain.

Greenhouse tomatoes

Canadian greenhouse tomato production

Canada is the largest greenhouse tomato producer in North America and produced 256,360 metric tonnes of greenhouse tomatoes in 2020. Nearly three-quarters of greenhouse tomato production takes place in Ontario (71 per cent), with around 90 per cent of this concentrated in the area of Leamington. Greenhouse production is expanding in other provinces such as British Columbia, Quebec and Alberta, however they currently only account for 15 per cent, 9 per cent and 5 per cent of national production, respectively.

Greenhouse tomatoes are grown exclusively for the fresh market. Although greenhouse tomatoes are available year-round, as indicated earlier in the report, only field tomatoes are used for processing due to their lower production costs and higher Brix.

Greenhouse tomatoes include a number of different tomato categories such as tomatoes-on-the-vine (TOVs), grape tomatoes, roma, beefsteak and specialty tomatoes such as cocktail.

One tomato crop cycle is completed annually. Currently, around 80 per cent of Canadian greenhouse tomato growers grow under natural light. New vines are started in the greenhouse in January and tomato harvesting begins in late March/early April and ends in late October/November when days in the Canadian winter become too short to sustain tomato production. Growing under artificial lighting (HPS or LED) is becoming increasingly popular to provide a year-round supply of local tomatoes. In these operations, tomato vines are started in September and harvesting takes place in December to July. In either production system when the crop cycle ends, the greenhouse is cleared out by removing all of the vines along with strings and growing media and the space is sanitized.

Greenhouse vegetables are most often grown in soil-less media such as rockwool contained in plastic bags, referred to as grow bags. Only organic greenhouse vegetables, which account for a small proportion of the greenhouse vegetables grown in Canada, are typically grown in an organic soil mix.

Unlike field tomatoes, which consumers are more accustomed to seeing in their own gardens and which grow to a determined size, greenhouse tomato varieties have indeterminate growth. This means that they continue to grow upwards throughout the entirety of the growing season. As they grow, vines are held up by plastic clips attached to polyester strings for support. As vines grow upwards, they are lowered each week so that although the vines reach around 40 feet in length by the end of the season, they are never more than 15 to 20 feet off the ground (Figure 5). As will be discussed in the next section, the presence of plastic clips and strings attached to vines is a significant challenge to organic waste management in greenhouse vegetables. Some growers have attempted to use strings made of natural materials such as jute or hemp but these materials are not able to sustain the weight of the vines as the season progresses. As such, the strings eventually fail and vines need to be re-strung. Compostable clips are also available on the market however, few growers use them due to their high cost.

Figure 5. Greenhouse tomato production.

Greenhouse tomato by-product streams

Greenhouse tomatoes are graded according to two grades: No. 1s and No. 2s. No. 2s include tomatoes that have slightly blotchy ripening, are slightly misshapen or have a scar from a cut that has healed over or are slightly over-ripe. In all of these cases, No. 2s are still edible products. However, since greenhouse tomatoes are grown exclusively for the fresh market, there is very little use for No. 2s. Some are sold to food service, but the food service market for greenhouse tomato grade-outs is very small. As a result, although the defects in No. 2s are largely cosmetic, tomato grade-outs are virtually all discarded.

In the Prairies and British Columbia, greenhouse tomato grade-outs are typically applied to a field near the greenhouse and allowed to decompose. While some greenhouses do not manage the field, others rent their fields out to agricultural crop farmers in alternating years so that the nutrients from decomposed tomato waste contribute to the nutrition of agricultural crop production. In the past, this practice was also applied in Leamington. However, due to the high concentration of greenhouse operations in Leamington, the practice was eventually banned due to concerns over the spread of airborne tomato diseases. Currently all of the No. 2 tomato fruit grown in Leamington is landfilled. Approximately 2 to 3 per cent of all the tomatoes grown in greenhouses are grade-outs and are therefore wasted. This is equivalent to around 15 thousand pounds of fruit waste per acre annually. Considering that there are approximately 1,000 acres of greenhouse tomato production in Leamington, this equates to around 15 million pounds of edible tomatoes that are landfilled every year in this one area of the country.

In addition to fruit waste, there is a substantial amount of green waste generated from tomato production. Throughout the growing season, leaves on tomato vines are selectively pruned (i.e. de-leafing) to ensure the tomatoes have adequate sun exposure and to facilitate harvesting of the fruit. Some greenhouse operations collect these leaves and add them to their organic waste pile (if they have land available for this purpose). However, due to the labour costs involved in gathering these leaves, the vast majority of greenhouses allow them to drop to the greenhouse floor where they dry out for the remainder of the growing season. Spread of tomato disease is not a concern from these leaves as the greenhouse floor is sanitized on a regular basis. At the end of the growing cycle, all the leaves from de-leafing as well as tomato vines and rockwool growing media are collected into large bins. Due to the contamination from plastic strings and clips on the vines, this waste cannot be added to a compost pile and it is instead landfilled in all regions of Canada. Roughly 60 million pounds of tomato vine and leaf waste is landfilled annually in Leamington alone. Note that this weight includes the wet rockwool growing media, plastic clips and strings mixed in with the vines.

In regions where tomato waste is allowed to be spread on fields, tomato vines are sometimes kept in a pile in a field and then transported to a landfill in the summer months after they have had time to dry out. Like all other fruits and vegetables, tomatoes are high in water content which makes them heavy and expensive to ship. Thus allowing time to dry out can substantially reduce shipping costs.

Of note, was that all of the greenhouse growers interviewed expressed a great deal of concern about the environmental impacts of landfilling their waste and were keen for more sustainable alternatives. The combination of the volume of waste and the willingness of the sector to adopt new, environmentally-friendly solutions make this a particularly attractive area for future innovation.

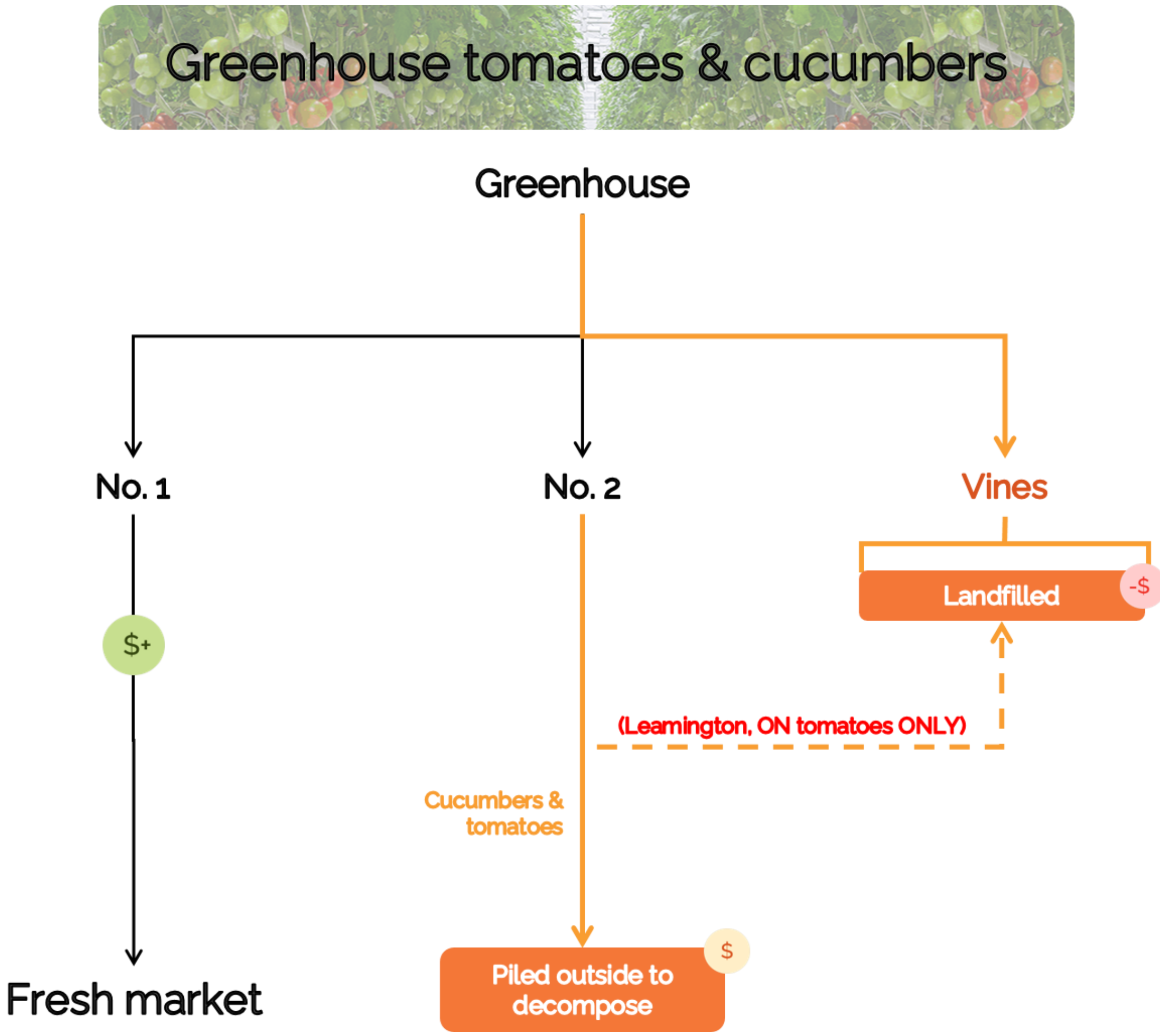

Figure 6. Sources of Greenhouse tomato and cucumber by-products in the value chain.

Onions

Canadian onion production

Canadian farms produced 232,800 metric tonnes of onions in 2020, with 42 per cent produced in Quebec and 38 per cent in Ontario.

Onions are grown for both the fresh market (i.e. cooking onions) and for processing. For ease of peeling and processing, processing onions must be three to four inches in diameter and have a single centre (Davidson, 2018). Unfortunately, it was not reported what percentage of onions are grown for the fresh market versus for processing.

Onions are typically mechanically harvested into crates and taken to storage for curing. During curing, onions are kept at warm temperatures for several weeks. During this time, as the onion bulbs mature, they draw energy from the green tops which dry out as a result. Once the tops dry out, the opening between the green top and onion bulb closes thereby preventing rotting and extending shelf-life. When curing is complete, onions are gradually cooled to refrigerated temperatures and are either packed on-site or shipped to a packer.

Onion by-product streams

There is little waste in onion production, harvesting and curing as the whole onion plant is harvested for curing and as the tops dry out they become wisps that simply fall away.

During packing, onions are sorted and graded for size, mechanical damage, deformed shape and rotting bulbs are removed. Onions are graded according to two grades: No. 1s and No. 2s. Approximately 3 per cent of onions are graded out and usually spread onto agricultural fields that are not used for onion growing so as not to transfer onion diseases. These onions decompose and add nutrients to the soil. If a grower does not have access to fields that are not used for onion growing, they may need to landfill the onions however it was reported that this was not common. Quebec is the province with the highest onion production in Canada with around 116 metric tonnes produced in 2021. Considering that approximately three per cent of harvested onions are graded out, this is equivalent to approximately 6.4 million pounds of onion grade-outs in Quebec alone. It was common for onion growers to also grow carrots and, interestingly, interviewed growers that cultivated both crops expressed more of an interest in finding solutions for by-product streams from carrot production than onion production.

In addition to the fresh market, many onions are also processed into fresh or frozen diced onion, onion rings or prepared products produced by CPGs such as sauces, salsas, soups or frozen meals. Onions that are graded out at the processing facility due to cosmetic issues, such as being severely misshappen or having discolourations, may also be sold for use in formed products such as vegetarian patties or hamburger patties. During processing, waste is generated from onion peels, hearts (the centre of the onion) and tops. Although we were unable to estimate the total volume of onion processing by-products, it was determined that there are several large fresh cut onion processors in Canada that produce significant volumes of onion processing by-products. The processors that were interviewed had arrangements with farms that accept the waste and apply it to their fields to decompose and add nutrients to their soils.

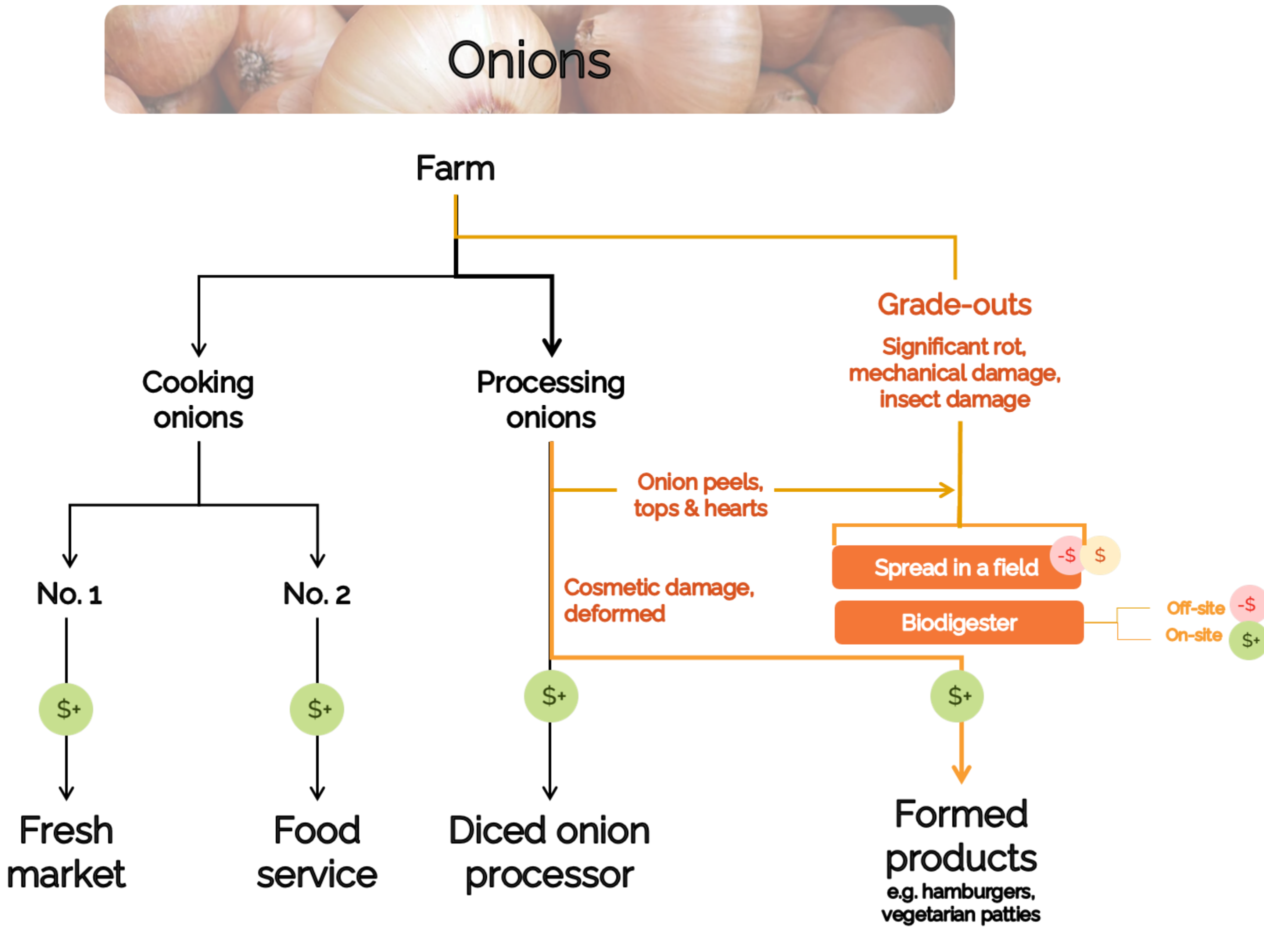

Figure 7. Sources of onion by-products in the value chain.

Greenhouse cucumbers

Canadian greenhouse cucumber production

Canadian greenhouses produced 243, 896 metric tonnes of cucumbers in 2020. Similarly to tomatoes, the vast majority of Canadian greenhouse cucumbers originated from Ontario (76 per cent), mostly from the Leamington area. Other greenhouse cucumber producing provinces include British Columbia (10 per cent), Alberta (8 per cent) and Quebec (5 per cent) (Statistics Canada, 2021c).

All greenhouse cucumbers are grown for the fresh market and they include variety categories such as long English cucumbers and mini cucumbers.

Depending on the operation, some grow cucumbers using what is called an umbrella system and others, often newer operations, use a high wire system (Figure 8). While cucumber vines remain relatively low to the ground in the umbrella system, high wire, as the name implies, trains cucumber vines to grow vertically.

Figure 8. High wire greenhouse cucumber production.

Cucumber vines in umbrella systems are strung up using either plastic or jute strings. However, the weight of the vines in high wire systems makes it impossible to use jute strings and therefore only polyester strings and plastic clips are used to string up vines in high wire systems. Similar to greenhouse tomatoes, greenhouse cucumbers are also grown hydroponically using media such as rockwool in grow bags.

Depending on the operation and growing system used, growers may have two to four growing cycles per year with cucumber vines and growing media being cleared out and disposed of in between each cycle.

Greenhouse cucumber by-product streams

Greenhouse cucumbers are graded according to No. 1 and No. 2 grades. No. 1s are sold exclusively in the fresh market while No. 2s are discarded. No. 2s include cucumbers that are not the correct size, are too curved or have nicks or cuts. Because there are no regulations prohibiting land application of cucumbers, even in Leamington, greenhouse cucumber grade-outs are typically spread or piled in fields outside greenhouses and are allowed to decompose. At the start of a crop cycle, around 1 per cent of cucumbers are No. 2s and as the season progresses, this percentage increases. However, the rate of No. 2s is never higher than five per cent. If we assume an average grade-out rate of three per cent, this equates to roughly 12 million pounds of edible cucumbers wasted across Canada with around 11 million pounds in Leamington alone.

Throughout the production season, leaves are selectively pruned from vines and allowed to dry out on the greenhouse floor. At the end of each production cycle, the dry leaves are removed along with cucumber vines. If using jute, the cucumber vines can be discarded in a field since jute is a natural fibre. However, as mentioned above, jute strings are only an option for umbrella cucumber growing systems and high wire systems may only use polyester strings. Therefore, vines from high wire cucumber growing operations, as well as greenhouses using umbrella growing systems with plastic strings and clips must be landfilled due to plastic contamination. Some operations shred and compact vines prior to shipping to reduce transport costs. Cucumber vine waste (including the weight of plastic contamination, excluding rockwool) accounts for around 15, 000 pounds per acre per crop cycle. In Ontario alone, mostly in Leamington, around 42 million pounds of vine waste is discarded annually if we assume an average of three crop cycles annually.

The flowchart depicting greenhouse cucumber by-products is show in Figure 6 on page 22.

Summary

Whole, uncut product seconds, such as apples and carrots that do not meet the standards for the fresh market, account for large volumes of product and these are generally sold for further processing. Since the lowest grades tend to generate only break-even returns for growers or distributors, they are open to new higher value uses for these streams. However, the need for innovation is greater in other sectors where by-product streams are highly underutilized. For example, the greenhouse sector is currently reliant on either landfilling much of their edible by-products or leaving them to decompose in piles outside greenhouses. Neither of these options are environmentally favourable and, in the case of landfilling, the current practice is also very costly for producers. By-products from the processing sector (e.g. peels, pomace) are most often diverted to livestock feed or biofuel though both zero-waste options usually come at a significant cost to the processor due to trucking costs or biodigester fees. Many processing by-product streams have a potential to be diverted to secondary processing to create value-added products and by-productwill be discussed in sections 4 and 5.

Table 2 on page 28 summarizes the sources and volumes of by-product streams in the top seven Canadian horticultural crops. Note that the volume estimates are only intended to provide a general sense of the size of by-product streams available for transformation and the estimates are not comprehensive. Considering that most processor relationships depend on contracts with individual suppliers, where possible, average waste stream volumes from a typical processing facility were provided.

Volume estimate limitations:

- Where possible, average volumes of by-product generated for a typical processing facility are provided in Table 2 on page 22. However, volumes are based on ballpark estimates provided by interviewees thus the values may not be representative of the industry as a whole.
- Whole fruit or vegetable by-product estimates (e.g. whole potato or whole apple) are based on Statistics Canada data for Canadian production volumes and estimates are calculated from grade-out rates provided by interviewees. These values only consider domestically grown product and there are likely to be more whole product grade-outs in the value chain from imported fresh market products. Thus, these values can be considered minimum amounts.

Table 2. Summary of horticulture by-product stream volumes

Crop	By-product stream	Annual volume estimates
Potatoes	Fresh market whole potato grade-outs (no rot)	8 million pounds (large potato distributor)
	Peels	133 million pounds (province of Manitoba) 114 million pounds (province of Alberta)
Field tomatoes	Peels	8.5 million pounds (large processing plant)
Apples	Whole apples, peeler grade (no rot)	99 million pounds (province of Ontario)
	Peels, cores, pomace	1 million pounds (mid-sized processing plant) 4.5 million pounds (large processing plant)
	Apple juice filtration retentate sludge	2 million litres (mid-sized processing plant)
Greenhouse tomatoes	Whole tomato grade-outs (no rot)	15 million pounds (Leamington area)
	Tomato vines (including plastic contamination and rockwool)	60 million pounds (Leamington area)
Carrots	Whole fresh carrot grade-outs (no rot)	11 million pounds (Holland Marsh area)
	Carrot tops, peels and bits and pieces	3 million pounds (large processing plant)
Greenhouse cucumbers	Whole cucumber grade-outs (no rot)	11 million pounds (Leamington area)
	Cucumber vines (including plastic contamination, no rockwool)	42 million pounds (Leamington area)
Onions	Onion grade-outs (small size, mechanical damage, deformed, rot)	6 million pounds (province of Quebec)
	Peels, tops	Unknown

4. Nutritional and functional composition of horticultural by-product streams

Fruits and vegetables are known for containing high levels of nutritional and functional components. Many such components can be capitalized upon when converting horticultural by-product streams into sellable products. Thus to provide insights into the potential of these by-product streams, the ensuing section will describe the most recognized macro and microcomponents of each of the top seven Canadian horticultural crops and their waste by products (e.g. pomace, peels).

The nutritional and functional composition of horticultural by-product streams will focus on two broad categories: macrocomponents (e.g. protein, fats, fibre content) and microcomponents (e.g. polyphenolics, pigments, vitamins and minerals).

4.1 Macrocomponents

Macrocomponents of whole horticultural crops and their waste by-products include total fibre, fat content, protein, carbohydrates and ash (indication of mineral and trace element content).

Macrocomponents are summarized in Table 3 on page 30, however it should be noted that their composition varies depending on variety, growing conditions, processing method and waste preparation, for example the drying method for apple pomace preparation.

Table 3. Macrocomponent composition of top horticultural crops and their waste by-products (% dry weight):

Crop (whole or waste by-product)	Total fibre[a]	Fat	Protein	Carbohydrates[a]	Ash	Reference
Apple (whole)	12.8%	1%	0.9%	81.1%	2.6%	(USDA, 2020)[b]
Apple pomace (fresh)	69.7% (includes 9.5% soluble)	2.4%	5%	nr	1.8%	(Younis & Ahmad, 2015)[b]
Apple juice retentate	nr	5.5%	31.3%	61.1%	nr	(Dhillon et al., 2011)
Potato (whole)	5.2-5.6%	nr	7.1-9.7%	70.5-72.4% (starch) + 3.3-6.0% (free glucose)	nr	(Liu et al., 2007)
Potato peel	44-56%	1-2%	18%	17-25% (starch)	6-11%	(Camire et al., 1997; Liang & McDonald, 2014a)
Tomato (whole)	22%	4%	16%	48%	9%	(USDA, 2019)
Tomato pomace (fresh)	54%	14.5%	17%	11%	3.5%	(Silva et al., 2016)
Tomato seed meal	34.7%	26.6%	30.7%	nr	3.9%	(Isik & Yapar, 2017)
Cucumber (whole)	12.63-25.01%	2%	12-18.46%	44%	nr	(Al-Far et al., 2022; Papadopoulos, 1994)
Cucumber peel	11%	1.8%	34%	43%	10%	(Niyi et al., 2019)[b]
Onion (whole)	6.1%	15%	9%	65.2%	2.3%	(Bello et al., 2013)
Onion peel	60%	1.1%	6%	9% (free sugar)	11%	(Osojnik Črnivec et al., 2021)
Carrot (whole)	30%	9%	33%	26%	1.9%	(Boadi et al., 2021)[b]
Carrot peel	45.5%	1.5%	9.7%	33%	10.3%	(Chantaro et al., 2008)

[a]Total fibre includes both insoluble (i.e. cellulose) and soluble (i.e. pectin) and carbohydrates include both free/soluble sugars and starch, unless otherwise specified.
[b]Composition converted to % dry matter DM, for clarity.
nr=not reported in publication

4.2 Microcomponents

Many vegetables and fruits and their corresponding waste products are rich in microcomponents including polyphenolics, flavonoids, vitamins and minerals. The following section will focus on the main or unique microcomponents for each individual crop and their by-products. For brevity, the nutritional and functional components listed in this section are not exhaustive and minor components rarely discussed in the literature will not be mentioned.

Due to their significance in by-product stream conversion to value-added products, naturally occurring toxins present in these crops and their waste streams will be discussed.

Potatoes

Potatoes contain antioxidant substances including phenolics (chlorogenic acid and caffeic acid) in abundance and certain purple varieties also contain anthocyanin content (O'Shea et al., 2012). The macromineral content of surplus and cull whole potatoes is highest in potassium (2.15 per cent dry matter) and phosphorus (0.22 per cent dry matter) (Wadhwa & Bakshi, 2013).

Additionally, potatoes are rich in several microcomponents, especially vitamin C. They are also a good source of vitamins B1, B3, B6, folate, pantothenic acid, riboflavin and minerals, such as potassium, phosphorus and magnesium (Murniece et al., 2011).

Potato peels contain a variety of valuable components including antioxidant, phenolic compounds (Gebrechristos & Chen, 2018a; Javed et al., 2019; Pathak et al., 2018; Torres & Domínguez, 2020) and can reach almost three times the antioxidant activity of the other plant tissues (Sepelev & Galoburda, 2015). The dominant phenolics in potato peels are chlorogenic and gallic acids.

Potato leaves, discarded after the harvesting of tubers, have high levels of carotenoids, particularly lutein, as reviewed in Torres & Dominguez (2020).

Potato peels contain 10 per cent of the glycoalkaloids, which are also present in leaves and act as a natural pest deterrent (Gebrechristos & Chen, 2018a). However, glycoalkaloids are toxic to humans when consumed above a certain threshold and levels must be monitored when converting potato peels to human food.

Glycoalkaloids are a class of bitter-tasting compounds naturally produced by plants of the Solanaceae family including potatoes and tomatoes. Mild cases of poisoning can cause a burning sensation in the mouth as well as flu-like symptoms including nausea and vomiting. More severe cases of poisoning can cause neurological effects such as shaking and confusion. Treatment is largely supportive and in severe cases of poisoning, recovery is expected within one to two weeks (Kliegman et al., 2020). Glycoalkaloids from different plants vary in their toxicity and it has been found that potato glycoalkaloids are more toxic than those found in tomatoes. Health Canada has an established allowable limit of 20 mg total glycoalkaloids per 100 g of fresh potato (Health Canada, 2011).

Potatoes contain the alkaloids alpha-chaconine and alpha-solanine. These alkaloids are mainly found in the peel and occur in higher concentrations in the parts of potatoes that are green, sprouting, cut or bruised (Health Canada, 2011). Concentrations vary by potato variety, growing locationand conditions, maturity and time in storage (Benkeblia, 2020). Although it is rare for people to encounter high enough concentrations of glycoalkaloids in potatoes to cause a problem, this must be considered if food ingredients are to be produced from potato peels.

Tomatoes

Lycopene is the main carotenoid found in tomatoes, accounting for 80 to 90 per cent of total carotenoids (Fărcaş et al., 2019). In addition to polyphenols and carotenoids, tomato is a source of vitamin C and has important levels of vitamin A, B and E (Domínguez et al., 2020).

Tomato wastes contain considerable amounts of phytochemicals and exhibit good antioxidant properties including phenolic compounds, flavonoids and carotenoids, such as lycopene (Fărcaş et al., 2019; P. A. Silva et al., 2019; Stoica et al., 2018; Szabo et al., 2019).

Tomato pomace contains approximately 42.18 to 70.03 mg lycopene/100 g dry weight, depending on the variety and pomace preservation technique (Fărcaş et al., 2019).

Tomato peels specifically contain lycopene and other carotenoids, β-carotene and lutein (Szabo et al., 2019). However, tomato seeds contain little lycopene (Lu et al., 2019b).

Much like potatoes, tomatoes are part of the Solanaceae family and therefore produce the toxic glycoalkaloids. Glycoalkaloids found in tomatoes include alpha-tomatine and dehydrotomatine. These compounds are mainly found in the leaves, stems and roots of tomatoes and only in low concentrations in the fruit. As mentioned in the potato section, tomato glycoalkaloids are less toxic than those found in potatoes. Due to the lower toxicity and the fact that people do not normally consume tomato leaves and stalks, poisoning from tomato alkaloids is unlikely and Health Canada does not have an established allowable limit. However, this is a factor that should be considered if tomato leaves and stalks are to be used for waste conversion into food products.

Apples

Apples are known for having large quantities of polyphenolic compounds and following the extraction process, it was estimated that 82 per cent to more than 99 per cent of polyphenols remained in the apple pomace (Antonic et al., 2020).

As reviewed in Skinner et al. (2018), apple pomace contains important microcomponents in higher amounts compared to whole apples, including potassium, calcium, phosphorus, iron, zinc, magnesium, vitamin C and E, likely due to the inclusion of the peel and seeds portion and an abundance of polyphenolics (predominantly located in the skin).

The enzyme activity profile of apple pomace powder indicates significant transglutaminase activity and low, but detectable tyrosinase (often called polyphenol oxidase) activity (Lantto et al., 2006).

Two compounds sometimes found in apples should be monitored during production of apple products, as they can be toxic to humans: patulin and amygdalin.

Patulin is a mycotoxin frequently found in rotting apple tissues and is directly associated with levels of blue mold. Apples that have stem punctures, insect damage or bruising are susceptible to the invasion of fungi producing patulin. Apples that are over-ripe or held in storage for a long time are also at higher risk of patulin contamination (Zhong et al., 2018). *P. expansum* is a blue mold that is the most significant cause of patulin contamination in apples and it can develop during storage. Apples that are over-ripe or stored for a long time may have enlarged pores that allow pathogens, such as *P. expansum*, to enter apple tissues. Thus the combined effect of increased susceptibility and potential for increased presence of blue mold during long-term storage, put stored apples at higher risk of containing patulin (Zhong et al., 2018).

Patulin is not typically a concern for fresh market apples but rather in processed apple products since these tend to use lower grade apples, some of which may have damage allowing mold development. Apples used in processing are sorted to remove damaged apples as much as possible. However, even with careful removal of all damaged and rotten apples, patulin is still detected in processed apple products due to the potential presence of blue mold in over-ripe apples or those that have been stored for extended periods of time (Zhong et al., 2018).

Health agencies around the world (Health Canada, WHO, FDA, among others) have set a maximum allowable limit of 50 µg/L in apple juice and apple cider. Apple sauce, often consumed by children, as well as apple products specifically produced for babies and infants have to meet stricter criteria and must have no more than 25 µg/kg and 10 µg/kg of patulin, respectively (Zhong et al., 2018).

Another toxic component of apples that should be considered in apple processing is the cyanogenic glycoside, amygdalin (Bolarinwa et al., 2015). Native enzymes in apples can act on amygdalin to release hydrogen cyanide, which is toxic to humans. Cyanide toxicity can occur in humans at doses of 0.5 to 3.5 mg/kg body weight. Mild toxicity can cause anxiety, headache, dizziness and confusion. More severe toxicity can cause decreased consciousness, hypotension, paralysis, coma or death (Bolarinwa et al., 2015).

Amygdalin is found in apple seeds, which are not normally consumed by humans. However, when apples are crushed for juicing, seeds may be broken, releasing amygdalin into juice. It has been found that the concentrations of amygdalin in apple juice are low (0.01-0.04 mg/mL) and not a concern for human health (Bolarinwa et al., 2015). However, if apple waste streams such as pomace are to be converted to food ingredients, higher levels of amygdalin may be present if the seeds are not removed. Thus, amygdalin concentrations should be monitored during product development and seed removal may be a required processing step.

Carrots

Fresh carrots come in a variety of colours and are a rich source of carotenes, especially β-carotene and other vitamins, like thiamine, riboflavin, vitamin B-complex, vitamin C (3.75 per cent wet basis) and minerals (Al-Amin et al., 2015; Bystrická et al., 2015) and are considered functional food (K. D. Sharma et al., 2012).

Carrot peels and pomace contain antioxidants such as phenolic compounds and pigments like anthocyanins and carotenoids (i.e. β-carotene), which vary with cultivar and processing treatment (Amin et al., 2021; Chantaro et al., 2008; Tiwari et al., 2019). Carrot peel contains 54.1 per cent of total phenols (Amin et al., 2021).

The total antioxidant activity of fresh carrot peels was 94.67 per cent and the antioxidant activity decreased after blanching and drying in in-vitro measurement of potential antioxidant activity (Chantaro et al., 2008).

Onions

Onions contain phenolics, flavonoids, flavonols, antioxidants and other phytochemicals.

Onion skin is a rich source of phenolics, including flavonoids with antioxidant capacities. In yellow onion, anthocyanins were the dominant pigment and flavonoids (80 per cent quercetin) accounted for half of the phenolics content (Osojnik Črnivec et al., 2021).

Red onion varieties were found to be a richer source of antioxidants than yellow varieties when using water extraction (Bedrníček et al., 2019) and ethanol extraction (Osojnik Črnivec et al., 2021).

Cucumbers

Bioactive compounds in cucumbers include polyphenolics and other phytochemicals including flavonoids, resins and terpenoids (Uzuazokaro et al., 2018).

Cucumber peel is a good source of flavonoids (John et al., 2018) and cucumber by-products (peel, pulp and seeds) can contain essential minerals such as sodium, potassium, magnesium and calcium (Niyi et al., 2019).

Summary

Fruits and vegetables are recognized for containing high levels of nutritional and functional components such as vitamins, antioxidants, texture-modifying compounds and vibrant natural colours, among others. In many cases, valuable components are even more concentrated in peels compared to flesh and these are often discarded during processing. Thus, the above identified by-product streams are teeming with potential for further use. A range of potential uses for these by-product streams will be explored in the following section. Table 4 on page 35 summarizes some of the noteworthy functional components of the top seven Canadian horticultural crops.

Table 4. Summary of macro and microcomponents of interest found in by-product streams of the top seven Canadian horticulture crops

Source of	By-product stream
Fibre	• Potato peel • Tomato pomace (peel, seeds) • Apple pomace • Carrot peel • Onion peel • Cucumber peel
Complex carbohydrates	• Apple (pectin) • Potato (starch)
Protein	• Potato • Tomato seeds
Pigments/antioxidants	• Potato peel (chlorogenic acid, gallic acid) • Tomato (lycopene, β-carotene, lutein) • Tomato vine (chlorophyll) • Apple peel (carotenoids, anthocyanins, chlorophyll) • Carrots (carotenoids) • Onion peel (3-O-gluside, quercetin) • Cucumber peel (chlorophyll)

5. Opportunities: Highlighting options for landfill diversion and conversion to value-added products

Background

Environmental stewardship is a major driving factor behind the recent push to improve waste management practices in various sectors of the horticulture and food industry. Landfill diversion is often the primary goal as this alternative has several major environmental downsides. Firstly, continued landfilling requires large and ever-expanding areas of land. Preservation of natural habitats is driving a need to limit urban sprawl, driving municipalities to make better use of the land within their boundaries. Landfills not only require large amounts of space, but their associated malodours and visual pollution limit the utility of their surrounding area.

Secondly, although there is a misconception that organic materials are not harmful to landfill as they typically decompose quickly, the environment within a landfill is not conducive to decomposition. Decomposition is accomplished by microorganisms and these act more quickly with access to moisture, nutrients and elevated temperatures. However, when waste is kept in large piles, moisture (e.g. rain) cannot penetrate far below the surface of the pile making the interior of landfill piles relatively dry. A study by Pommier et al. (Pommier et al., 2010) estimated that even cardboard requires around 15 years to degrade in a landfill.

When moisture and microorganisms are present, such as in the case of many food by-product streams, the lack of oxygen due to being buried under a vast amount of waste, favours anaerobic fermentation. Anaerobic fermentation produces greenhouse gases and landfills therefore are a notable source of carbon emissions (Nordahl et al., 2020; United States Environmental Protection Agency).

Clearly, landfilling is undesirable from a sustainability perspective. However, the costs of landfilling are also significant and often a major contributor to organizations' desire to divert from landfills. Producers and processors who landfill their by-product streams must not only pay labour costs associated with by-product stream handling and trucking costs for shipping to the landfill, but once the material arrives at the landfill they also must pay landfill tipping fees. In Ontario, tipping fees for organic waste from farms and from food processing are typically around $35-$60/tonne but can be as high as $260/tonne (Region District of Nanaimo, 2019) in other areas such as in parts of British Columbia. Thus, depending on the volume of by-product, tipping fees alone can add up to tens or hundreds of thousands of dollars annually depending on the size of the operation. Even when the distance to the landfill is less than 50 km, labour and trucking costs may add up to a similar amount as the cost of tipping fees.

Many landfills are operated by municipalities and the costs involved to operate these sites are substantial. Thus, municipalities are often motivated to divert from landfills and encourage the public to make use of alternative options such as composting and recycling which produce sellable products. In an effort to reduce landfill use, some regions have begun banning landfilling of organic waste. For example, the provinces of Nova Scotia and Prince Edward Island both banned landfilling of organic waste in the 1990s and Ontario will be implementing a similar ban in a phased approach, starting in 2022 (Logan, 2019).

For all of these reasons, there is growing pressure on the food and agricultural sectors to divert their organic waste streams from landfills and to find more sustainable and economically-viable solutions.

Two major approaches that producers can take to divert their waste from landfills exist: direct use of the by-product streams in their raw form or conversion to value-added products. Direct use includes options such as biofuel, animal food, land application, selling the material for further processing or donation. As has been described in section 3, direct use is currently the most frequently adopted approach by the fruit and vegetable value chain. This approach is low risk, requires little to no research and development, has limited upfront capital investment and is easy to implement while usually achieving sustainability goals. The major drawback is that the returns on these options are often either break-even or negative. Alternatively, organizations can invest in converting their by-product streams to value-added products. Conversion to value-added products requires more resource investment and higher risk however, it has the potential to generate better returns. Both of these options will be discussed in this section.

Direct use of by-product streams

Animal foods

As was described in section 3, the use of fruit and vegetable waste as animal feed (livestock, hunting bait or pet food) is very common in the Canadian horticulture and food processing sectors.

Livestock feed

Many fruit and vegetable growers and processors have developed relationships with livestock farmers who accept their raw by-products and feed them to their animals. This is a common solution as growers do not need to dry the product before selling and livestock farms can accept large volumes of product on an ongoing basis.

Some fruit and vegetable by-product streams are more suitable than others as animal feed. In general, the product needs to be fresh and ideally whole so as to not spoil too quickly. For example, chopped greens are not suitable for animal feed as they have too short a shelf-life. However, whole greens such as heads of lettuce were provided as an example of produce that is more acceptable. Furthermore, the material can only have a small amount of decay in the lot for it to be acceptable for animal feed. Another consideration is that not all produce is useful as animal feed since products with high water content have low nutrient concentrations and some produce, such as onion, is not well liked by livestock animals. Other fruits including apples can only be used in small proportions in the feed as too much can cause digestive problems in ruminants. The format of the fruits or vegetables is also important as whole, round products such as potatoes pose choking hazards to farm animals and must be ground prior to sale.

Among the by-product streams that are the subject of the current report, all but onions have been shown to be applicable as animal feed. Potato-processing waste is a valuable livestock feed ingredient for beef (Charmley et al., 2006; Radunz et al., 2003) pigs (Gebrechristos & Chen, 2018a), chickens (Wadhwa & Bakshi, 2013) and for aquaculture (Leyva-López et al., 2020). Tomato pomace and its seed component have been widely used as animal feed ingredients (Lu et al., 2019b; Wadhwa & Bakshi, 2013). However, interviews with an animal feed supplier indicated that whole tomatoes are not well liked by cattle. It was shown that cucumber fruit waste can replace a portion of cereal-based ingredients in goat feed without adverse effects (Romero-Huelva & Molina-Alcaide, 2012). In general, vegetable wastes (carrots, cucumber, etc.) are good sources of protein (up to about 20 per cent crude protein on a dry basis), energy, micro and macrominerals and mostly have high acceptability and palatability, making them efficient and valuable sources of animal feed (Bakshi et al., 2016). Apple pomace has also been used as animal feed however, it may only be used in limited quantity due to the high potential for rapid spoilage (Shalini, 2010) and its poor protein content (Antonic et al., 2020). Interestingly, it has been found that fermenting apple pomace makes it possible to use it as a dietary supplement for pigs (Ajila et al., 2015).

Another factor that must be considered when opting for diverting fruit and vegetable by-product streams to animal feed is the transportation costs. Interviews with the horticulture value chain indicated that the party responsible for trucking costs varied by the relationship. In some cases, the logistics and transport costs of material delivery fell to the livestock farmer but in most cases it was the fruit or vegetable producer or processor's responsibility to deliver the material to livestock farms. These costs can be substantial. However, many producers and processors opted to accept the transport costs to deliver to livestock farms as they considered them to be a cost savings compared with landfilling where they had to pay for trucking as well as tipping fees.

It was noted that some growers or processors invested in equipment to dry their by-product streams before diverting it to livestock farms. In these cases, growers or processors were able to sell the product to livestock farms rather than to give it away free of charge.

One area of concern related to diverting raw fruit and vegetable by-product streams to livestock farms is the potential for transmission of pathogens from the fruit and vegetable waste to farm animals. One interviewee noted that a farmer who used to accept their material stopped doing so over concerns related to the recent increase in outbreaks of pathogens such as S*almonella* and *E.coli* in fruits and vegetables.

Outbreaks linked to fresh fruits and vegetables have been increasing in recent years (Carstens et al., 2019; Kozak et al., 2013). Prior to 2019, the fruit and vegetable sector was primarily regulated for quality rather than food safety monitoring. However, new regulations were introduced in 2019 requiring any fruit or vegetable establishments that import or prepare fresh fruits and vegetables for interprovincial or international sale to be licensed. As part of the licensing, these fruit and vegetable establishments must now be responsible for managing the safety of their products via preventative controls, control plans and traceability (CFIA, 2019). Although this is beneficial for livestock farmers who are accepting fruit and vegetable by-product streams, it is worth noting that international standards for feed are also becoming increasingly more rigorous with regards to feed safety. Many regulatory bodies are working to align with international standards such as those recently released by the Food and Agriculture Organization of the United Nations (FAO and IFIF, 2020).

The Feeds Act stipulates that livestock feed must be either approved or registered before being manufactured, sold or imported into Canada. Canada is in the process of modernizing their Feeds Act and will begin implementing a requirement for feed producers to put in place hazard identification processes and preventative controls to manage food and feed safety (CFIA, 2021). Livestock producers who manufacture feed on-farm for their livestock (as would be the case when accepting raw fruit and vegetable by-product streams) are exempt from the Feeds Act as long as the feed is not medicated or sold off the farm (CFIA, 2021). Thus, selling fruit and vegetable by-product streams to livestock farms is currently in a grey area as these are not directly subject to the same regulations as the primary products produced by fruit and vegetable growers (e.g. fresh market product) and processors, and they are also not currently subject to feed regulations.

Considering that feed regulations are becoming increasingly strict, the long-term viability of this arrangement is unknown and it is possible that there may be barriers in the future to diverting raw fruit and vegetable by-product streams to livestock farms.

Other animal food

Selling by-product streams to the pet food sector is another option available to growers and processors. For example, apple juice filtration retentate is rich in protein and a study by Cruz et al. (Cruz et al., 2018) suggested the retentate would be suitable for use in feed industries that seek out alternative high protein sources, such as pet food or feed for racing pigeons.

However, this option was less common as pet food manufacturers most often only accept dry product that can readily be incorporated into their packaged pet food formulations. Some by-product streams, such as tomato peels, exit processing already dry making it easy to sell to pet food manufacturers. However, other by-product streams require a drying step. One apple processor that was interviewed indicated they invested in a dryer and dried their pomace for sale to pet food companies.

The idea of using by-product streams for sale to hunters came up several times in interviews, with some indicating they were already selling grade-outs (e.g. carrots) to them. This option was reported to generate better returns than selling for food processing. However, the need for hunting bait is seasonal and may not align with the availability of some by-product streams. One interviewee suggested that by-product streams could be processed into dry pellets and stored for sale to hunters during their hunting season. Overall, this is a niche market and may not be a suitable outlet for processors with large volumes of by-product.

Land application

Land application of by-product streams was another approach that was commonly applied by food producers and processors in Canada. It should be noted that land application is a general term that can have different meanings. In some cases, land application does not bring additional value, such as in the case of many greenhouse cucumber operations where cucumber grade-outs are dumped in large piles to decompose. Such piles are typically not managed and do not have favourable conditions for composting. If not moved or turned, these waste piles lead to anaerobic conditions, generating greenhouse gas emissions (typically methane) as the products decompose.

Alternatively, many growers or processors supply their by-product streams to farms that spread the material on pasture or agricultural fields. In both of these cases, the product decomposes aerobically as it is distributed in a thin layer or mixed in with topsoil. As it decomposes it adds nutrients and organic matter back to the soil to promote soil health. Particularly in the case of agricultural field amendment, the addition of fruit and vegetable waste can potentially offset a proportion of the need for synthetic fertilizers.

Interviews with growers highlighted a few challenges with land amendment of fruit and vegetable waste streams with disease transfer an important consideration. Before applying waste streams to agricultural fields, growers consider if diseases or pests affecting the waste crop may be transferable to the crops grown in that particular agricultural field. In some cases, due to disease transfer potential, farmers may not have a suitable agricultural field to accept the waste stream.

Another challenge may be encountered if the waste stream is wet and contains large chunks. This type of material can be difficult to spread evenly in the field with readily available equipment, such as manure spreaders.

Finally, prior to using fruit and vegetable waste streams as agricultural amendments, if large amounts will be land-applied, farmers need to understand the nutrient profiles of the waste streams and how these will complement the nutrient needs of their soils. The high water content of many waste streams is seen as a negative since nutrient concentrations will be low in the waste material relative to the total weight. Additionally, some waste streams may contain components that bind soil nutrients and therefore additional amendments must be added to compensate for this.

It was reported that the addition of potato pulp to potato fields before planting was particularly beneficial as it resulted in an increase in soil organic matter content, the C:N ratio, macroaggregation, carbon mineralization, microbial biomass and enzyme activities (Gagnon et al., 2001; Muter et al., 2014).

Nosalewicz et al. 2021 (Nosalewicz et al., 2021) conducted two laboratory experiments using raw apple pomace as soil amendment for growing wheat and faba beans under optimum and limited water availability. They found increases in soil respiration rate, reductions in nitrate levels and increases in ammonium levels, soon after incorporating the apple pomace into field soil. The growth of faba beans was not affected by the addition of apple pomace compared to the control, however the chlorophyll content was found to be higher in the apple pomace treatment. Wheat grown under limited water availability experienced reduced growth in the apple pomace treatment compared to the control, but no growth differences were observed in the optimum water availability treatment.

Biofuel

Biodigesters use microbes to digest materials and convert matter to methane gas (i.e. biogas), carbon dioxide and digestate. The methane gas is used to produce electricity, while the nutrient-rich digestate can be used as a fertilizer on agricultural fields. Fruit and vegetable by-product streams are already used as biofuel in biodigesters in a number of areas. Large potato processors in Atlantic Canada find a great deal of value in having on-site biodigesters due to high local energy costs and the high volumes of by-product streams available year-round from their processing facilities. However, this option may not be viable for all organizations depending on the volumes of feedstock available and local energy costs.

In some regions of Canada, such as Ontario, local biodigesters accept fruit and vegetable waste streams from processors. Processors pay biodigesters (or a third party) to accept their waste streams as biofuel for energy production. One of the benefits of diverting waste streams to biofuel is that the products can be accepted in various formats without prior to sorting such as rotting or fresh, raw or cooked. Some biodigester facilities can also accept products in packaging. Thus, some processors select biofuel as their preferred waste management option for the convenience and labour cost savings due to not needing to sort waste streams before disposal.

Plant materials differ in their efficiency as a feedstock in biodigesters. Therefore, different feedstocks must be studied to determine whether they can be used alone or in combination with other feedstock (e.g. manure) to optimize their fermentation.

Many of the crop by-product streams, that are the focus of this report, have already been investigated for their potential as biofuel. Biogas (CH_4) can be produced from potato peel waste produced from the anaerobic fermentation of starch present in peels (Javed et al., 2019; Wu, 2016). Cucumber agricultural and industrial waste has also been shown to be useful for biogas production (Lowe et al., 2020). When various onion solid wastes were investigated for biogas production under several pre-treatment conditions, it was determined that onion bulb wastes had relatively higher methane production potential and biodegradability compared to the leaves (Ligisan & Tuates, 2016). Apple pomace, from cider production, was found to provide excellent biogas production when co-digested with waste from meat production (Llaneza Coalla et al., 2009).

Selling for further processing

Due to the low need for investment and potential for returns, many growers and processors indicated interest in selling their by-products.

In many sectors, particularly for whole fruit and vegetable grade-outs, this approach has become standard. With the exception of greenhouse vegetables, all other fruit and vegetable growers that grow for the fresh market, sell their lower grade product to food service (e.g. restaurants, school and hospital cafeterias, catering) or for further processing at reduced prices. Although returns are generally break-even after accounting for costs, this alternative is more economically beneficial than landfilling or giving product away to local farms at no cost.

While this option is a common outlet for whole fruits and vegetables, similar opportunities are lacking for by-product streams arising from fruit and vegetable processing. One of the challenges of using materials such as pomace and peels is that plant tissues are cut, therefore spoilage progresses more quickly. If processors were to accept these materials, particularly if they are wet, they would need to be located in close proximity to the source and be able to run the product through their processing line soon after arrival. Additionally, some by-product streams are not pure fruit and vegetable discards and may contain processing aids or debris. For example, some processors that process multiple crops on parallel lines within a plant direct all waste streams onto a single conveyor. Thus, the final by-product stream may contain varying amounts of discards from different crops depending on the week as well as field debris from the washing and sorting stages of processing, making these streams no longer food grade.

Several processors indicated that although they see the value of their processing by-products, investment to develop a new processing line to transform their by-products into sellable ingredients is too far outside the scope of their core business. Most processors instead hope that a processing industry may be developed that would have a need for their by-product streams.

Considering the perishability of cut horticultural by-products, in order for these to be used in further processing some compromise may be required. Fruit and vegetable processors may need to consider purchasing drying equipment to extend the shelf-life of their by-product streams thereby opening opportunities to sell the by-products to other enterprises that would then convert these to value-added products. Alternatively, there is an opportunity for a company specializing in drying fruit and vegetable products to situate itself in close proximity to various fruit and vegetable processors and make a business out of drying and re-selling fruit and vegetable by-products to other processors.

Food donation

In the case of whole fruit and vegetable grade-outs, there may be an opportunity to establish relationships with local charities in need of food for disadvantaged communities. Although this option would not generate direct returns, some companies engage in these initiatives as part of their corporate social responsibility strategy and as a marketing tool.

One carrot producer indicated that they regularly donate No. 1s to a local food bank to promote their product to the local community while supporting individuals in need. However, it is not necessary to donate No. 1s and some growers, such as in the greenhouse sector, indicated they donate a portion of clean, edible product with minimal cosmetic defects (i.e. No. 2s) to local food banks. Of interest is that there is a Canadian organization, Second Harvest, that helps businesses from across Canada with surplus food donate their product by connecting them with charities and non-profits via an online and mobile app, thus simplifying the donation process.

Another interviewee noted an initiative in recent years in France, whereby a large potato processor hired individuals unemployed for a long time to pick up unharvested potatoes from their fields. These potatoes were then used to produce potato soup sold to local retailers and some of the soup was also donated to local food banks. The initiative was part of the company’s social responsibility strategy (Beal, 2017).

Some regions of Canada provide tax benefits to farmers that donate their product. For example, Ontario has implemented a Food Donation Tax Credit for Farmers. This tax credit gives farmers a tax credit of 25 per cent of the fair market value of the product they donate (OMAFRA, 2021).

Conversion to value-added products

As was outlined in section 4 of the report, fruit and vegetable by-product streams contain many valuable components providing nutritional or functional value. Many options are available for converting these by-product streams to value-added food and non-food products. Both food and non-food by-product conversion opportunities may hold a great deal of potential, however the current report will focus on food-related opportunities. Thus, the ensuing section will provide an in-depth discussion of food-related opportunities as well as a brief overview of several non-food by-product conversion opportunities.

Food applications

Background

A number of consumer packaged goods companies were interviewed to better understand some of the trends currently driving ingredient selections. These interviews provided insights into how horticultural by-product streams may be converted to fill gaps in the food ingredient market.

A number of major food consumer packaged goods companies indicated that they had assembled an environmental sustainability team in recent years. The initiatives undertaken by these teams vary across companies but in general, many aim to find solutions to reduce processing waste, to use more sustainable ingredients and packaging or to reduce the organization's carbon footprint. A number of interviewees felt that the backstory of using ingredients converted from by-product streams would be attractive, as long as these ingredients came at a reasonable cost.

This waste conversion opportunity also fits within another major trend in the food industry: clean label products. This was the most frequently cited trend currently impacting ingredient selection and product reformulations at most of the interviewed consumer packaged goods companies. Clean label is defined as "non-scientific, plain language on packaging, reduced allergens and additives, and fewer, more recognizable ingredients" (Gordon food service, 2022). Fruit and vegetable extracts or concentrates have a great deal of potential to fit within this trend. Fruit extracts, concentrates or purees are simple for consumers to understand and are well received. Additionally, they are free of common allergens such as dairy, soy and gluten and the vast majority of fruits and vegetables are not genetically modified.

Fruit and vegetable by-products also have the potential to offer functionality that may be needed when allergens are removed while trying to meet clean label objectives. For example, dairy, soy and gluten are sometimes added to food products for their desirable texture properties such as thickening. Some fruit or vegetable by-products may be able to replace allergens as thickeners, since some fruits and vegetables are high in starch or pectin. Furthermore, fruit by-product streams that are high in pectin may be useful to account for the loss in water holding capacity when gluten is removed from some products (e.g. sausages). A functionality that was noted as being difficult to achieve using currently available clean label ingredients was emulsifying. Some products derived from fruit and vegetable waste, such as potato and tomato seed protein, have been shown to exhibit good emulsifying properties (Sarkar et al., 2016). One limitation of the clean label initiative that should be noted is that whatever ingredient is added should not look out of place in the ingredient list from a consumer perspective. For example, an apple powder may seem out of place in a lasagna and would therefore be unlikely to be used in that context.

Starting in 2019, Health Canada began to make significant overhauls to food labelling regulations aiming to increase clarity for consumers. This overhaul poses another challenge to clean label initiatives. For example, one of these changes was that all sources of sugar must be declared together. Food ingredients are listed in order of content by weight. In the past, companies could use various sources of sugar (sucrose, cane sugar, etc.) and then list these separately such that the sources of sugar would be further down the ingredient list. This is no longer possible as such ingredients would now have to be listed as a combined ingredient i.e. "sugar (sucrose, cane sugar, molasses)". This regulation is also of interest to the current discussion as food companies sometimes use fruit purees or concentrates for sweetening. Now, these fruit juice concentrates, purees or fruit pastes must be grouped together under sugars in the ingredient label. Despite this, interviewees indicated that using fruit concentrates or purees as a source of sweetness was still attractive as it maintains a cleaner label than ingredients such as corn syrup or fructose.

Another challenge to clean label initiatives due to the recent overhaul in food labelling in Canada, is the upcoming changes to sugar, sodium and saturated fat labelling. In the coming years, Health Canada will introduce regulations requiring companies to include front-of-package labelling for packaged foods that are high in sugar, sodium or saturated fats (Health Canada, 2021). As such, sugar and salt reduction is trending in a number of product categories. It is known that some flavour volatiles in fruits and vegetables can enhance the perception of sweetness. Therefore, it may be possible to reduce sugar levels in products by using fruit concentrates for sweetening rather than pure sugars. Furthermore, fruit or vegetable concentrates (or similar products) may be able to compensate for some of the functionality that sugar accounted for and is now lost by sugar reduction including viscosity, browning and providing bulk.

Fruit and vegetable by-product streams can provide a number of different functionalities while helping CPGs meet clean label objectives. In order to benefit from these functionalities, these waste streams may be converted to powders, concentrates or extracts. Some potential roles that fruit and vegetable wastes could play in product formulations will be discussed below.

Fibre

When asked if added fibre was of interest in product formulation, interviewees indicated that adding fibre was a trend from a few years ago however, there was not much uptake for it in the market. In particular, added fibre is not an element sought after in indulgent products. On the other hand, fibre content is an element product developers target in some categories such as healthy baked goods (e.g. whole grain muffins, granola), healthy breakfast cereals and health-conscious kids snack foods such as whole grain crackers, extruded fruit and vegetable snacks (e.g. green pea crisps). Recently, a number of consumer packaged goods companies have also released product lines with added fruit and vegetable powders such as kids crackers and macaroni and cheese.

All fruit and vegetable by-product streams offer a good source of fibre. As recently reviewed, potato peel waste is a source of healthy functional dietary fibre in the baking/food industry for biscuits, muffins and as a replacement for wheat bran (Javed et al., 2019) and able to replace up to 10 per cent of flour without changes in sensory quality (Sepelev & Galoburda, 2015). Potato peel powder can produce a protein/fiber-enriched cake with good sensory quality (Jeddou et al., 2017) and can replace 5 per cent wheat flour with acceptable sensory quality (Dhingra et al., 2012).

Onion waste powder can be used as a healthy ingredient in bread to enhance dietary fibre (Prokopov et al., 2018) and onion by-products (brown skin, top and bottom) are being researched as a source of dietary fibre for other food applications (Gray, 2011).

Carrot peels or discards can be used to create dietary fibre powders that are nutritionally-rich food ingredients or supplements (Chantaro et al., 2008; Clementz et al., 2019). Carrot pomace can be included in corn starch extrudates (Kaisangsri et al., 2016), carrot waste flour can be added to substantially enhance the fibre content of pasta (Porto Dalla Costa et al., 2016) and carrot mash or pulp can be included in meat patties (Lee, 2020; McDonnell & Tobin, 2021).

Apple pomace is a source of dietary fibre that can be used in a variety of food applications (Shalini & Gupta, 2010) including yogurt (Wang et al., 2019, 2020), baked goods (Kohajdová et al., 2014; Rocha Parra et al., 2015) and sausage (Yadav et al., 2016; Younis & Ahmad, 2015). Additionally, pectin from apple pomace has been added to a wide variety of food applications, imparting not only desired textural characteristics but also favourable apple flavours (Rabetafika et al., 2014). The ability of apple pomace to reduce yogurt syneresis (undesirable phenomenon that appears as an accumulation of whey on the surface of yogurt), is also attributed to its pectin content which can improve water holding capacity and trap whey separated from casein (Wang et al., 2019).

Tomato peel flour added to conventional pasta yielded high levels of dietary fibre and carotenoids, but lower overall scores for sensory properties including elasticity, firmness and overall quality. However, in a second step, researchers demonstrated that hydrocolloids (e.g. guar seed flour) can be added along with the tomato peel flour in order to improve the sensory properties of enriched pasta (Padalino et al., 2017).

Adding fibre-rich cucumber pomace powder to soft wheat flour used in noodle production at six per cent, produced noodles with better nutritional value while maintaining optimal sensory acceptability and other desirable characteristics, such as reduced cooking time (44 per cent reduction in cooking time over the control noodles) (Saad et al., 2021).

Natural colours

Currently, natural colours are very much in demand due to the clean label trend in the food industry. Natural colours are extracted from a variety of fruit and vegetable sources including red cabbage, tomatoes, berries, red beets, purple potatoes and others.

While a number of Canadian companies engaged in natural colour extraction in the past, in recent years many have moved away from extraction due to a fierce international competition. It was reported that the vast majority of natural colour suppliers in North America import and distribute colours produced in China and India due to their lower cost and only a minority have continued to manufacture in North America. Those who do manufacture in North America are able to do so as they have found a space in the market producing specialty natural colours. For example, Capol Inc. is a company with a facility in Quebec, that specializes in modifying imported colours with specialized encapsulation technologies to make the colours suitable for a wider range of applications (e.g. fat dispersible).

A small number of companies outside of China and India have been able to compete in the colour extraction market by offering premium products produced with proprietary extraction and/or colour stabilization techniques. For example lycopene, the red/orange pigment in produce such as tomatoes and orange sweet potatoes, is known for being difficult to stabilize. An Israeli company with locations in the United States (Lycored), has carved a space for themselves in the natural colours market due to their proprietary technologies enabling them to better stabilize lycopenes and offering a wide range of premium orange and red colours. Another company in the Netherlands (GNT Colors) developed a competitive edge by growing their own fruits and vegetables and selecting varieties that produce superior natural colours for extraction.

In most cases, when North American natural colour extraction companies have been able to remain on the market, they have done so with natural colour extraction of anthocyanins. Anthocyanins are pigments that may be red, orange, pink, purple or blue-purple depending on the pH (Falcone Ferreyra et al., 2012) and are found in many berries as well as red cabbage and purple potatoes. These pigments are generally simpler to extract and to keep stable and thus can be produced at competitive prices. Typically, North American companies that produce anthocyanin extracts do so from processing by-product streams such as cranberry or blueberry pomace from juice manufacturing or grape pomace from the wine industry.

Despite the market competition, there remain some gaps in the natural colour extraction market. For example, true blues, fire engine reds and greens are difficult to produce from natural sources and keep stable. This sentiment was echoed by an interviewee who commented that natural colours tend not to be as vibrant as artificial colours and consumers have to get accustomed to less vibrant colours in products. Additionally, clean label ingredients that can add whiteness to products are also in demand. Titanium dioxide has been used extensively to provide whiteness to products however, as of 2022 it is now banned as an ingredient in the European Union (European Food Safety Authority, 2021; Kades, 2022). Thus, companies exporting to Europe must find alternatives.

Some Chinese and Indian companies produce natural greens from extracted chlorophyll. Chlorophyll is difficult to keep stable and these companies typically use metals or salts to stabilize the pigment. Such stabilized chlorophylls tend to encounter regulatory barriers in many countries due to toxicity limits. Thus, it was reported that vibrant natural greens are also hard to come by in the market.

There may be opportunities to extend the applicability of natural colours to a wider range of applications by stabilizing them to different conditions. For example, manufacturers of products cooked at high temperatures (e.g. meat, baked goods) or products with certain pHs may experience more difficulty in finding suitable natural colours that are stable in those product environments.

Colouring foodstuffs are another category of natural colours. Unlike extracts, these are typically concentrates of fruits or vegetables used to add colour to a product (e.g. pumpkin concentrate). In the European Union, natural colour extracts are considered additives and as such are assigned an E-number (e.g. E102). Many European consumers recognize E-numbers as being additives and have negative associations with these ingredients. A benefit of using colouring foodstuffs is that they are not considered additives and therefore are a desirable option for companies seeking to maintain clean labels. The use of colouring foodstuffs is a growing trend in the food industry and an increasing number of companies are now beginning to offer colouring foodstuff options (Frankenne, 2010).However, it has been reported that colouring foodstuffs can be difficult to work with as they tend to have more stability challenges and a shorter shelf-life compared with extracted natural colours.

Of the crop by-products examined in this report, carrots, tomatoes, apple peels, onion peels and cucumber peels all have natural pigments that may be useful to the food industry.

In one study, the carotenoid-rich extract from carrot pomace was produced using a green bio-refinery concept to create a natural colourant (Tiwari et al., 2019). Encapsulated solid pigment can also be generated from carrot juice (Ramos-Andrés et al., 2021a).

Tomato by-products have been used as natural colourants for various meat products (Domínguez et al., 2020). Lycopene from tomato peels has been tested as a nutritional supplement or food colourant in several food categories, from breakfast cereal to butter to ice cream (Rizk et al., 2014; Stoica et al., 2018; Trombino et al., 2021).

Onion solid waste, containing cyanidin 3-O-glucoside, has been used to produce a red-coloured stable yogurt (Mourtzinos et al., 2018). In apples, the total pigment content is always much higher in the peel compared to the flesh for both total chlorophyll and carotenoid content, although this varies with cultivar. Granny Smith has by far the highest pigment content when compared to other green-skinned apples and yellow and red cultivars (Delgado-Pelayo et al., 2014). Cucumber peel as well as tomato and cucumber vines are sources of chlorophyll pigment (M. Sharma et al., 2021; Sonia et al., 2016).

Natural colours are very much in demand and horticultural waste streams offer a great potential to meet this need. However, the market is becoming increasingly competitive and in order to succeed, natural colour manufacturers must provide a unique value proposition such as vibrant, high quality natural colours with superior stability in a variety of conditions (e.g. pH, temperature, water/fat-soluble, shelf-life).

Antioxidants

Antioxidants include compounds such as phenolics, carotenoids and anthocyanins. These valuable compounds play several functions in health and food formulation.

Developing antioxidant rich food products for health promotion was reported to be a major trend several years ago however, this trend has decreased in priority for many companies in recent years. Canadian food regulations make it very difficult to qualify for a health claim related to antioxidant benefits in a food product. In order to be able to make a health claim related to antioxidants, the manufacturer must be able to prove that the antioxidant activity is still at the target level after the product is cooked or otherwise processed and throughout its shelf-life.

Phenolics, carotenoids and anthocyanins have other properties that make them useful to food formulation particularly for companies aiming for clean label products. As the term, antioxidant implies, these compounds can slow oxidation thereby preventing rancidity and extending product shelf-life. Some companies use natural antioxidant ingredients (e.g. rosemary extract, tea extract) for product shelf-life extension such as clean label meat products. However, a challenge noted with these ingredients is that they impart a taste that can be difficult to mask. Thus, there may be an opportunity to investigate the antioxidant activity of fruit and vegetable waste streams and its ability to prevent rancidity and to examine any corresponding contribution to product flavour.

Some naturally-occurring antioxidants have also been found to provide antimicrobial and/or antifungal properties and could play a role in food preservation. However, the use of naturally occurring antioxidants for food preservation would need to be thoroughly investigated and validated in each target product for effectiveness as it would have an important impact on food safety.

All of the waste streams examined for the purposes of this report have been found to contain valuable compounds with antioxidant properties.

The dominant phenolics in potato peels are chlorogenic and gallic acids, which have strong free radical scavenging ability in oily foods like soybean and vegetable oil (Gebrechristos & Chen, 2018a). Potato peel extracts contain antimicrobial compounds against bacterial and fungal organisms, potentially due to flavonoids and terpenes, giving them the potential application in food processing industries as an antimicrobial or food preservative (Gebrechristos & Chen, 2018a).

Industrial onion waste powder is rich in phenolics and flavonoids, mainly quercetin. In baking trials, onion waste powder containing bread showed significantly higher total phenolics, flavonoids and antioxidant activity compared to control bread (Prokopov et al., 2018). Onion skin-sourced flavonoids in pork patties have the potential to be used as a natural, strong antioxidant (Bedrníček et al., 2019) and onion skin extracts promote stabilization of olive oil products (Osojnik Črnivec et al., 2021). Additionally, yellow onion skin extracts showed antimicrobial and antifungal activities, presumed to be from both antioxidant substances in the onion skin in addition to quercetin (Osojnik Črnivec et al., 2021).

Tomato by-product extracts, such as flour from tomato waste can create a food additive rich in phenolics and carotenoids (Fărcaş et al., 2019; P. A. Silva et al., 2019; Paulino et al., 2020). Acceptable sensory quality in bread was achieved with up to approximately six per cent tomato waste addition (Nour et al., 2015).

Cucumber peel is also a source of phenolics and is considered a valuable natural antioxidant and source of flavanoids for industrial applications (Sonia et al., 2016). Finally, as mentioned in the colourants section, carrots are renowned for their high levels of carotenoids (Tiwari et al., 2021), while apple skins are rich in anthocyanins (M. Sharma et al., 2021).

Protein

Plant-based proteins are a major trend that has resulted in most major meat and dairy product manufacturers creating new divisions in their organizations dedicated to commercializing products in this space. Two of the investigated by-product streams have been reported to be good sources of protein: potatoes and tomato seeds.

Potato proteins are derived from potato juice and industrial potato waste, and they are soluble, nutritious and can be easily extracted. Additionally, their functional properties can be modified for specific purposes, for example as a food-grade, non-allergic protein for human consumption in functional foods (Hussain et al., 2021). Potato proteins can be divided into three main types including most notably, the potato protein patatin. Patatin is a high quality, in-demand protein with applications in the food industry including emulsifying, gel-forming capacity, antioxidant activity and fining of wine (Fu et al., 2020).

Tomato seeds are a rich source of good quality plant protein (based on amino acid score and calculated protein efficiency ratio) and could be a potential source of protein-rich adjunct in various food applications (Sarkar & Kaul, 2014). These proteins have been shown to contribute to emulsion stability (Sarkar et al., 2016), water absorption capacity as well as oil absorption capacity (Shao et al., 2014). More work is required to better understand the functional properties of tomato seed protein isolated using different extraction methods (Lu et al., 2019a).

As can be seen in Table 3 on page 30, a number of other by-products are notably high in protein content on a dry basis such as carrots, cucumber peels and tomato peels. Yet these have not been explored as alternative protein sources and work is needed to better understand if they have the potential to be used as functional plant-based proteins and if the extraction from the raw product would be economical.

Fermentation substrates
There are ample opportunities for using horticultural waste products as fermentation substrates. One of the most commonly investigated uses is for ethanol production, both food-grade and non-food grade.

High quality vodka can be produced from potato peel waste (SpudSmart, 2017). Additionally, carrot discards (Clementz et al., 2019) or the sugar-rich, carotenoid-free fraction of carrot juice have been shown to be a suitable starting material for production of ethanol (Ramos-Andrés et al., 2021a). Carrot pomace treated with pectinase and other enzymes, can also be used to produce bioethanol with a heat-tolerant yeast (Yu et al., 2013).

Tomato pomace, pre-treated to obtain free sugars has been fermented with various microorganisms and determined to be a potential feedstock for acetone-butanol-ethanol-isoproanol (ABEI) biorefineries (Hijosa-Valsero et al., 2019). Onion waste can be used as starting material for an alcoholic fermentation by *S.cerevisiae* yeast as a first-step to producing onion vinegar (Celano et al., 2021). Apple pomace has been determined to be an excellent source material for producing ethanol, which could be used either as a beverage or as biofuel (Magyar et al., 2016). Finally, apple retentate can be added to apple juice concentrate to aid in the production of fermented apple cider, with protein in the retentate supplementing amino acids to aid in yeast performance (Cruz et al., 2018b).

Other studies have examined the use of fruit and vegetable waste streams as substrates for production of fermentative products. For example, cucumber peel has been found to be a suitable substrate for bioconversion to single cell protein production by *Saccharomyces cerevisiae* which has the potential to provide an economical protein ingredient for food and feed (Mondal et al., 2012). Additionally, potato peels and carrot discards can be used as substrates for lactic acid production (Liang et al., 2014; Ramos-Andrés et al., 2021b).

Snack foods

Dried or extruded fruit and vegetable snack foods have been growing in popularity in recent years. Fruit chips were reported to be among the fastest growing categories of snacks in 2020, with an increase of 7.1 per cent in sales from the previous year. Apple chips in particular experienced a growth of 24 per cent in 2020. Meanwhile, savoury vegetable-based snacks grew by nine per cent in the same time frame (Jennings, 2020).

The increase in popularity of fruit- and vegetable-based snacks presents an opportunity to incorporate dried fruit and vegetable by-product streams in new snack food formulations. While many new snack foods include fruit and vegetable powders as an ingredient, some consist of dried, sometimes seasoned, slices of whole fruits and vegetables. Compared to a formulated product, dried slices of a whole fruits and vegetables are relatively straightforward to produce and could be undertaken by growers themselves or by specialty processors that purchase grade-outs from nearby farms. Examples include already well-established products such as apple chips (e.g. Martin's Family Fruit Farms) as well as potential new products including seasoned parmesan tomato crisps. Many recipes for parmesan tomato crisps concocted by home cooks can be found online but such a product does not appear to be commercially available as of yet.

Non-food applications

Soil amendments

As was discussed in the land application section, horticultural by-product streams are frequently applied to agricultural fields directly to add nutrients back into soils. However, these can also be used as feedstock for producing value-added soil amending products such as biofertilizer, prepared substrate mixes and compost.

Potato peel has been efficiently used for the synthesis of biofertilizer (Javed et al., 2019).

Vegetable seedling transplants produced on substrate mixtures supplemented with 5 to 10 per cent tomato waste were of higher quality, compared to those produced exclusively with peat substrate (Abdel-Razzak et al., 2019).

Composted onion waste was shown to help disinfest the soil of onion farms of white rot fungus, which is one of the most serious diseases of onion (Coventry et al., 2002). Mixtures of tomato-plant waste (greenhouse tomatoes) with paper-mill sludge at a ratio of 2:1 or 1:1 were found to improve earthworm development during the vermicomposting of paper-mill sludge alone and also allowed the vermicomposting of tomato-plant waste (Fernández-Gómez et al., 2013). Vermicomposting can also work to decompose apple pomace into a value-added product with enhanced nutrient content and organic matter quality (Hanc & Chadimova, 2014).

Materials engineering

Bioplastics are an alternative to conventional petroleum-derived plastics. Food wastes can be converted to bioplastics through biopolymer extraction (i.e. cellulose extracted from carrot waste, starch extracted from potato peels, pectin extracted from apple pomace or cutin extracted from tomato waste) or more complex processes involving bacterial fermentation in order to produce biopolymers, such as polylactic acid (PLA) (Acquavia et al., 2021).

Bioplastics are gaining a considerable interest, as consumers demand a reduction in the use of plastic packaging in exchange for more compostable materials. However, uptake of bioplastics in the packaging sector has been slow due to the cost as well as technical and logistical issues. For example, many bioplastic packages do not compost within the short required timeframes of commercial composting facilities even if they meet the standards to receive compostability certifications. Furthermore, the small amount of bioplastics currently in the market has not made it economically worthwhile for recycling and composting facilities to invest in modifying their systems to be able to accept bioplastics. Thus, for the time being, bioplastics largely end up in landfills. However, an increasing number of major consumer goods manufacturers are committing to improve the recyclability and compostability of the packaging they use for their products by joining initiatives such as the New Plastics Economy Global Commitment (www.newplasticseconomy.org). It is possible in the future, there may be sufficient critical mass of bioplastics in the market to develop systems to handle them at their end of life. Already, new certification systems such as the Composter Approved certification from the Compost Manufacturing Alliance, are gaining momentum as they provide the testing capabilities and standards for ensuring the packaging they certify will compost successfully in commercial composting facilities.

A number of produce waste streams have been shown to have potential for use as bioplastics. Potato peel waste can be used to create biopolymer edible films, which could act as a replacement to plastic counterparts (Canadian Agriculture and Food Museum, 2018; Kang & Min, 2010). Cellulose extracted from tomato pomace can create a robust and transparent film or plastic wrap with multiple applications (Branthome, 2021). Cellulose nanocrystals from cucumber peels could be used instead of single-use plastic for food packaging material (DTE Staff, 2020).

Some by-product streams, such as tomato peel, have also been shown to be a suitable source for pectin that acts as a corrosion inhibitor for tin used in the canning industry (Grassino et al., 2016).

In the automotive sector, Ford and Heinz are collaborating on a tomato waste derived bioplastic to include in various applications in Ford vehicles (McDaniel, 2014). Additionally, tomato skin waste has been found to have a potential as a more environmentally-friendly additive to include with rubber materials for the production of tires (Rieland, 2017).

Finally, in the construction sector binders from potato peel waste can be used in manufacturing gypsum wallboard and acoustical tile (Rogols et al., 2002).

Other applications

Although the applications described in previous sections are the most commonly investigated, a number of other possibilities have also been explored. Some of these include, but are not limited to, the use of produce by-product stream components for bioremediation (Hamoudi-Belarbi et al., 2018; K. Sharma et al., 2016), pharmaceutical and skincare applications (Gebrechristos & Chen, 2018b; Yamamoto et al., 2004) as well as biological fuel cells (Nosowitz, 2016).

As organizations increasingly strive for zero-waste objectives, there is no doubt more uses for fruit and vegetable waste streams will be uncovered.

Summary

Table 5. Summary of options for waste diversion of horticulture by-product streams.

Waste diversion option		Pro	Con
Direct use			
	Livestock feed	• Logistically simple	• Produce grower/processor often takes on trucking costs • Material typically given away at no cost • Potential risk of pathogen transmission from by-product stream to livestock • Potential risk that regulatory barriers could affect this option in the long-term
	Pet food	• Better returns than livestock feed • Logistically simple	• Material must be dry or otherwise ready to incorporate in formulations • Low margins
	Hunting bait	• Better returns than livestock feed or pet food • Logistically simple	• Niche market • Seasonal and may not overlap with seasonal availability of by-product stream
	Land application	• Logistically simple • Offsets a portion of fertilizer needs • Adds organic matter to soil	• Potential for disease/pest transfer must be considered • Produce grower/processor often takes on trucking costs • Material typically given away at no cost • Material may be difficult to spread in field homogeneously • Some nutrient analysis is required to determine impact on fertilizer needs • May contain compounds that bind desirable soil nutrients • High moisture content = low nutrient density
	Biofuel	• Logistically simple if sent to off-site biodigester • Offsets some energy costs if on-site • Digestate can be used as an agricultural fertilizer • Can accept raw, cooked, fresh or rotting product without prior sorting	• Associated cost if sent to off-site biodigester • Requires some study to determine if material is cost effective for energy production
	Sale of raw product for further food processing	• Generates returns • Logistically simple	• Returns are minimal (often break-even)

				• More logistically challenging for processing by-products as cut fruits and vegetables spoil quickly
	Donation		• Good for CSR (corporate social responsibility) • Potential tax benefits	• Produce grower/processor often takes on trucking costs • Material given away at no cost
Value-added				
Food applications			• Potential for higher returns • Meets current food industry trends (clean label ingredients, healthy ingredients)	• Requires investment in R&D, processing facilities and marketing • Some by-product streams are not suitable for food grade applications due to being mixed with field debris • By-product streams from processing spoil quickly (cut plant tissues) • Cost of material conversion to value-added products may be a challenge
	Clean label food ingredients	Fibre	• Attractive component for healthy foods and healthy kids snacks • Can add bulk to products • Some fibre components can contribute to water holding capacity or thickening	• Little market uptake for added-fibre in indulgent and other food categories not specifically marketed as healthier • Many fruit and vegetable powders contribute flavour which may not match all formulations
		Natural colours	• Natural colours are in demand • Opportunity to develop more stable vibrant natural colours such as greens, fire engine reds and true blues	• Can be difficult to stabilize particularly for foods that undergo harsh processing or require long shelf-life
		Anti-oxidants	• Shelf-life extension: slow oxidation, antimicrobial or antifungal effects • Potential health benefits	• May impart flavour • Antimicrobial and antifungal effects need to be validated in product matrix • Antioxidant health claims are difficult to substantiate
		Protein	• Plant-based proteins with desirable functionality • Few tomato seed protein powders on the market - opportunity for new entrants • New protein sources - room for more R&D to extend functionality	• Tomato seed protein functionality and processing effects not yet well understood • Potato protein powders are already on the market and becoming more competitive
	Snack foods		• Healthy snack foods derived from fruits and vegetables continue to be a major trend	• Existing market competition in some categories such as apple chips

		• Minimal R&D required compared to extracts or otherwise specialized food ingredient production	
	Fermentation substrates	• By-product streams are low cost substrates • Diverse opportunities for fermentative production	• Limited publically available research
Non-food applications	• Soil amendments • Biomaterials • Others	• Plant-based solutions are increasing in popularity (biomaterials, bioremediation, biocells, skincare ingredients)	• The novelty of many of these solutions means they have yet to be proven and there may be barriers to adoption

6. Future outlook

The current report outlined sources of underutilized unavoidable by-product streams from the top seven fruits and vegetables produced in Canada. Horticultural by-products arise at various points in the value chain including grade-outs from farms and packers as well as peels, pulp, cores or pomace removed during processing. These by-product streams contain valuable nutritional components such as fibre, protein, vitamins and minerals as well as functional components including antioxidants, natural pigments and thickeners (e.g. starch, pectin). The rich composition of these by-product streams makes them applicable to diverse potential uses.

The sectors with highest rates of landfilling included greenhouse vegetable production as well as some fruit and vegetable processors, particularly some (but not all) apple processors. These areas can be considered the highest need for change in order to divert from landfills.

Some producers and processors have developed waste management strategies that are economically beneficial (e.g. on-site biodigesters in Atlantic potato processing plants that off-set high energy costs) or at the very least, break even for costs (e.g. selling whole apple grade-outs for processing) and as such may not be greatly motivated to change their current strategy. However, many indicated an interest in exploring alternative options for their by-product streams due to the high costs associated with their current arrangements or a desire to generate better returns.

Currently, most producers and processors divert their by-product streams to direct use alternatives such as animal foods (livestock, pets, hunting bait), land application, biofuel, sale for further processing or food donation. Although these solutions are logistically simple, they often come at a financial cost to the producer or processor (trucking costs, biodigester fees) that can add up to hundreds of thousands of dollars annually for a single organization and may not be easily available to all entities depending on trucking distance. Additionally, the direct use as animal feed, one of the most popular landfill diversion approaches, may not continue to be an option in its current barrier-free form in the long term. Animal feed regulations are becoming stricter and therefore it is unknown if the direct use of untreated fruit and vegetable by-product streams as animal feed will continue to be an option in the future.

For all of these reasons, many organizations that are currently diverting their by-product streams to direct use options expressed an interest in evaluating other alternatives for their by-product streams.

Setting up in-house processing of by-product streams to generate new value-added products requires significant capital and R&D investment and may be too far outside the scope of many organizations’ core businesses. While some may be interested in investing in further processing their own by-product (or have already invested in this option), the majority of fruit and vegetable producers or processors are hopeful that a by-product processing sector can be developed with a need to purchase their by-product streams as raw material. However, simple processing steps such as the implementation of a dryer to extend the shelf-life of their by-product streams is an option that some producers or processors may consider.

It was determined that simply drying by-product streams typically enables growers and processors to sell their by-products for some profit rather than having to give it away. Drying solves several logistical challenges of using fruit and vegetable by-products, particularly once they are already cut or peeled and spoiling more quickly. Shelf-life is greatly extended after drying, allowing many of these products to be stored for upwards of a year making their use less time-sensitive and logistically simpler. Furthermore, the greatly reduced water weight decreases trucking costs opening up the potential to sell the material to customers in a much wider area. In addition, drying close to the source not only ensures that the material will remain food safe but can also preserve valuable nutrients, particularly if a gentle drying process is adopted. Producers with whole products (e.g. fruit or vegetable grade-outs) may also consider slicing and drying their products for sale as snack foods (i.e. crisps).

While forced air drying is most common and has the lowest up-front capital costs, new technologies are being developed enabling more time and energy efficient drying at lower temperatures to preserve produce quality. For example EnWave, a Canadian spin-off company from the University of British Columbia, produces a system that completes microwave drying under vacuum and already has systems operating on a commercial scale at their production facility (UBC, 2011). New technologies can be adopted to create products with unique value propositions.

Commercial drying systems require a significant capital investment and for many organizations, especially SMEs, purchasing an in-house system may be outside of their budgetary capabilities. Therefore, there is an opportunity for either a standalone company or a produce grower or processor to invest in a drying system and accept by-products from other nearby operations during down times to help producers and processors extend the shelf-life of their by-product streams for sale.

The agri-food industry is the largest manufacturing sector in Canada and contributes more than $110 billion to Canada's Gross Domestic Product (GDP) (Global Affairs Canada, 2018). Canada is a net exporter of food however, the country is a net importer of secondary processed foods. Therefore, although our agriculture and horticulture sectors produce large volumes of food, food processing happens outside of the country more often than domestically (McInnes & Yeon, 2014). The Canadian government has recognized this issue and has identified the food processing sector as an area of focus for expansion, particularly around R&D. To support this vision, the government has recently announced a number of new investments in the food processing sector (Government of Canada, 2019).

The current report found that high volumes of fruit and vegetable production and processing by-products are generated across the horticulture value chain. These by-product streams have a great deal of potential to not only be managed differently to help companies reach environmental sustainability targets but also to produce value-added products to bring better returns to Canadian producers and processors. The horticulture value chain's growing interest in improving their sustainability combined with the current political environment motivated the support to grow the food processing sector and to create highly favourable conditions to bring these by-product conversion opportunities to fruition.

There are many opportunities to convert fruit and vegetable by-products to value-added food products such as snack foods (extruded snacks, dried chips), fermentation substrates or functional clean label food ingredients (sources of fibre, protein, antioxidants for shelf-life extension, natural colours) as extracts, concentrates or dried powders.Although not the focus of this report, there are countless options for converting these by-products to non-food products such as packaged soil amendments (compost, substrate mixes, biofertilizer), engineered biomaterials (bioplastics, biofilms), bioremediation aids, as well as pharmaceutical and skin care ingredients.

Some companies focusing on converting fruit and vegetable by-products already exist in Canada (e.g. Outcast Foods Inc., Loop Juices, Inc.). However, there are clearly still massive volumes of underutilized by-product being generated and these provide ample room for new entrants to play a role in this space both as research providers and food processing entrepreneurs. It is hoped that the current report will provide not only the inspiration but also the much-needed information to develop a strategic approach to tackle these by-product streams thereby improving the sustainability of the horticulture sector and supporting the growth of Canada's agri-food production and processing sectors.

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