Integrity in the fresh produce supply chain: solutions and approaches to an emerging issue.

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Food fraud is the misrepresentation of food in terms of labelling or documentation. The fresh produce supply chain is global with fresh produce grown many thousands of miles from the point of purchase and consumption. Long supply and complex fresh produce supply chains provide opportunity for fraudulent activity to occur especially further processing or re-packing of products to mask opaque practice and non-compliant behaviour. Price premiums for products designated as 'high-value', for example, organic produce, produce of particular provenance, or geographical production area provides motivation for less scrupulous actors to present for sale, produce that is mislabelled or misrepresented. People integrity as well as data, product and process integrity are gaining wider attention in the horticultural sector. Types of fraud critiqued in this review paper include mislabelling, substitution or misrepresentation of origin (country or regional location), method of production (organic or conventional) or incorrect varietal declaration. These challenges and the existing and emerging technologies that are both used within a quality assurance programme and alternatively used by regulators when investigating potential instances of fraudulent behaviour are considered. New methodological solutions and approaches are emerging and such techniques will develop rapidly to meet the growing challenge of fraud and to ensure consumer trust in the industry is maintained especially as types of food fraud evolve and become more sophisticated.

Keywords: produce, integrity, food fraud, substitution, provenance

1. Introduction

Food fraud is the misrepresentation of food in terms of labelling or documentation i.e. the food is not what it is purported to be. Fraudulent mis-description on food product labels is a widespread problem, particularly with high added-value products commanding a premium price (Woolfe and Primrose, 2004:222). Food fraud is 'deliberately placing food on the market, for financial gain, with the intention of deceiving the consumer' (Elliott Review, 2013). Food fraud can lead to food safety issues, but in the food industry food fraud is increasingly seen as a different challenge to food safety problems. This means that in order to reduce the likelihood of occurrence and also to reduce the impact should an incident occur countering the risk of food fraud requires both similar and alternative methods to those that are currently used to address food safety risk.

The types of fraud critiqued in this review paper include mislabelling, substitution or misrepresentation of origin (country or regional location), method of production (organic or conventional) or incorrect varietal declaration. The aim of this work is to consider the challenges and the existing and emerging technologies that are both used within a quality assurance programme and alternatively used by regulators when investigating potential instances of fraud. Fresh produce sold in the European Union (EU) is of particular interest here because of the need for market compliance with EU ten specific marketing standards for ten types of fresh producec where criteria such as class (quality attribute), variety and country of origin must be truthfully ascribed (Gov.uk, 2019). Thus, there is a clear financial motivation for perpetrators of fraud to substitute alternative products with different varietal attributes or geographic origin where existing quality control methods would find it difficult to identify that such substitution has taken place. In the years 2016-18 there were fifty-nine notification for fruit and vegetables for "adulteration/fraud" within the Rapid Alert System for Food and Feed (RASFF) Database linked to problems such as illegal importing, absence of health certificate(s), Common Entry Documents (CED) and certified analysis reports and improper health certificates that were signed before the analysis was performed (Source: RASFF, nd). Examples of non-compliant products included dried figs from Turkey; frozen okra, curry leaves and red chilli from India; raisins from Iran and Turkey; dried beans and watermelon seeds from Nigeria; fenugreek from Ethiopia, dragon fruit from Vietnam, and peppers from Egypt.

Global supply chains are becoming more sophisticated and complex, and together with the potential for weak governance, this means that the low probability of discovery or the low severity of punishment or sanctions provides an incentive for perpetrators to commit food fraud (Sarpong, 2014; Pustjens et al. 2016). However, food fraud may also be motivated as a mechanism to appear to meet stated customer (retailer or food service) requirements e.g. substituting ingredients to meet supply chain constraints and barriers (Kowalska et al. 2018). The constraints and barriers identified in the literature that drive this mendacious behaviour include, first, regulatory or political pressures, and then supply chain pressures. These supply chain pressures include: economic, competitive or coercive dynamics; information asymmetry with associated power concentration with specific actors; data swamping, opacity i.e. a lack of visibility; or organisations being time poor and looking for quick solutions to deliver value in the supply chain (Manning, 2016; Manning et al. 2017). Indeed, reasons for mislabelling of fresh produce whether intentional or unintentional might be due simply to human error, a lack of verification during product labelling changes in production system or even an error in original artwork design (Kowalska et al. 2018). Changes in the fresh produce supply chain that increase vulnerability and risk include: globalisation, especially where horticultural production takes place in countries with lower regulatory standards and governance; more prescriptive food safety management standards; the impacts of climate change on supply and demand dynamics; and transitions in food culture and consumer behaviour (Kleter and Marvin, 2009; Jacxsens et al. 2010; Marvin et al. 2016) Further factors that influence fresh produce chains have been synthesized (Table 1).

Take in Table 1

It is arguable that, to date, fresh produce food safety has had a higher profile than fraudulent activity. There has been more focus on the direct risk to consumer health of inadequate production practices being linked to foodborne illness outbreaks (FIOs). These FIOs can be large, with fresh produce accounting for 10% of FIOs in the European Union from 2007 to 2011, 26% of individual illness cases, 35% of hospitalisations, and 46% of deaths (EFSA, 2013). In response, production standards have been developed that follow the principles of hazard analysis and critical control point (HACCP) systems and apply a systems-based approach to managing food safety (Gil et al. 2015; Monaghan et al. 2017). Growers are required by many customers to adhere to a quality assurance scheme (QAS), either an industrywide QAS such as Red Tractor Assurance (RTA, 2017) or a customer-specific QAS such as McDonald's good agricultural practices (GAP) guidelines (McDonald's Corp., 2012). However, these systems rely heavily on a formalised system to show that actions are being completed and as a result there is a difference between developing and developed countries in the efficacy of food safety control systems employed (Faour-Klingbeil and Todd, 2018)

Food integrity has been defined as ensuring that food which is offered for sale is not only safe and of the nature, substance and quality expected by the purchaser, but also considers other aspects of food production, such as the way it has been sourced, procured and distributed and being honest about those elements to consumers (Elliott, 2014). Thus, developing supply chain systems and standards that assure food integrity will enhance food safety, authenticity, quality, and increase consumer trust in product claims (Kleboth et al. 2016; Goddard et al. 2018). Integrity in the horticulture supply chain is driven by consumers who demand that the produce they purchase is firstly, what it purports to be (product integrity); secondly is produced in line with defined standards (process integrity); thirdly that these standards address ethical corporate behaviour (people integrity); and finally the data associated with the produce (data integrity) is valid and reflects the intrinsic and extrinsic characteristics of the product (Manning, 2016; Manning, 2018). Thus developing product integrity and traceability protocols can underpin product integrity, trust and an open and transparent supply network (Soon et al. 2019).

The differentiation of fresh produce as previously described at the production and retail level provides opportunity for certain types of food fraud such as economically motivated substitution or mislabelling to occur. Economically motivated substitution could also happen when produce from one country of origin is substituted for another product from a different source especially if the produce is visually similar and there is a large price differential between the produce from the claimed source and the source being substituted. Further, the additional value derived in differentiating between conventionally grown products and organic production means that there is an economically motivated opportunity to substitute conventional for organic produce and label this as organic. Examples of reported cases of mislabelling and misrepresentation have been collated to show the types of fraud that can occur (Table 2).

Take in Table 2

Product identity from source through to processing/packing and distribution has been aligned with notions of traceability (Bertolini et al. 2006); a so-called ‘chain of custody’ (Thakur and Hurburgh, 2009). Indeed identity preservation is becoming an increasingly important credence or process attribute that adds economic value to a product (Dabbene et al. 2014). Regulation EC/178/2002 defines traceability as the ability to trace and follow a food, feed, food-producing animal or substance intended to be, or expected to be incorporated into a food or feed, through all stages of production, processing and distribution. In high information input and complex supply chains such as fresh produce, the market requirements for identity preservation and traceability often need to exceed the legislative requirements for 'one step back-one step forward' processes (Manning, 2017). Thus, an effective traceability system should establish and enable the identification of product lots and their relation to batches of raw materials, processing and delivery records (BS EN ISO 22000:2005).

Industry mechanisms to ensure that identity preserved products are what they are purport to be include the use of business to business (B2B) or business to consumer (B2C) supply chain standards. B2C standards through associated cues on packaging such as organic certification logos, geographic indication [British flag or country of origin designation], method of production [Red Tractor] and the associated traceability and mass balance checks i.e. extrinsic product characteristics, need to be verified in order to ensure consumer trust (Manning and Soon, 2014). Whilst some of these transactional tools are private mechanisms, legislative standards in the European Union (EU) also underpin the use of the term 'organic' or provenance designated geographic origin (EU Protected Food Name Scheme via the requirements of Regulation EU No 1151/2012).

This review paper considers specifically food fraud in the fresh produce supply chain and the existing and emerging product and process verification activities that take place. The British Retail Consortium (BRC, 2018) Global Food Standard describes verification as the application of methods, procedures, tests and other evaluations, in addition to monitoring, to determine whether a control or measure is or has been operating as intended. Process verification is the assessment of objective evidence that relates to process integrity such as the assessment of documentation, product and process certification and traceability data rather than product testing. However, process verification, such as third party certification (TPC) relies upon the ability to assess valid, authentic, objective and representative evidence (Manning and Soon, 2014). Product verification involves the analysis and testing technologies used both within a quality assurance programme and by regulators when investigating potential instances of fraudulent behaviour.

2. Process verification: the role of auditing

An audit is the systematic, independent and documented process undertaken to obtain and then evaluate valid, representative, objective evidence (records, statements of fact or other information) to determine whether the evidence demonstrates that audit criteria (policies, procedures and requirements) and standards have been fulfilled (BS EN ISO 9001: 2015). Therefore, auditing is an effective form of verification when it identifies both conformity and any deviations from standards, legislation or regulation whilst trading this outcome against using the minimum amount of resources to achieve the audit objectives (Kleboth et al, 2016). In a transactional way, the industry often sees audits as being of value when they are quick yet accurate, sometimes referred to as a snapshot, independent, objective, unbiased, transparent, reliable, scalable and as a result promote consensus building (Albersmeier et al. 2009; Salama et al. 2009; Powell et al. 2013). However, TPC audits, a key element of process verification activities in the supply chain, are a market interaction and there is a risk that this economic framing could impact on independence and validity (Martinez et al. 2013; Verbruggen and Havinga, 2015). The Elliott Review (2013) noted that the quality and completeness of TPC audits was variable and that there is a danger that an audit regime can be used for raising revenue, placing unnecessary costs on food businesses. TPC audits alone will not deliver effective verification of integrity in the food supply chain and they need to be undertaken in co-ordination with other activities such as product testing.

One challenge to the efficacy of TPC and even first party or second party audits as a form of verification is the degree of data integrity. Data integrity, quite simply, is the quality of data i.e. the degree of accuracy, consistency or validity of data held by an organisation or multiple organisations in the food supply chain. This data is either hard form (paper based) or digital form contained on computers, networks and clouds. Whilst the increased ability to store information might improve timeliness for process and product verification, conversely the volume of data being held can lead to data swamping for supply chain organisations, regulators and certification bodies undertaking third party verification (Manning et al. 2017; Manning and Wareing, 2018). Data swamping arises as a result of the sheer volume of data being collected and stored, the inefficient control or storage of data either as a result of strategic weakness or because of the cost of implementing digital solutions, or simply a misunderstanding of the timeline for data to be collected and then shared with others. There is no current literature on the challenge of data swamping or indeed the effective management of data in the food literature suggesting this is an area for future empirical research. In this context, data management can be considered as the actions taken, and governance implemented, to ensure data integrity when an organisation acquires, validates, stores and shares data.

One technological solution put forward to address data integrity and data management is the use of distributed ledger technology, with one option being Blockchain. The proposed advantages of this type of technology are reduced cost and increased speed of transactions in the supply chain, more effective incident identification and responsiveness, and the ability to overcome information asymmetry especially for consumers and as a result improving inter-actor trust and transparency (Manning and Wareing, 2018). The disadvantages are the need for strong governance of systems to prevent cyber-security breaches. The nature and type of cyber threats is increasing and shifting rapidly in line with the use of digital data technology and the risk of infiltration of digital networks (Khursheed et al. 2016).

Hollands et al. (2018) consider the benefits and challenges associated with Blockchain and argue that traceability systems are already a core strategic process within many food company management systems that control products and manage supply chain data especially through enterprise resource planning (ERP) platforms. However they counter ERP systems are expensive to implement and Blockchain technology may provide the opportunity to link "blocks of information" associated with distinct transactions that can form a tracking and tracing system. The IBM platform "Food Trust" has been used to trace mangoes to source in seconds superseding the one step forward one step back systems mentioned earlier in this paper. However Bateman and Cottrill (2017) suggest that there are challenges to the use of Blockchains, distributed ledgers, especially if the data is of poor quality that is entered into the system especially where the data them becomes immutable. They further argue that not all members of the supply chain have digital access especially smallholders in developing countries so this can mean that some data is still recorded manually before later being entered into a system. There is still a risk too of fraudulent behaviour where incorrect data is intentionally entered into the system.Thus, data integrity and associated management and security protocols need to be more actively developed and verified in fresh produce supply chains to reduce the potential for both intentional and unintentional mislabelling incidents.

3. **Product verification: testing technologies**

An alternative approach to audits for establishing product attributes is to test the produce for its innate integrity. When determining an appropriate testing technology the first consideration is whether the technology is using a targeted or a non-targeted method. Targeted methods are seeking to identify the presence or alternatively absence of specific markers that can demonstrate i.e. authenticate the identity of a given food or identify the presence of a given chemical or contaminant. Non-targeted methods are used as a wider screening mechanism for food. Ballin and Laursen (2018) in a review of analytical approaches for food authentication have proposed definitions and nomenclature for targeted and non-targeted approaches. Targeted analysis focusses on one or more pre-defined analytical target(s) e.g. a specific pesticide residue. Non-targeted analysis, simultaneously detects numerous unspecified targets or data points (often>100) and is often qualitative e.g. ‘fingerprinting’ or metabolomics (Ballin and Laursen, 2018). Difficulties in developing authenticity methodology include finding appropriate markers that characterise an element of the food that is consistent and can be measured accurately and having authentic samples that can assist methodology development in the first place (Primrose et al. 2010). Chemical methods to determine authenticity include primary metabolites such as sugar, amino acid and/or organic acid profiles of certain fruits (Bat et al. 2018). However, they argue secondary metabolites are influenced by geographic origin and production methods. Proving fraud has taken place requires detailed detection techniques (Woolfe and Primrose. 2004) and studies deploying DNA markers to identify mislabelling of plant-derived products are limited (Scarano et al. 2015). Fresh produce can be characterised using ‘classical techniques’ such as the use of isotope ratio mass spectrometry. Increasingly, new technologies are superseding and complementing these techniques. The majority of these constitute the so-called ‘omic’ technologies where high throughput analyses are combined with chemometrics and bioinformatics

The key authentication issue in fresh produce, as previously described, is that of origin i.e. is the correct variety named; is the geographic origin of the crop correctly identified; have unapproved/illegal pesticides been applied; is the crop ‘wild harvested’; is the crop ‘organic’; (Esslinger et al. 2014). Different approaches are considered here that address these issues and provide data where authenticity, identity or provenance and regulatory compliance can be determined.

3.1 Variety testing

DNA analysis techniques have developed to identify species or variety include detection of single nucleotide polymorphisms (SNPs), simple sequence length polymorphisms (SSLPs), restriction fragment length polymorphisms (RFLPs), and the use of real-time polymerase chain reaction (PCR) and heteroduplex analysis (Woolfe and Primrose, 2004; Primrose et al. 2010). Identification techniques based on PCR amplification followed by simple sequence repeats (SSR) analysis and principal coordinate analysis (PCA) can identify genetic differences in varieties of tomatoes especially in processed products where morphological markers may be lost (Scarano et al. 2015). SSR techniques have also been used for variety identification, genetic fingerprinting, genetic diversity analysis and parentage verification in Prunus species, but specifically sweet cherry (Liu et al. 2018). However, the level of DNA may not reflect accurately the amount of material originally substituted or added especially if processing has degraded the DNA or there are multiple copies of a given gene sequence in a cell (Primrose et al. 2010).

3.2 Geographic origin

Consumers are willing to pay a premium for local food (Feldmann and Hamm, 2015), but the geographic origin of produce can be difficult to quantify. Isotope abundances can vary with the geographic location, and if samples of the soil or water are available from geographical regions, it may be possible to identify material grown in that area. For example, it was possible to discriminate between peppers of different geographical origin by correlating the $\delta^{18}O$ of water in the peppers with a database of isotope ratios for water (Flores et al. 2013). Another approach is to use elemental fingerprinting (Danezis et al. 2016) where the profile of groups of macro elements, trace elements, rare earth elements and ultra-trace elements can be used as an indicator of geographical origin as the profiles are linked to the geology of the production area (Danezis et al., 2016). Perini et al. (2018) conclude from their studies on soft fruit that the $\delta^{13}C$ and $\delta^{15}N$ value of pulp and the $\delta^{18}O$ of juice can be used to differentiate geographical origin and verify declared provenance. In addition, microbial populations may differ between geographical locations and El Sheika et al. (2009) analysed the yeast community structures on the surface of Physalis and successfully discriminated between geographical production areas.

3.3 Misrepresented use of pesticides

Fresh produce monitoring programmes by retailers and enforcement agencies target residue testing towards levels of specific compounds either the active ingredient or the associated breakdown products. Multi-residue analysis methods commonly use gas or liquid chromatography coupled with mass spectrometry (GC/LC-MS) (Stachniuk, 2018). Residue testing has two uses: it can establish whether label recommendations have been followed i.e. Good Agricultural Practice (GAP); and whether residues are present of non-approved or illegal pesticides. However, the approach has limitations as residues decline over time and early application of non-approved compounds may mean residues are undetected at reportable levels.

3.4 Misrepresented use of synthetic fertiliser

It is possible to detect the accumulation of synthetic N fertiliser in plant tissues by looking at stable isotope ratios in the produce in a targeted approach. Crops grown organically have $\delta^{15}N$ values of +0.3 to +14.6%, while crops grown with synthetic N fertiliser range from negative to positive values, i.e. −4.0 to +8.7% (Inácio et al. 2015). However, a number of studies have highlighted the weaknesses in this approach where the organic and conventional values can overlap e.g. Schmidt et al. (2005) reported that lettuce, onions, cabbage and Chinese cabbage from field production had $\delta^{15}N$-values in the range of +5 to+6 for conventional production and +5.5 to+7.5 ‰ for organic production. In addition, the application of a small amount of manure or the use of water with a large concentration of nitrate can result in an increase of the $\delta^{15}N$ values, close to those obtained in organic production (Laursen et al. 2014). On its own, $\delta^{15}N$ data can only provide supporting evidence in suspected fraud cases, but not for discriminating between both production systems (Bueno et al. 2018).

3.5 Substitution of conventionally grown produce as organic.

Studies have suggested using multiple isotopes of nitrate derived N and O (Laursen et al. 2013; Mihailova et al. 2014). Approaches based on the measurement of multiple biomarkers and/or complex chemical or physical profiles/fingerprints supported by multivariate statistical analysis show more potential (Capuano et al. 2013). Bueno et al. (2018) demonstrated that a combined chemo-metric analysis of high-resolution accurate mass spectrometry (HRAMS) and $\delta^{15}N$ data was able to discriminate successfully between organic and conventionally grown tomatoes. Multivariate analysis, combining isotope data with mineral content (Yuan et al. 2018), and mineral content and key metabolites (Flores et al. 2013) have been able to classify organic and conventional brassica, peppers and lettuce.

Studies have found that organic methods of vegetable production have increased concentration of total glucosinolates and benzylglucosinolate which can be used to differentiate methods of cultivation (Rossetto et al. 2013); and major and trace element profiling has been used to determine whether onions and peas were conventionally or organically grown (Gundersen et al. 2000). Bioactive components such as phenolic and hydrophilic antioxidant capacity were identified as markers for being able to determine organic and conventional tomato juices (Vallverdú-Queralt et al. 2012).

Trace element and nitrogen isotope data is of value in differentiating conventional and organic tomatoes but less effective with lettuce indicating a concern over analytical testing being used in isolation as a single determinant of provenance (Kelly and Bateman, 2010). Picchi et al. (2012) urged caution that phytochemical content as a marker for considering a crop's response to growing methods, in this case cauliflower, was affected by genotype i.e. some genotypes showed improved phytochemical content under organic production and others particularly with regard to glucosinolates and ascorbic acid did not.

Conventional and organic production influence the external microbial populations and internal metabolite production. There is a significant focus on the use of metabolomics (metabolite fingerprinting) to discriminate between production systems using both targeted and non-targeted approaches (Cubero-Leon, 2014; Medina et al. 2019). Bigot et al. 2015 analysed the yeast and bacterial community profiles on the surface of nectarines and peaches using PCR-DGGE to differ between organic and conventionally produced crops. Llano et al. (2018) demonstrated that an untargeted metabolomics approach was able to identify metabolites (biomarkers) that could discriminate between organic and conventional goldenberry fruit.

4. Conclusion

One of the challenges of additional supply chain risk assessment processes and verification steps is that this can add quality cost to the supply chain but it is a preventative cost that will offset the costs of a recall. Risk assessment processes for food fraud include the use of threat analysis critical control point (TACCP) and vulnerability analysis critical control point (VACCP). However, only known and assessable threats can be prioritised (using a semi-quantitative assessment of likelihood and severity) to then develop a control measure(s) (countermeasure) and then a subjective scoring system to identify CCPs. Then effective fraud risk management, monitoring and verification systems can be developed. However the binary aspect of known/unknown threats means that decision-makers may then identify a subsequent incident that could lead to a major food recall as simply being "unforeseeable" (Manning, in press).

Since the Elliott Review, the notion of food integrity has been developing not just in terms of the product itself, but also the processes employed, the behaviour of individuals and the validity of data that is being used (Manning, 2016). This growing interest in integrity has led to the emergence of new techniques to confirm origin, variety and method of production e.g. organic or conventional. Indeed, metabolomics is enabling metabolite fingerprinting which is showing the potential to discriminate between a range of production factors. Further studies will require large numbers of samples to be taken, analysed and the results included in reference databases. These will need to encompass a wide range of sources of variation for the target biomarkers i.e. different agronomic conditions, vegetable varieties and geographical locations (Bueno et al. 2018). Non-targeted metabolomics utilized in metabolite fingerprinting can generate very large datasets, requiring bioinformatics analysis and increasingly machine learning (Medina et al. 2019). These developments are of value in determining the potential for mislabelling and mis-description, and effective verification protocols combining product and process verification need to be developed and effectively implemented in order to maintain consumer trust in the fresh produce industry.

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Table 1. Factors that influence fresh produce supply chains (Adapted from Ahumada and Villabos, 2009; Shukla and Jharkharia, 2013).

Strategic	**Tactical**	**Operational**
Financial planning	Harvest planning	Production scheduling activities
Demand forecasting accuracy and modelling	Crop choice	Harvesting
Capacity (warehouse and production facilities)	Crop scheduling	Storage
Supply network design Technology	Logistics and transportation	Transportation (vehicle routing)
Demand-price elasticity	Inventory management	Weather conditions
	Labour selection	Plant maturation rates
		Product shelf-life/rate of deterioration

Table 2. Examples of fresh produce mislabelling and misrepresentation

Case	Details
Case 1	Vidalia spring onions (Georgia United States) have a premium price compared to product from other US states. 1986 saw state legislation to delignate a specific production area. Additional quality control systems were put in place. Incidences of rebagging occurred. Between 2001 and 2003 there were six fines ranging from $5,000 to $29,000 for misuse of Vidalia label. A further case fine was $100,000. (Carter et al. 2006)
Case 2	The "San Marzano" tomato is one of the most important processing tomato varieties in the world. The tomato has a designated origin but is often substituted with other plum tomatoes from both Italy and outside Italy leading to deception of consumers (Scarano et al. 2015).
Case 3	The labelling of Greek produce as Cypriot when there was oversupply of Greek product due to the Russian embargo in 2014 (Joyce, 2014)
Case 4	A Canadian company AMCO Produce was fined $210,000 in 2018 by the Canadian Food Insepction Agency (CFIA) because between 2012 and 2014, the company was said to have intentionally mislabelled produce, including tomatoes and cucumbers, as being from Canada when the country of origin was in fact Mexico. The products were sold to Sobeys Inc. and other retailers. The CFIA undertook a random inspection and found products labelled as Ontario produce when in February the temperatures were too low in the region for greenhouse production (Karst, 2018).
Case 5	Australian Supermarkets Coles and Woolworths were fined in 2011 when two stores were identified as selling mislabelled fruit – one for not declaring the country of origin and the other store for selling lemons origination from the USA as "Product of Australia" (Eckersley, 2011).