Identifying new Product Opportunities From Waste: Eliminating Waste in Tomato Production

Diana Salgado, Nicholas Ford and Christopher Simms
University of Portsmouth, UK
Diana.salgado@port.ac.uk
Nicholas.ford@port.ac.uk
Chris.simms@port.ac.uk

Abstract: The challenge of new product development (NPD) has seen a growth in literature on both idea generation and sustainability, but these two areas have not yet fully been integrated. The development of products from agricultural waste has particularly been overlooked, although the need to utilise sustainable materials and reuse waste is increasingly acknowledged. Our paper answers the question: *How can different sources of agricultural food waste be utilized to create new product opportunities?* We present a new framework for the identification and evaluation of NPD opportunities. This framework offers a new perspective to conceptualise different types of waste and identify their relative sensory, nutritional and functional properties. We present a case study of a UK tomato grower, using data gathered from interviews, attendance of meetings, observations and secondary data. Tomato production creates significant volumes of waste from unripe, imperfect, damaged and overripe fruits. Furthermore, processing tomatoes (for ketchup, passatas, juices, etc.) generates other kinds of waste such as seeds, skins and water. We show how firms can uncover new product opportunities through an analysis of each of these properties. For example, in tomato juice production around 5% of the raw material goes to waste since skins and seeds cannot be used. However, skins and seeds are nutritionally, sensorially and functionally useful and versatile. *Nutrition:* skins and seeds are rich in essential amino acids, minerals, fatty acids and lycopene, an antioxidant with several reported health benefits. *Sensory:* skin contains crystalline cellulose which can improve mouthfeel of food in low fat products, while seeds can increase hardness in flat breads. *Functional*: skins are partially permeable to liquids and gases, giving them potential for packaging and biodegradable tableware, while seed powder can be effective in removing organic dye molecules from coloured textile effluents. On the basis of our analysis we conclude that by examining the nutritional, sensory and functional characteristics of tomato waste, this can lead NPD managers to explore new alternatives in industries different from the original source of waste.

Keywords: tomato waste, NPD framework, identification of new products, product opportunity, nutritional, sensorial and functional properties of waste

1. Introduction

In 2006, the European Union's food industry was the cause of 22% of global warming (Castellani, Fusi and Sala, 2017). By 2015, the food industry had reached 34% of total man-made greenhouse gas (GHG) emissions globally with the highest contributions coming from agriculture and land-use change (Crippa *et al.*, 2021). It has been reported that food waste alone represents around 9% of the total GHG emissions in the food system (Crippa *et al.*, 2021). Some authors state that most of this food waste is still edible (Pearson, Minehan and Wakefield-Rann, 2013; Thyberg and Tonjes, 2016).

Good management of waste is essential to sustainable development (UNHSP, 2010; UNEP, 2012), and sustainable resource management calls for waste to be recycled (Bleischwitz and Bringezu, 2008; Papargyropolulou *et al.*, 2014). Food waste has a substantial economic, environmental and social impact (Evans, 2011; Papargyropolulou *et al.*, 2014), and reducing it is a priority challenge in global waste management (Defra, 2011; EPA, 2012; Papargyropolulou *et al.*, 2014). Critically this waste can also impact on agricultural producers, small holders, farmers and processors. This paper will focus on agricultural producers with small processing capacity. In this context, food waste produced between agricultural production and before reaching retail is normally referred to as food loss (HLPE, 2014). Food loss comprises a significant environmental issue due to the resource intensive nature of agricultural production and its significant carbon dioxide (CO_2) footprint. Furthermore, whilst lost food can be composted, this can result in significant methane (CH_4) and CO_2 emissions (Adhikari, Barrington and Martinez, 2006; Defra, 2011). The United Nations identified that 14% of the food produced is lost between harvest and retail (United Nations, 2021). Decreasing food loss offers the potential for significant reductions in emissions and therefore in environmental impact (Barrett and Scott, 2012).

Furthermore, better food waste management could also help to address the wider societal problems of insufficient food and material supplies for the population of the world, as well as the need to ensure the affordability of food for those in relative poverty. In the case of insufficient food, the United Nations World Food

Programme states that 957 million people do not have enough to eat (Laganda, 2021). The coexistence of food waste and hunger is a matter of concern to the food industry and policy makers alike. In the case of material supplies, as an example, 20% of the world's population lack adequate housing (Kuo, 2019). However, companies like The Urban Bio-loop have demonstrated that food waste can become a construction material. Thus, food waste management holds several opportunities to create both new food and products for other industries. This can reduce the environmental impact of growing food, reduce food shortages and potentially generate useful materials for other industries. Hence, the valorisation of waste forms an important subject for both academics and practitioners.

Recognition of the environmental problems faced by society has led to increasing scholarly attention to the circular economy (CE). However, to date the emphasis has been on technical cycles rather than biological cycles (as explained in the next section) (Sehnem *et al.*, 2019). In the biological cycle, nutrients refer to renewable materials, which can typically be regenerated through composting and anaerobic digestion (Ellen McArthur Foundation, 2013). The lack of research into the biological cycle may also reflect the small number of companies adopting CE practices and the difficulty in gaining access to them for data collection (Sehnem *et al.*, 2019).

Moreover, whilst a lot has been written on idea generation within the new product development (NPD) literature (e.g. Bossle et al., 2016), little has been written about idea generation in a sustainable NPD context. Indeed, the eco-innovation literature has tended to focus on broad managerial considerations within innovation management, and has thus overlooked the specific issues of valorising waste. The purpose of this study is to examine how lost food can be used to create new products. We address the following research question: *How can different sources of agricultural food waste be utilized to create new product opportunities?*

Our study presents a new approach to the identification and assessment of the new product opportunities presented by food loss. We illustrate this using a case study of a UK tomato producer. We analyse the different sources of product loss within production operations, and develop a novel method that provides a systematic approach to the identification of different opportunities to turn different sources of waste into product opportunities. Our case study analysis reveals the volumes of different types of tomato waste produced and their different sensory, nutritional and functional properties. We demonstrate how an analysis of each of these properties can help firms to uncover NPD opportunities. Thus, this paper contributes to the understanding of how to categorise food waste materials to identify their useful primary components which can be used in more complex products, typically with higher added value. In the long term, this contributes to environmental, economic and particularly societal development focused on the principle of circular economy.

2. Literature review

2.1 Tomato waste

Several researchers have investigated different uses of tomato waste in and outside of the food industry. Nutritionally, Riggi et.al. (2008) extracted carotenoids from tomato waste (Riggi and Avola, 2008); other researchers have found high levels of protein, fat and particularly fibre which processed food tends to lack (Nour *et al.*, 2018) and others have tried to incorporate tomato waste into different food products like bread, hamburgers or sausages with various different effects (Lu *et al.*, 2019). Outside the food industry, Ozbay et. al. (2016) compared the surface and structural properties of activated carbon produced from tomato paste waste, finding it to be a useful precursor to produce low-cost activated carbon (Ozbay and Yargic, 2016). Khiari et.al. (2019) explained how to recover energy from tomato waste via combustion (Khiari, Moussaoui and Jeguirim, 2019). Researchers agree that alternative uses of tomato waste can contribute to reducing environmental impacts. This is one of the main pillars of the circular economy principle.

2.2 Circular Economy

The concept of circular economy (CE) has been attributed to Pearce and Turner since 1989 (Geissdoerfer *et al.*, 2017). CE is the counterpart of a linear economy (LE). This means that while CE tries to maximise the use of resources and recirculate them and their waste in loop-like ways, LE extracts resources from nature, processes or uses them and then disposes of the residue. Both kinds of economies have their advantages and disadvantages. Among the advantages of CE are resource-use efficiency and innovation and the minimisation of space for waste disposal, this last being the main disadvantage in a LE. The disadvantages of CE are that some kinds of waste pollute the air during the reprocessing stages (e.g. for glass and plastic) which may require another kind of technology to decrease or reprocess pollutants. The relative merits of CE and LE will depend on the material in question. MFor example, plastics require less energy to melt and transform into different products than glass. Therefore, for the reprocessing stages, plastic will be more desired than glass in a CE. However, with the recent problems of microplastics pollution, and given how far we are from a perfect CE, plastics are no longer considered a good option to use. In contrast, a LE will not have problems associated with fume waste from reprocessing materials.

CE has two basic cycles, the technical cycle and the biological cycle. The previous example of plastic and glass represents the technical cycle. However, in this paper we will focus on the biological cycle (BC) only. BC consists in returning the nutrients to the Earth via composting or anaerobic digestion so the land can regenerate and continue the cycle of growing more nutrients (Ellen McArthur Foundation, 2019). One part of CE corresponds to eco-innovation.

2.3 Eco-Innovation

There is a growing interest in the concept of eco-innovation (Bossle *et al.*, 2016). Eco-innovation is described as a novel method (production, service, business method, etc) to reduce the environmental risk, pollution or negative effects of using resources (Díaz-García, González-Moreno and Sáez-Martínez, 2015). This method requires more than individual technologies and artefacts and includes a system innovation referred to as "technological transition" (Ekins, 2010). Eco-innovation is encouraged by stakeholders interested in obtaining a competitive advantage like reducing costs or gaining a better reputation (Díaz-García, González-Moreno and Sáez-Martínez, 2015). In order to obtain those benefits, stakeholders need to rely on idea generation among other strategies.

2.4 Idea generation in a sustainable new product design/development context

The central pillar of product design is idea generation. A method for sustainable product design was showcased by Clark et.al. (2009) in the developing economies of Fiji, Costa Rica and Cambodia (Clark *et al.*, 2009). Chiu et.al. (2012) showed how software and other methods can help achieve sustainable product design (Chiu and Chu, 2012). Other authors have considered biomimicry as a foundation for environmentally sustainable product innovation (Kennedy and Marting, 2016) while others applied the eco-compass method in sustainable product development (Brzustewicz, 2016). However, not much has been written about idea generation in sustainable NPD in the agricultural sector. This paper attempts to explain how there are vast product opportunities in this sector and how, by using our framework, these opportunities can be discovered.

3. Methodology

This study forms part of a broader Knowledge Transfer Partnership (KTP) which has been running for more than two years investigating food waste and the development of innovative new food products that integrate and upgrade food produce that currently goes to waste. Collaborative research of this nature is considered an effective means of understanding managerial practices and issues (Adler, Shani and Styhre, 2003; Shani *et al.*, 2007).

Our data analysis followed the principles of naturalistic enquiry (Lincoln and Guba, 1985) and the process of constant comparison (Glaser, B. G., & Strauss, 1967). Interviews were recorded and transcribed and patterns in the data were identified using analytic induction. Specifically, the analysis process followed the four steps outlined by Green et al.(2007): data immersion; coding; identifying categories; and creating themes. Discussions during observations were analysed using a similar process, supported by reference to notes. To minimise subjectivity, multiple data sources were used in accordance with principles of 'triangulation' (Eisenhardt, 1989; Yin, 1994; Flick, 1998). Interviews were conducted with key managers within the company (Table 1) and data was gathered from internal presentations, documentation, and email communications.

Table 1: List of participants of survey for the analysis of food loss in the tomato grower company.

PARTICIPANT CODE	JOB TITLE
001	Managing Director
002	New Business Development Manager
003	KTP Associate
004	Logistics Manager
005	Compliance and Technical Manager

PARTICIPANT CODE	JOB TITLE
006	General Manager
007	Digital Marketing Assistant
008	Purchasing & Fruit Planner
009	Sales Account Manager
010	Development Kitchen Production Manager

The study employed an exploratory longitudinal case-study-based methodology, a strategy that is optimal when 'how' or 'why' questions are being addressed (Eisenhardt, 1989; Yin, 2003). A case study methodology was suitable as it involves intensive analysis to identify issues and generate insights (Bryman and Bell, 2003). In particular, focusing on a single case has been found to reveal interesting phenomena and provide significant findings (Siggelkow, 2007). The access to rich data afforded by the KTP made this a viable and valuable strategy. Furthermore, it is not uncommon in research studies to select a single case for practical reasons (Daymon and Holloway, 2002), particularly if a case has 'intrinsic value' (Stake, 1995) and offers a depth of information which may not be available if multiple cases were explored (Noke, Perrons and Hughes, 2008).

4. Results

In this section we present the sources, kinds and disposal methods of waste from growing tomatoes in the nursery through to transporting them to sell. We show the enablers and barriers for reducing or transforming waste and an example using our novel framework to find product opportunities.

4.1 Waste at the tomato grower

The tomato producer produces approximately 8 000 tons of tomatoes a year of which more than 700 tones go to waste. This means that around 9% of the total production goes to waste, mainly from the nursery and packhouse. Furthermore, processing tomatoes into juices and sauces adds an extra kind of waste in the form of peels/cuticle, seeds and small pieces that cannot be used for these kinds of products. Another unusual kind of waste is the water obtained via dehydration. At least 79% of the total weight of the tomato is water lost through dehydration. This water could be captured and used for human consumption or for other processes through the food production chain. One small source of waste comes from tomatoes that have been returned from market stalls every week because of insufficient demand. Most of these returned tomatoes and other products are reused in the kitchen so about 15% (20 to 30 kg) of the returned product (~200 kg/week) goes to waste. The key sources of waste are summarized in Table 2.

Table 2: Sources of food loss

Chain of production waste (nursery)	Operational waste (packhouse)	Processing waste (kitchen)	Logistics (transport and returned product)
Excess pollinated flowers: Non-ripened fruit (green)	Excess fruit from packaging operations	Seeds and Peels/cuticle from juices and sauces	Unsold product in markets
Ripe damaged/split fruit (e.g. manhandling)	Excess production of ripe fruit	Leftover from sauces	Damaged/rotten product during transport
Ripe fruit with rot	. Unsold due to ild splitting or softening	Water from dehydration	External courier manhandling product
Misshapen fruit	Unsold due to overripeness	Chopped pieces from semi-damaged tomatoes	Excess fruit as a result of imbalances in supply and demand
Blossom end rot, catfacing, cracking, fungi.	Oversize/undersize fruit (out of market specifications)	Rotten tomatoes (delays in processing or tomatoes arrived damaged)	
Bad handling practices	Bad handling practices		

About 6.0% of the total production is lost from the nursery, 3.0% is lost in the pack house, 5.5% is lost at the process level (in the kitchen) and 0.02% is lost in the logistics sector. This food loss ends up in the compost site of the tomato grower. The compost site processes annually more than 700 tonnes of tomato waste from the sources cited above. Moreover, each part of the tomato fruit has several routes of use and disposal (sTable 3).

Table 3. Current use/discard methods of each part of the tomato plant.

Item	Current use/discard methods
Whole ripe fruit	Raw Drying/smoking Preserving
Flesh	Pureeing Juicing Saucing
Green fruit, seeds, skins and defects	Composting
Water	Drainage
Stems and stalks	Composting

All that arrives at the compost site is mixed and therefore, it is difficult to differentiate what is edible from what is inedible. All that ends up at the compost site is eventually used to grow organic tomatoes.

The company required new solutions to remove excess stock under each of the above circumstances. For the company, this also held the potential for a significant environmental benefit. "*All the money and energy gone into creating the product, but it's a short shelf life product. So, we have to find a solution to it*", Participant 001.

4.2 Waste reduction barriers and enablers

4.2.1 Enablers

- Install new software to measure daily waste in the kitchen. Knowing the precise quantities and sources of waste can help recognise points of control.
- Develop new products. New products with tomatoes as main ingredient are in constant development in an attempt to reduce waste as much as possible. Some of these products have been launched within weeks of inventing them in order to minimise tomato loss through spoiling.
- Manufacture products for other companies.
- Donate tomatoes to charities and food banks.
- Process some tomatoes with unmarketable defects.

4.2.2 Barriers

- Rot occurs fast: tomatoes are highly perishable and lose quality. "Tomatoes have ten days of good quality and after that they stop being not that fresh. This is assuming they were treated appropriately", Participant 001. Also, "As they start to go off they start to redden, the flavour becomes affected and they shrink. They are fine for cooking. However, they have less water, less flavour and are less sweet. Overripe are better for cooking applications in general but the lycopene content decreases as the tomato darkens", Participant 003.
- Rot occurs particularly fast in varieties that are more susceptible. Varieties like the San Arrentino, Beef tomato and speciality tomatoes like green and white are the ones that represent more waste due to fast degradation. Also, large varieties tend to be more susceptible to fungal degradation than small varieties. "Once tomatoes get older they grow fungus very quickly and the flavour deteriorates, so we need to get them in the stage prior to this when they start to shrink. Also have to be aware of damage as they will grow fungus soon after any damage occurs. Window of opportunity", Participant 003. Constant check-ups of the product are needed since fungus can develop in tomatoes in the bottom of the boxes where rotting is more difficult to notice.
- Tomatoes become unmarketable: nursery. If not picked up on time, large varieties of tomato can grow beyond the acceptable size for the market while small varieties tend to split in the vine. Splitting happens due to variations of water content in the plant but it has been observed in piccolo tomatoes after being harvested. Unmarketable defects like blossom-end-rot, catfacing, cracking and others can also occur. For example, Beef tomatoes tend to present more blossom-end-rot than other varieties.
- Too many tomatoes per vine: excess pollinated flowers. For example, customers require six tomatoes per vine so if eight flowers were pollinated, two green tomatoes go to compost. "Green tomatoes cannot be left to ripen as they are [of] inferior [quality]", Participant 001.

5. Developing product opportunities

The new framework developed for characterising tomato loss has three stages: Nutritional, Sensorial and Functional. In this section we present one example of how the new framework can be applied to waste arising from the initial stage of growing tomatoes: green fruit arising from excess pollinated flowers.

5.1 Green fruit

5.1.1 Merits

Green tomatoes have several advantages. First, they are mainly composed by fibrous carbohydrates and water. The fibrous carbohydrate makes green tomatoes very sturdy, so transportation and storage are rarely a problem. Microbial degradation is slow. Second, they are edible after cooking. The main components of green/unripe tomatoes are water, fibre and chlorophyll. The latter is a widely used food supplement due to its antioxidant properties.

5.1.2 Challenges

One challenge of raw green/unripe tomatoes is the flavour. The peels and seeds have a very strong astringent and bitter flavour which leaves a strong aftertaste. This improves by cooking the tomatoes.

Another disadvantage is that people normally do not consume green/unripe tomatoes and soproducts derived from them could elicit disgust.

Table 4: Characteristics of the different parts of green tomatoes and potential product opportunities within three aspects. The final column gives examples of NPD opportunities arising from one or more of the parts listed

Aspect	Seeds	Flesh	Skin	Whole fruit	Potential product opportunities
Functional	Hard	Thick, bulky structure	Dense, impermeable, relatively strong	High cellulose content	Cellulose useful for insulation in buildings.
Sensory	Astringent and bitter	Astringent, acid, fresh aroma	Astringent, bitter, smooth	Astringent, juicy, acid, hard, fresh aroma	Use in home fresheners and other fragrances.
Nutritional	Lipids and proteins (Lu *et al.*, 2019)	Complex carbohydrates (Vogg *et al.*, 2004; Trebolazabala *et al.*, 2013).	Complex carbohydrates, waxes and potassium (Vogg *et al.*, 2004; Trebolazabala *et al.*, 2013; Lu *et al.*, 2019).	Complex carbohydrates, chlorophyll, less vitamin C than in red tomatoes (Dūma *et al.*, 2018).	Green tomato skin waxes to be used in citrus fruits to extend shelf-life. Vegan protein from tomato seeds. Extract insoluble fibres for supplements or as ingredient for low calorie foods.

Some of the challenges to utilising each source of waste involve the technological, economic and biological aspects of the company. Being relatively small, the company lacks technology and research infrastructure to explore the different uses of tomato waste in a circular economy context. This is mainly due to the costs of investment faced by the company. Also, the speed of decomposition of tomato waste requires it to be used immediately or stored at low temperatures. These challenges can be overcome by creating a strategy to collaborate with institutions with appropriate infrastructure and to develop the quality control practices of the company. This strategy needs to quantify the short and long term benefits of recirculating the tomato waste and to specify how to direct the different kinds of waste accurately.

6. Conclusion

Company stakeholders have recognised that the novel framework outlined here offers significant opportunities that have not been previously recognised. More widely, this framework can help producers to reduce food waste and food loss by characterising the different components of the waste and thus finding new product opportunities both within and beyond the food industry.

As stated by other authors, CE practises entail different challenges like unaffordable costs of developing technologies and purchasing equipment. These challenges can be overcome by associating the industry with universities and other institutions having the facilities and knowledge to help build up CE.

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