Australian Eggs Traceability Technology Desktop Review

Defining available technologies and methods to support enhanced traceability in the Australian Egg Industry

by J. Szabo, P. Carter, Dr R. Barlow
and Dr N. Welti

Australian Eggs Limited Project No 1FS001

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Foreword

This project was conducted between September-November 2019 to review current egg traceability systems and available technologies to support enhanced traceability in the Australian egg industry.

The desktop research has been led by GS1 Australia in partnership with researchers from the CSIRO. GS1 Australia is an independent, global not-for-profit organisation that specialises in standards and systems for product traceability through supply chains. GS1 Australia and CSIRO are neutral in terms of technology and solutions. GS1 standards are industry owned and open to all industries.

Egg traceability is important when it comes to demonstrating product provenance and validating production system claims, quality assurance and to secure premium prices. In practice, however, traceability is challenging as the egg supply chain is quite fragmented. Multiple production methods are undertaken on farms making identifying, separating, segregating and tracing system inputs and outputs complicated. Production and trade records are hard to verify and can easily be manipulated, allowing for potential mislabelling and fraud.

Good traceability systems are also critical to keeping our food safe, tracking and, if needed, recalling contaminated food quickly. Traceability allows the tracking of products and all inputs into those products in the event of an animal disease outbreak. Recent Salmonella Enteritidis (SE) outbreaks in New South Wales and Victoria have further highlighted the importance of supply chain transparency and system integrity.

This project aims to define available technologies and methods to support enhanced traceability in the egg industry: bringing together national research capability and global perspectives on supply chain and traceability standards. It has been funded from industry revenue which is matched by funds provided by the Australian Government.

This report is an addition to Australian Eggs Limited's range of peer-reviewed research publications and output of our R&D program, which aims to support improved efficiency, sustainability, product quality, education and technology transfer in the Australian egg industry.

Most of our publications are available for viewing or downloading through our website: www.australianeggs.org.au

Printed copies of this report are available for a nominal postage and handling fee and can be requested by phoning (02) 9409 6999 or emailing research@australianeggs.org.au.

Acknowledgments

Several solution examples are provided in this report with consent from companies including Frost and Sullivan, TruTag Technologies (USA), and Source Certain (Perth, Australia). Other content has been sourced from publicly available literature and media coverage.

The inclusion of company names and/or examples in this publication is intended strictly for learning purposes and does not constitute an endorsement of the individual companies by GS1 Australia or CSIRO. Furthermore, the report does not represent any official positions or views by the companies or organisations that are members of GS1 Australia or the GS1 Global Network. This report, from which no legal consequences may be drawn, is for information purposes only.

Australian Eggs Limited provided the funds which supported this project.

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John manages the GS1 Australia Consult team and oversees the delivery of strategic projects with industry including traceability and digital transformation initiatives. He has a bachelor's degree in Engineering (Industrial) from Monash University and is an accredited GS1 Global traceability auditor. For over 30 years John has contributed to improvements in supply chain management for multinational organisations commencing his career as an Industrial Engineer working in the textile and then confectionery industries, where he spent 16 years working for Cadbury confectionery.

Peter Carter

Peter is an agricultural economist, innovator and passionate advocate for digital transformation in industry and government. Having lead CSIRO|Data61 National Digital Missions focused on supply chain integrity and food provenance, Peter joined GS1 Australia to direct new business and innovation activity through industry collaboration and support for the adoption of global standards. Peter has recently been awarded a Churchill Fellowship to undertake international research into food traceability systems and best practice in the industry.

Dr Robert Barlow

Robert is a senior research scientist at CSIRO. He leads the Food Microbiology team within the Food Program of CSIRO Agriculture & Food. Robert has over 20 years' experience conducting research projects for Agriculture R&D organisations that assist the delivery of safe and trusted products into global markets. His research efforts primarily focus on investigating food safety and quality hazards (e.g. pathogenic *E. coli* and antimicrobial resistance) that impact on the supply of safe and trusted products into international supply chains with a view to enhancing Australia's reputation as a provider of clean, green and wholesome foods internationally.

Dr Nina Welti

Nina is a biogeochemist and research scientist at CSIRO. She uses a broad range of methods, with a specialization in isotope methods, to trace the provenance and origin of food and quantify aquatic and soil-based biogeochemical processes. She is developing tools which combine modelling and monitoring approaches in order to gain a better understanding of how anthropogenic changes impact key biogeochemical reactions.

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Abbreviations

CSIRO	Commonwealth Scientific and Industry Research Organisation
CTE	Critical tracking event
DNA	Deoxyribonucleic acid
ESA	Egg Standards of Australia
FMCG	Fast Moving Consumer Goods
FSANZ	Food Standards Australia and New Zealand
FSC	Food Standards Code
GC	Gas chromatography
GFSI	Global Food Safety Initiative
GLN	Global location number
GTIN	Global Trade Item Number
HPLC	High-performance liquid chromatography
ICP-AES	Inductively coupled plasma atomic emission spectroscopy
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
ICP-OES	Inductively Coupled Plasma Optical Emission Spectrometry
ID	Identification
IR	Infrared
IRMS	Isotope ratio mass spectroscopy
ISO	International Standards Organisation
KDE	Key data element
LC	liquid chromatography
NMR	Nuclear magnetic resonance
NSW	New South Wales
PCR	Polymerase chain reaction
PIC	Property Identification Code
PLU	Price Look Up
QLD	Queensland
QR Code	Quick Response Code
REIMS	Rapid evaporative ionization mass spectroscopy
RNA	Ribonucleic acid
SA	South Australia
SE	Salmonella Enteritidis
UFAS	Universal Feed Assurance Scheme
UK	United Kingdom
USA	United States of America
UV	Ultraviolet
WA	Western Australia
WGS	Whole Genome Sequencing
WHO	World Health Organisation

Executive Summary

The ability to track food products as they move through supply chains has received increasing attention over the last decade as consumers and all supply chain participants seek greater levels of transparency and assurances of a range of product attributes.

The Australian egg industry, like egg industries globally, is experiencing a premiumisation of their products caused predominantly by a shift in production practices. Consistent with this premiumisation across the egg industry is an expectation that the Australian egg industry develops a world-class traceability system that:

1. enhances the level of trust that consumers have for the industry, and
2. there is an ability to conduct rapid, targeted recalls should the need arise.

This review focuses on identifying segments of the supply chain that are considered most vulnerable and may benefit from strengthening through enhanced traceability measures. The report considers current domestic and international approaches to egg traceability and provides examples of digital and biological verification and authentication technologies that may address existing supply chain traceability vulnerabilities.

Whilst the implementation of egg stamping in Australia and other countries globally has provided enhanced traceability, vulnerabilities remain. Despite the extensive and effective adoption of egg stamping by industry, there is scope to better harmonise and standardised requirements across states and territories.

The Australian egg industry needs practical solutions:

- To better understand where eggs, especially ungraded eggs, are moving (inter or intrastate) and how they move;
- For simple and effective technology and processes that can help prevent egg substitution – especially cage eggs sold as free-range/organic; and
- To improve how eggs can be traced back to their origin from any point of the supply chain.

The development of solutions to offset such vulnerabilities will provide incremental advancement of existing traceability systems and provide benefits to the industry and consumers alike. This may be in the form of improved market access, premium pricing or improved insurance or finance products that may not currently be available or affordable to egg producers.

The sharing of traceability information across the supply chain in a standardised format and making this accessible to participants in the egg supply chain would enable improved identification of eggs to the source. This would require a national approach and modernisation of traceability systems, standards and processes to improve the transparency of interstate and intrastate egg movements which will further strengthen consumer confidence.

Standards and processes work together with biological verification and authentication systems to ensure product integrity through supply chains. The natural eggshell encasing presents both a challenge and an opportunity for traceability verification, rendering some authentication technologies impractical and making other methods including stamping, printing and tagging feasible. Consequently, there is no 'one size fits all solution' for egg traceability in Australia.

A mosaic of technologies and capabilities are available to solve different traceability and verification challenges. Methods and capabilities are of varying degrees of maturity, cost and usefulness in terms of availability and response time. They all contribute to a suite of measurements that can be used to enhance and reinforce egg industry traceability and integrity systems.

Authentication techniques and enable science discussed in this report include:

- Isotope ratio mass spectroscopy (IRMS)
- Elemental profiling
- Rapid Evaporative Ionization mass spectroscopy (REIMS)
- Nuclear magnetic resonance (NMR)
- Infrared (IR) spectroscopy
- Chromatography
- Trace element labelling
- Omic methods

In each case, a description of the method is given, minimising the use of jargon as much as possible. An explanation of industry applications and specific opportunity for the egg industry is provided in each case. Finally, a comparative analysis of costs, accuracy, processing time, accessibility, ease of use and commercial readiness is given.

Our focus is to explore the current science which provides an opportunity for enhanced product and supply chain integrity rather than specific in-market solutions. Traceability in food industry value chains is increasingly being underwritten by innovations in forensic authentication systems and tools. Increased availability, reduced cost and miniaturisation of equipment and systems previously restricted to labs have created a new market opportunity for testing services, traceability software and certification systems. Analytical methods have a lower potential for fraud or falsification and are useful as complementary tools to prevent or investigate fraud and ensure customer confidence.

Many of the required data systems and process components to support industry modernisation are generic and have evolved to harmonise business models for trade. Industry stakeholders rather than Government have largely led this movement to deliver efficiency, cost savings and competitiveness.

The opportunity exists for the industry to move to implement world-leading interoperable traceability infrastructure that comprises data standards and processes as well as biological verification and authentication technologies and tools systems that combine to deliver improved industry and consumer trust.

Conclusions

There is potential and enabling science to support enhanced egg traceability systems from farm to packing and grading facilities in Australia. Technology and solution availability, cost or performance are not, however, critical factors limiting the ability of the industry to achieve higher levels of transparency and supply chain integrity.

Conclusions from the research focus on four main areas.

1. *Foundational elements – property and product identifiers*

Traceability analysis often focuses on traceable items (in this case, eggs and cartons, etc.) and makes assumptions that standards are in place and working to manage property/farm and other identifiers critical to delivering supply chain transparency and efficiency. This is very much the case for the egg industry. A nationally coherent approach will greatly improve the effectiveness of egg traceability systems. This will deliver enhanced food safety and quality assurance systems and biosecurity risk management.

2. *Standards and a framework for industry*

The challenge of enhanced product traceability is not new, and the Australian egg industry stands to benefit from the application rather than the invention or development of systems and tools. Traceability standards are used worldwide and provide a powerful tool kit for industry and government implementation of enhanced traceability systems that are independent of technology and systems that continually change. Drawing upon elements of international frameworks and standards, the Australian egg industry can modernize and better position itself and provide broader market access.

3. *Affordable and reliable product verification and authentication systems*

Evolving and emerging technologies may provide new solutions for tracing and authentication of product through the supply chain. This research contributes to industry understanding of the maturity of enabling science and potential application to the egg industry. Without having to change any existing industry processes, solutions are currently available to trace a product from farm to the packhouse. Micro-tags and other low-cost applications including DNA are showing potential for rapid and reliable verification. The likely value for the industry is to test these emerging technologies alongside established forensic measures including element and isotopic profiling to strengthen system integrity and re-enforce existing assurance systems.

The Australian egg industry traceability challenge cannot be addressed in isolation. A national (perhaps generic) and multi-sector approach to both regulated and commercial traceability systems across all agricultural supply chains will likely benefit the whole agriculture sector. A generic model has potential for benefits through consistent, coordinated regulation across jurisdictions, and the sharing of information and experiences between industries.

Alongside the commercial benefits and opportunities provided by a national approach to traceability systems, it is also clear that food safety or biosecurity incidents have economy-wide impacts and damage domestic consumer confidence and Australia's brand reputation abroad. Reputational damage can take some time to repair, possibly years. Increasing global production and movement of agricultural products and food means that the risk of such an incident occurring is also increasing.

1 Project Overview and Background

1.1 Introduction

The ability to track food products as they move through supply chains has received increasing attention over the last decade as consumers, and all supply chain participants, seek greater levels of transparency and assurances of a range of product attributes. Whilst the concept and definition of traceability remains necessarily broad and is typically driven by the convergence of multiple objectives across a supply chain, traceability systems generally address the following objectives:

- improve supply chain management
- enable product traceback during safety or quality recalls, and
- provide differentiation of products with subtle or undetectable market attributes.

In 2018, the Australian Department of Agriculture undertook an investigation into Australian food and fibre industry traceability and found, in general, that they were satisfactory and, in some cases, constituted leading practices. Nevertheless, the sophistication and maturity of systems vary widely between industries and value chain segments. Product traceability from packing and processing is generally more mature than from point of harvest or production to packhouse and processor.

Industry adoption of standards for retail product identification, and to support logistics systems, makes traceability more feasible as a product moves up and through the supply chain. Like many other farming systems, disease and other risk exposure are high on-farm through to processing. This is in part attributed to the complexity, or inability, to easily identify or track product being produced through biological systems that are themselves dynamic and intricate.

The Australia New Zealand Food Standards Code, and the associated Primary Production Standards include traceability measures for egg producers and processors. Although Australian consumers place considerable trust in the ability of supply chains to deliver products that are clean, green and wholesome, the value of a traceability system is perhaps most apparent when the quality or safety of a product is questioned. The implication of eggs in *Salmonella*-associated foodborne disease outbreaks and consumer-driven verification of production systems (e.g. free-range or organic) are key scenarios for which the Australian egg industry must ensure an appropriately sophisticated traceability system.

Consumers across all food categories are shifting towards sustainably produced goods with an elevated emphasis on animal welfare and food safety parameters. The latest figures, as published in the Australian Eggs Annual Report 2018/19, describe this trend for the Australian egg industry. The percentage of free-range and caged eggs sold in Australia currently sits at 47% and 40%, respectively. This represents a 5% increase in free-range egg sales and a 7% reduction in caged sales. Furthermore, free-range eggs represent 56% of the market value compared with 30% for caged eggs.

Consequently, the potential for deliberate or accidental co-mingling and subsequent sale of caged eggs as free-range eggs must be prevented via the development of world-leading digital and biological verification and authentication solutions.

This investigation focuses on methods and techniques to enhance traceability from farm to packing and grading facilities. This segment of the supply chain is one of the most complex. Biosecurity risks are prevalent and means to manage economically motivated behaviour detrimental to the industry are limited. Specifically, there are few simple and effective technologies and processes that can help prevent egg substitution or co-mingling of product from different farming systems, farming areas of farms.

Branding and labelling aside, from the customer's perspective the product is almost homogeneous. Retail prices for typical 700g eggs from caged birds sell for as little as $3.50 a dozen, free-range eggs between $5 to $7 a dozen and organic or specialty eggs can be over $9.

This raises several questions:

1. How does the consumer know that what is labelled as organic or free-range is not from a cage-based farming system?
2. How can we identify and trace-back product that has originated from one region or type of farming system?
3. What measures can be put in place to reduce the risk of contamination of product through co-mingling, that may occur through grading and packing or from smaller farms that are largely unregulated?

Box 1 Desktop review focus

1.2 Project Objectives

In view of the above, Australian Eggs desires to identify relevant technologies, currently used locally and globally by other industries or any other emerging traceability technologies, to improve supply chain integrity via enhanced product traceability.

Key outcomes and benefits to industry, customers, community and government include:

1. Improved industry health and safety
2. Reduced cost to industry of recall or incident response
3. Enhanced consumer trust and confidence in product quality and value

In addition to an improved understanding of traceability options available to industry, the project will enhance understanding of risk exposure and measures available to industry to mitigate and manage with a focus on safety, quality and value/return to producers.

1.3 Scope of Investigation

The project scope is intentionally narrow and focused on segments of the supply chain that are considered most vulnerable and may benefit from strengthening through enhanced traceability measures. The analysis, therefore, concentrates on product traceability from farm to packing, grading and processing facility rather than a complete end-to-end egg industry value chain analysis.

The report considers current domestic and international approaches to egg traceability. It provides examples of digital and biological verification and authentication technologies that may address existing supply chain traceability vulnerabilities. Verification and authentication technologies are evaluated only to the extent that underlying capabilities can assist the egg industry to address issues of traceability of products through the supply chain.

This project is not focused on certification processes or schemes adopted by industry to manage quality. Neither does it consider techniques or measures to identify product defects or the presence of disease, pathogens or contaminants. The report mentions these capabilities but only to provide context and perspectives on current and future use cases of possible benefit to the industry.

The Australian egg industry needs practical ways:

- to know where eggs, especially ungraded eggs are moving (inter or intrastate) and how they move;
- for simple and effective technology and processes that can help prevent egg substitution – especially cage eggs sold as free-range/organic; and
- to know how eggs can be traced back to their origin from any point of the supply chain.

This project aims to identify and evaluate available technologies and methods to support enhanced traceability in the egg industry.

1.4 Egg Traceability Standards

1.4.1 Australian Egg Marking Requirements

The *Australia New Zealand Food Standards Cod*e and the associated Standard 4.2.5 - Primary Production and Processing Standard for Eggs and Egg Products (Food Standards Australia New Zealand Act 1991) describes traceability requirements for Australian egg and egg products. The standard states:

1. Any egg producer must not sell eggs unless each individual egg is marked with the producer's unique identification.
2. An egg producer, who supplies egg pulp must mark each package or container containing the pulp with the producer's unique identification.
3. Subclauses (1) and (2) do not apply to eggs or egg pulp sold or supplied to an egg processor (the supplied product) if that egg processor complies with clause 20 in respect of the supplied product.
4. In addition to subclauses (1) and (2), an egg producer must have a system to identify to whom eggs or egg pulp is sold or supplied.

Under the intergovernmental Food Regulation Agreement (1991), each state and territory has agreed to implement the FSANZ Food Standards Code (FSC), and each state and territory has now incorporated these requirements into its relevant legislation. A summary of the regulatory body, egg stamping code generation requirements and state-specific exemptions are shown in Table 1 below.

Whilst a national standard exists, there is scope to better harmonise and standardised requirements across states and territories.

A harmonised approach to egg stamping between states and territories, would allow the ability to rapidly identify producers or processors implicated in foodborne disease outbreaks associated with eggs or egg products.

Table 1 - Summary of food safety regulators, egg stamp code requirements and exemptions

STATE	Regulator	Egg stamp code generation	Egg stamping exemptions*
QLD	Safe Food Production Queensland	A unique identifier must be registered with Safe Food Production Queensland	No Exemptions
NSW	Department of Primary Industries – NSW Food Authority	The Food Authority must be notified of, and approve, any new or alternative egg stamp design to ensure that it is unique	Less than 240 eggs per week. (Less than 50 layers) AND Only sell directly from farm gate OR use for fundraising purposes where the eggs will be cooked
VIC	Department of Economic Development, Jobs, Transport and Resources (DEDJTR)	DEDJTR will allocate a stamp code to use	Less than 50 layers (Less than 240 eggs per week). Duck and quail eggs exempt
SA	Primary Industries and Regions SA (PIRSA)	PIRSA must be notified of any alternative egg stamp design to ensure that it is unique	No exemptions
Tas	Department of Primary Industries, Parks, Waters, & Environment	The unique identifier must be approved by Biosecurity Tasmania	Less than 20 dozen eggs per week; AND ONLY supply eggs to work colleagues, friends, and family
WA	Department of Health	A unique identifier is encouraged to be registered with Dept Health Food Unit	No exemptions
ACT	ACT Parliamentary Counsel		No exemptions
NT	Department of Health		No exemptions

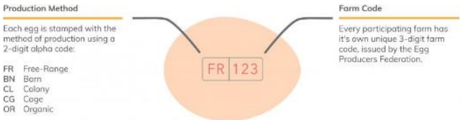
* "No exemptions" means that ALL eggs must be individually stamped

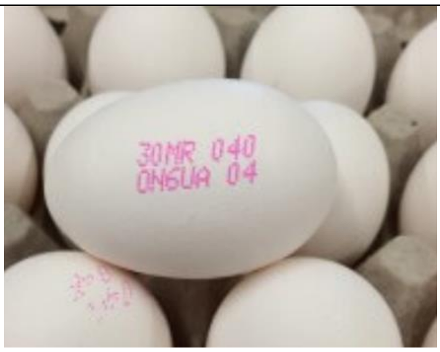
Source: Egg Stamping Guide, published August 2018 Australian Eggs Limited

1.4.2 International Egg Marking Requirements

Egg marking is practised worldwide but mostly in the form of egg carton labels. In most countries, there are legal definitions on the designation of the egg size, production method, packager identification and best-before dates. In nearly all cases below, the egg codes assigned are not globally unique allowing for potential duplication of egg codes by egg producers.

Table 2 - Examples of international egg stamping practices

<table>
<tr><th>Country</th><th>Egg stamping requirements</th><th>Egg stamping code format</th></tr>
<tr><td>New Zealand</td><td>
In June 2019 the Egg Producers Federation of New Zealand (EPF) introduced the Trace My Egg initiative (https://tracemyegg.co.nz/).
The initiative is voluntary for industry and is supported across all farming production methods.


</td><td>
The initiative employs the use of a two-part 5-value code: a two-digit alpha code, which indicates the production method followed by a three-digit numerical farm code that identifies the location of the farm on which the egg was produced.
Farms participating in the Trace My Egg initiative must stamp all eggs on-farm. To date, the initiative has participating farms that collectively represent 70% of the egg supply entering New Zealand commerce.
</td></tr>
<tr><td>Canada</td><td>


</td><td>
Canadian egg codes include best before date, production system and farm identification to allow traceability.
Information is printed on multiple lines for ease of printing, reading and legibility.
Line 1: The best before date (MM/DD/YY) and a grading station identification code
Line 2: The specialty egg type (when applicable)
Line 3: The identification code for the local Canadian farmer
</td></tr>
<tr><td>European Union</td><td>
All the 28 European Union member countries are required to mark their eggs as provided in the image to the right.


</td><td>
The first number identifies the production system;
“0” = Organic,
“1” = Free-range,
“2” = Barn and
“3” = Caged.
The second set of code refers to the country of origin and the last set of letter or number system identifies the registered production site and the unique producer code.
There are no legal requirements for the best before date to be stamped on the eggs, however many of the producers do stamp this information on the eggs to gain consumer loyalty.
</td></tr>
<tr><td>Israel</td><td>
All eggs sold in Israel must pass through a sorting station and be stamped.


</td><td>
The four-digit number on the egg is the code for the sorting station that the egg passed through. The first line is the name of the farm where the egg comes from.
This egg has “L” for large and the stamp states the type of farming system used to produce the egg, in this case, it is an organic egg. The first date 02.05, is the last day the egg can be sold, which is 16 days from the sorting date.
The second date 01.06, which is 30 days after the first date, is the egg’s expiration date assuming it was stored in the refrigerator. The reason there are two dates is that the eggs are stored in the supermarket at 20°C and at home in a refrigerator.
Imported eggs to Israel have letter codes stamped on the eggs, e.g. Netherlands (NL), Spain (ES) and Turkey (TR)20.
</td></tr>
</table>

Country	Egg stamping requirements	Egg stamping code format
Singapore	In Singapore, egg farms under the Singapore Quality Egg Scheme now have to implement a system that allows them to trace and recall produce quickly.	This involves farmers stamping their eggs with their farm's code and the production date on the eggs.
United States	The United States of America does not require egg producers to stamp their eggs, however egg traceability is captured under the Fair Packaging and Labelling Act (15 U.S.C. 1451et seq.).	Eggs supplied to consumers need to be packaged in containers with appropriate labelling identifying the manufacturer of the egg, best by or use by date, size, grade, quantity.

1.4.3 Current Industry Challenges/Observations

1.4.3.1 Public Sentiment

The Australian egg industry has developed a Sustainability Framework which "reflects the Australian egg industry's objective of farming eggs for Australians in a manner which is socially, environmentally and economically responsible" (Moffat et al 2019). In supporting the Australian egg industry to implement this Sustainability Framework, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) was engaged to bring the voice of Australians into this process.

More than 5,000 survey respondents provided information. CSIRO aimed to go beyond a description of how Australians feel about the egg industry but to also describe how it may work to improve the level of understanding and trust that Australians have in the industry.

Key findings from the report found the following (Moffat et al 2019):

- 57% of Australians expressed trust in the industry, up 4% from 2018, and only 10% of respondents conveyed distrust.
- A growing number (76%) of Australians recognise egg farming's lower environmental impact relative to other agricultural industries, up from 66% last year.
- Hen welfare continues to be very important to the community with 93% of Australians stating they care about the welfare of hens.

The community survey results demonstrate that the egg industry is viewed positively within the Australian population. However, the results also highlight the key challenges the industry faces in developing deeper levels of trust with the Australian people. Australians see the egg industry as important to our way of life in Australia, as they do the agriculture sector more broadly. Eggs were seen to be an affordable, nutritious staple in the Australian diet, while the industry itself was seen to be responsive to community sentiment.

Australians also agreed strongly that food security was a critical issue for the egg industry, and that the industry was regulated well to ensure this. Examining the economic contribution of the egg industry to Australia, participants also felt the industry contributes positively and creates jobs for Australians.

In line with these positive findings for the egg industry, acceptance of the industry in Australia was found to be strong.

Yet the industry faces real and important challenges to maintain this level of acceptance and positive support from the Australian community. While Australians indicated trust in the egg industry is strong, addressing animal welfare concerns is a major challenge for the industry.

The growth of smartphones in the past few years has seen a large growth in user apps that provide customers insights into sustainability, nutrition, the provenance of products in the food supply chain. The growth of free-range egg sales in the market coupled with the growth in smartphone usage and consumer interest has resulted in the development of the app CluckAR.

CluckAR is a popular mobile phone application developed by Choice in 2016. It's somewhat misleading Appstore title referrers to it as an augmented reality 'free-range egg detector'. The app aims to provide consumers with more information about free-range farming systems by showing egg purchasers the density at which each farm's chickens are stocked.

Using image feature and pattern processing, the application utilises the mobile phone camera to identify the producer/packaging and augmented reality and animation to depict chicken stocking density based on Choice market research.

Example screenshots are below with density ratings (1-7) and density animations.

The application developers have focused on users that are animal welfare conscious and potential confusion associated with the use of free-range on labelling and packaging. It is estimated that between 20,000 and 30,000 applications have been installed since the application was launched.

Novelty value and gamification of the application have no doubt contributed to its appeal. Simplicity and real-time elements (users are typically depicted scanning in-store prior to purchase) has been used to great effect and to support social engagement and boycott activity.

It goes without saying that the application does no detect free-range eggs but rather links the brand to third-party data collected by Choice.

It is also worth noting that the same image and pattern matching methods could easily be employed to allow users to make sense of egg stamps. This would require that state and territory food authorities provided a mechanism for shared data access and look-up of codes/stamps registered for use.

Box 2 Example response to animal welfare concerns

1.4.3.2 Improved Traceability and Effectiveness

Traceability of eggs, once they have been inspected and graded through to consumer sales is well developed and mature. Product recalls and withdrawals are managed with a reasonable amount of confidence and efficiency:

- Traceability is achieved via product identifiers post grading and packing utilising barcodes on egg cartons and associated packaging levels.
- Traceability pre-grading/packing is dependent on systems used and data shared between egg producers and grading/packing facilities.

A review of the egg stamping implementation in NSW found that egg stamping has improved traceability efforts across NSW as well as traceability for individual businesses. Stamping has also improved traceability for foodborne illness investigations, with an egg-related foodborne illness outbreak investigation in May 2015 able to rapidly identify where eggs were affected and trace the eggs to the Queensland based suppliers. Similarly, producers have also reported unexpected benefits of egg stamping, with 26% of surveyed producers reporting benefits for their own business through an ability to confirm their product or assess whether their products are associated with reported consumer complaints.

1.4.3.3 Egg Standards of Australia

Egg Standards of Australia (ESA) is the egg industry’s national voluntary quality assurance program and it provides a comprehensive set of voluntary compliance standards for farmers to meet.

ESA assists egg businesses to:

- minimise food safety risks;
- achieve high animal welfare standards;
- manage biosecurity risks;
- minimise the risk of eggs being mislabelled; and
- ensure the production and delivery of the consistent product.

The comprehensive set of standards was developed in line with national retailer and regulatory requirements and audits are carried out by independent, third-party auditors.

ESA accredited egg farms currently have more than 80 per cent of the national flock.

1.4.3.4 Limitation of Current Stamping Requirements

A major concern reviewing available documentation is the tracking of eggs from the time of production (laying) through to the sorting/grading and packing process.

The Standard clearly states that an egg processor must not sell eggs unless each individual egg is marked with the processor’s or producer’s unique identification (Food Standards Australia New Zealand Act 1991.

The Eggs Standards of Australia (ESA) for Rearing and Layer Farms – November 2018 has clearly defined control criteria for Egg Identification, Traceability and recall.

1.4.3.5 ESA Traceability and Recall Code

ESA traceability requirements are outlined in Table 3 below.

Traceability throughout the supply chain is a regulatory requirement for all foods, including eggs. The ESA Code (P7.1 and 7.2 - Level 1:) requires that traceability information shall be maintained for eggs from the collection point at the farm (including farm ID), including the date and type of system through to the despatch of the eggs. This requirement also applies to eggs sold or supplied directly from the farm. Records need to be maintained by the farmer to demonstrate that traceability has been managed.

It is a regulatory requirement (P7.3 – Level 1) to maintain truth in labelling so that eggs produced under a particular system are accurately labelled and sold as such. To this end, when there is more than one type of production system on-site, the Code makes clear the need for a clear and defined system for segregation.

The Code requires that an annual verification exercise be conducted and documented to demonstrate reconciliation of eggs from each of the production systems. The exercise includes a reconciliation of at least 3 days of production from each of the systems, and clear documentation to demonstrate compliance. Where applicable, the verification exercise includes eggs purchased from external sources or suppliers.

In the event of a significant hazard and where the product does not meet regulatory requirements, it may be necessary (see: Table 3 - P7.4 - Level 1) to recall product from the market. The Code requires the farm to have a documented recall procedure. The procedure must be communicated to staff who are likely to play a key role in the recall and management of product and processes. Key staff need to be trained to understand how a recall operates and the specific requirements of the recall procedure. The code requires key customer and staff contact details should be kept up to date to assist in quick communications in the event of a recall.

FSANZ provides a Food Recall Protocol and GS1 Australia provides operational support for food and healthcare products in Australia and New Zealand via its national product recall service (see: https://www.gs1au.org/our-services/recall/) . FSANZ guidance in writing a food recall plan is published at foodstandards.gov.au.

Table 3 - Egg Identification, Traceability and Recall Standard

Code Element		Compliance Criteria	Records
P7 Egg identification, traceability and recall			
P7.1 **LEVEL 1**	Maintain an identification and traceability system to enable eggs to be traced from production to supply.	1. Traceability records include as a minimum: • farm ID • production method (e.g. free range, barn laid, cage) • date of collection 2. Dispatch records include the information stated above, plus • quantity and quality of eggs • shipment/dispatch date 3. For eggs sold or supplied directly from the farm to the customer, use and record unique ID as required by legislation. 4. For egg sold or supplied directly to another farm, the supplying farm shall document the quantity, type and date of sale. 5. Where eggs suitable only for further processing e.g. pulping, are sold or transferred to a grading floor, these eggs are clearly identified. 6. Records are kept.	
P7.2 **LEVEL 1**	Manage externally sourced eggs.	1. Where eggs are bought in/purchased from other farms, they are clearly identified and accounted for. The receiving producer/processor shall ensure this consignment of eggs have accurate traceability prior to any sale/supply. 2. Records of all egg transfers or purchases are kept.	
P7.3 **LEVEL 1**	Manage egg traceability for each production method undertaken on site.	1. Where multiple production methods are undertaken on a single site, an effective system is documented and implemented to identify, segregate and trace eggs by production method. 2. System effectiveness is verified by reconciliation exercise conducted at least annually on a minimum of three consecutive days of production. 3. Records are kept.	
P7.4 **LEVEL 1**	Maintain a product recall procedure enabling unsafe eggs to be effectively recalled.	1. A documented recall procedure is available. 2. Key staff have undertaken training in the recall procedure.	

1.5 Cost of Egg Stamping

According to the NSW review of the impact of egg stamping conducted in 2016 (http://www.foodauthority.nsw.gov.au/_Documents/industry/egg_stamping_review.pdf), overall egg stamping has been implemented at lower costs than those estimated by the Productivity Commission in 2009 and has improved the speed and reliability of egg traceability in NSW.

The cost of implementing egg stamping is estimated at 2-4 cents per dozen eggs for medium businesses and 1 cent for small businesses. Egg businesses, both licensed and non-licensed, are now egg stamping and the Food Authority has an egg stamping database which provides details of each egg producer.

Egg stamping has improved the speed of traceability and has improved targeting of egg recall information with the current approachable to trace a single box of eggs back to one pallet or one hour's batch production.

The British Lion is the UK's most successful food safety scheme. The Lion stamp is a mark that can be stamped onto eggs by producers who are signed up to the Lion Quality Code of Practice. The code of practice requires that:

1. All Lion hens and eggs guaranteed British
2. Hens are vaccinated against Salmonella Enteritidis and Salmonella Typhimurium
3. Registration and a unique 'passport' system, ensuring complete traceability of hens, eggs and feed
4. Increased hygiene controls and salmonella testing of all flocks in the integrated egg production chain, in excess of the National Control Program, including turnaround swabbing of breeding, pullet rearing and laying flocks; and packing centre hygiene swabbing
5. Regular egg testing (not included in National Control Program)
6. Stringent feed controls, including the production of feed to Universal Feed Assurance Scheme (UFAS) standards
7. Lion Quality eggs are stamped on-farm with the farm code and production method
8. Best-before date and Lion logo to be printed on the shell of Lion Quality eggs as well as on the egg box
9. Regular independent auditing, including unannounced audits, of all producers and packers in the Lion scheme, in accordance with the ISO 17065 standard

As of 2016, over 90% of UK eggs are now produced under the British Lion scheme and more than 130 billion British Lion eggs have been sold since its launch in 1998. The British Lion scheme has been responsible for a drastic reduction to the presence of *Salmonella* in UK eggs and the Food Standards Agency has recently confirmed that they are the only eggs that are safe to be consumed runny, or even raw, by vulnerable groups (e.g. pregnant, children and the elderly).

Box 3 British Lion Egg Example

1.6 Food Safety Implications

The purpose of the introduction of the national Standard 4.2.5 (FSANZ, 2012) was to reduce the incidence and impact of foodborne illness from *Salmonella* by minimising the prevalence and concentration of this pathogen in eggs and egg product (FSANZ, 2011).

The lack of traceability for eggs, once they were removed from their packaging, had compounded difficulties in investigating egg-related foodborne illness outbreaks. The purpose of introducing the Primary Production and Processing Standard for Eggs and Egg Products which included the requirement for egg stamping was to alleviate these difficulties and provide efficient traceback capability across the industry. Since the introduction of egg stamping in 2014 (NSW) there has been one case where a foodborne illness outbreak investigation was assisted by egg stamping which was used to trace eggs back to an interstate producer. There has also been a Queensland example where egg stamping was used to rapidly trace eggs back to the farm.

Whilst the recommendations and implementation of egg marking has improved egg traceability, there remain several vulnerabilities within the current system that could impact the effectiveness of product traceability and effective recall. These include:

- Egg stamping may occur at either the producer or the processor. Stamping at the processor level may increase the potential for co-mingling of eggs from differing production systems
- Lack of egg code harmonisation nationally
- Dependency on accurate documentation/data transfer from producer to processor
- Varying minimum requirements in each state (exemptions).

Efforts to address these vulnerabilities will enhance forward and reverse traceability across the egg supply chain thereby increasing the trust of the consumer and facilitating rapid, targeted responses to food recall situations.

2 Traceability Infrastructure for Industry

Infrastructure to support food traceability systems comprises data standards and processes as well as verification and authentication technologies and tools. Many of the systems and process components are generic and have evolved to harmonise business models for trade. They have become international standards.

Internationalization and digitisation of commerce have been major drivers for standards-based approaches to traceability. Retailers rather than Government have largely led this movement to deliver efficiency, cost savings and competitiveness. Product identification through barcoding is one manifestation of this change that has had a global impact.

Standards and processes work together with verification and authentication systems to ensure product integrity through supply chains. Product integrity provides tangible quality and safety assurance and draws on national and international reference data based on evidence, research and science.

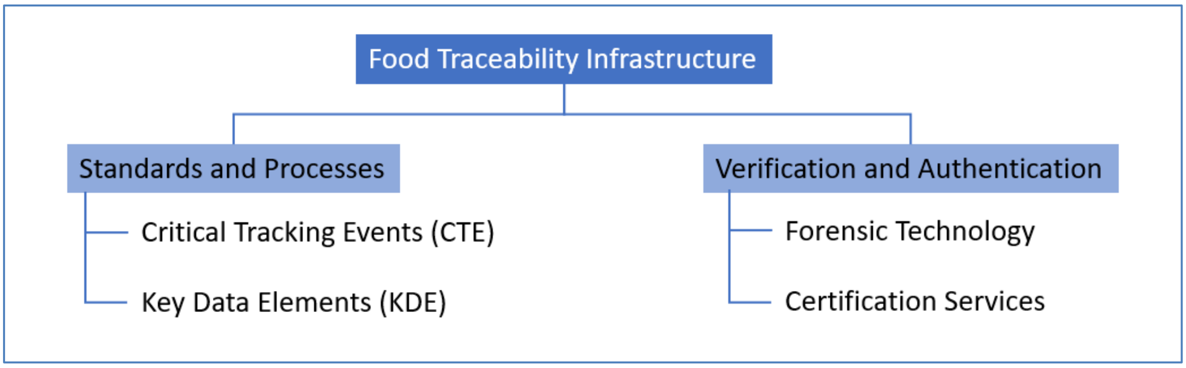


Figure 1 Food Traceability Infrastructure

Verification and authentication services have evolved from the traditional food safety and testing industry. Forensic methods once limited to test laboratories and universities are now more widely accessible and supporting independent certification of product integrity. Miniaturization, sensor innovation and broader internet of things (IoT) are rapidly expanding the range of capabilities available to support industry standards and processes.

Traceability infrastructure components are overlapping rather than mutually exclusive as shown in the venn diagram below.

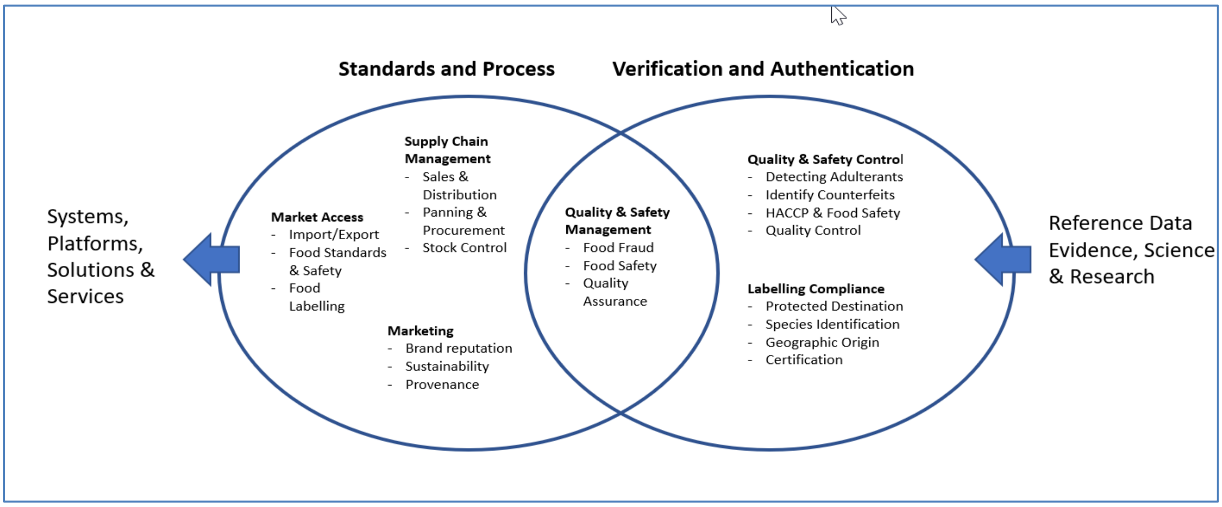


Figure 2 Standards and Processes vs. Verification and Authentication

2.1 Traceability Framework

The following section provides an overview of a Traceability framework based on the GS1 Traceability Framework Release 2.0 published August 2017 and the GS1 Foundation for Fish, Seafood and Aquaculture Traceability Guideline Release 1.3, February 2019.

Traceability is the ability to trace the history, application or location of an object. When considering a product or a service, traceability can relate to:

- Origin of materials and parts;
- Processing history; and
- Distribution and location of the product or service after delivery.

2.1.1 Introduction

Traceability processes and requirements for the egg industry bear a close resemblance to the loose product, fresh fruit and vegetable sector where similar requirements for product grading, sorting and packing exist.

In recent years, packing houses and large growers have implemented barcoded labels on loose product to strengthen traceability processes.

Previously, a national identifier (Price Look-Up (PLU) Code) was printed and applied to fresh produce. This process allowed retailers to identify the type of fruit or vegetable but did not identify the supplier/packing house and required manual entry of PLU codes at the point of sale check-out. The new label containing a barcode allows not only the identification of the specific product but also identifies the supplier of the product.

The notion of tracking fresh produce to packing house was initially considered unobtainable and too hard, however the introduction of new standards and technologies has made this transition possible.

With the emergence of this new standard and technology, both retailers and suppliers have benefited as follows:

- Improved category management
- Increased checkout speed
- Improved inventory accuracy
- Enhanced product quality management efforts
- More products automatically and accurately identified at point-of-sale
- Improved traceability
- Shrink control via front end accuracy
- Facilitated self-checkout

The egg industry is facing a similar challenge as it looks to further improve. Whilst the application of barcodes, in the above scenario was fit for purpose, a similar solution for the marking of eggs is unlikely and current processes are meeting minimum traceability requirements.

2.1.2 Traceability Principles

Traceability principles include:

- An organisation must determine what needs to be traced. This is commonly referred to as the 'traceable object'. A traceable object can be:
    - A product or traded item (consumer item, case/carton)
    - A logistic unit (e.g. pallet, bin, container)
    - A shipment or movement of a product or trade item
- All traceable items must be uniquely identified, and this information is shared between all affected supply chain partners
- As a minimum, the identification of products for the purpose of traceability requires:
    - The assignment of a unique identifier
    - The assignment of a batch/lot
- When a product is reconfigured and/or re-packed, the new product must be assigned a new unique product identifier. Linkage must be maintained between the new product and its original inputs
- All supply chain parties must systematically link the physical flow of products with the flow of information about them. Traceable item identification numbers must be communicated on related business documents

2.1.3 Supply Chain Context

The main driver for egg traceability is improved industry and consumer health and safety and trust.

Product traceability in the egg supply chain is already a requirement under the FSANZ Standard 4.2.5 which prescribes the relevant egg marking and processing stages from farm to consumer (Food Standards Australia New Zealand Act 1991).

2.2 Key Enablers for Interoperable Traceability Systems

2.2.1 Traceable Objects

A traceable object is a physical or digital object for which there is a need to retrieve information about its history, application, or location. In the context of the egg supply chain, these will include single eggs, packaged eggs, pallets of eggs and may include assets (e.g. trucks, forklifts, returnable packaging).

For the physical identification of traceable objects, generally three main levels of identification can be distinguished:

- Class-level identification, where the object is identifiable by its product/part ID, enabling it to be distinguished from different kinds of products
- Batch/lot-level identification, where the product/part ID is extended with a batch/lot number, limiting the number of traceable objects with the same ID to a smaller group of instances

- Instance-level identification, where the traceable object is identified with a serialised ID, limiting the number of traceable objects with the same ID to one individual instance.

2.2.1.1 Application by Industry

Carton labelling

Class level (object only) and Batch/lot level identification is extensively used in the food supply chain that includes eggs. Cartons of eggs (half dozen or dozen) purchased by consumers are uniquely identified with a barcode number. This barcode number does not contain any batch or use by information. Batch and Use by information is printed onto the egg carton at the time of packing. In the event of a product recall, the batch and used by information printed on the egg carton is used to determine if eggs purchased are impacted.

Example of current egg traceability data printed on a carton of eggs

Example of a current egg carton barcode printed on a carton of eggs

Figure 3 Examples of Egg Carton Labelling

Egg Stamping

As defined in section 1.4.1, the traditional method used for egg marking is ink printing or stamping a registered mark on the shell of the egg. This is typically achieved using low-cost rubber stamps, automated machines or ink-jet printers.

Ink based stamps are low cost and accessible, however:

- the ink needs to be food grade
- the markings are not always readable
- the ink needs to dry, slowing the production line

The use of laser CO_2 in food production processes has become a well-accepted trend. Laser is often used to replace labelling processes or the printing of expiry dates, identifying codes and other distinguishing marks on food products.

Laser marking is more costly and complex, however, has several advantages:

- the markings are permanent
- potentially hazardous substances aren't used

- the process is faster than ink marking

Laser markings are superficial and in no way damage the egg as only around a fourth of the eggshell's thickness is marked.

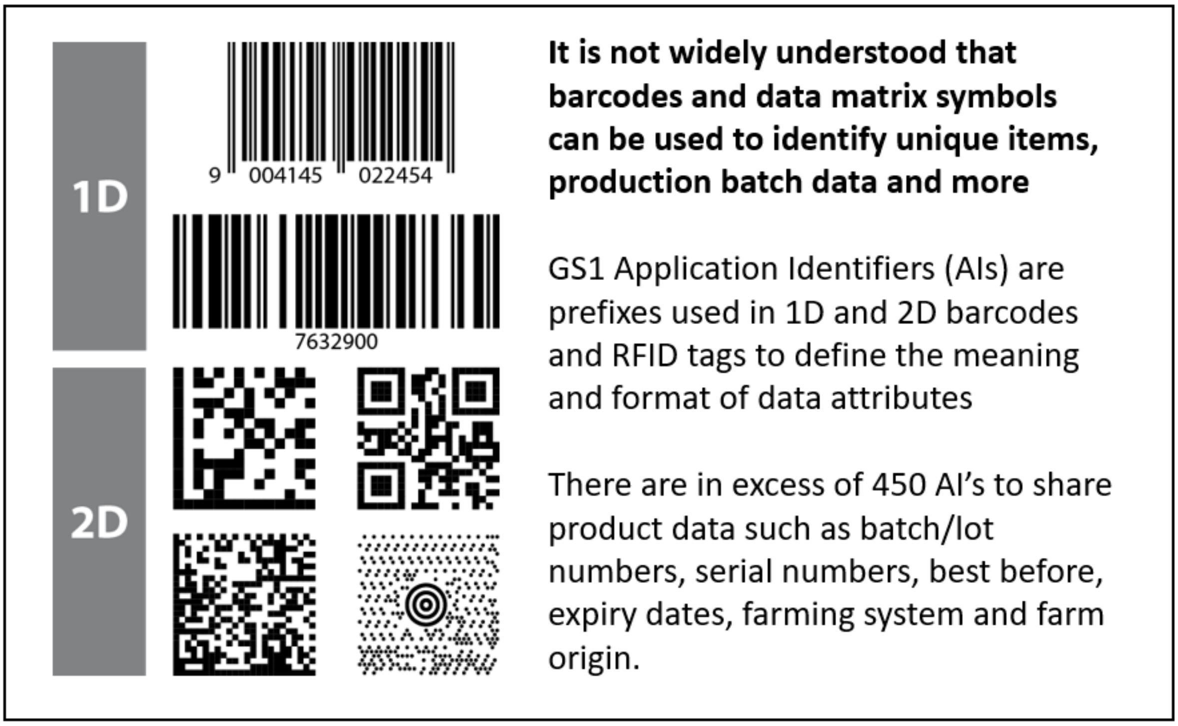
A current example of individual egg marking	Example of laser printing
	

Figure 4 Examples of Egg Stamping

2.2.1.2 Opportunity

A unified national standardised approach to batch/lot level identification should be considered when reviewing the national egg traceability standard and review of egg marking requirements. Whilst carton level marking is well established, the use of individual unique identifiers for eggs with related batch and use by information is not in place and relies on manual record-keeping and transfer of information.

Barcodes are used extensively for retail product labelling in Australia including for egg cartons. The system has been adopted globally as a data standard and has been in use since the early 1970s. Originally developed for stock and inventory management, barcodes are now being used extensively for end-to-end product traceability.



One and two-dimensional barcodes have proven economic and easy to use. Being both machine and human-readable, they have dramatically improved the efficiency of FMCG and retail operations and are increasingly being applied to healthcare, agriculture/farming and heavy industries to enhance supply chain performance and product traceability worldwide.

Major Australian retailers are in the process of implementing major upgrades to stock management and point of sale systems to capture the benefits of more embedded data in barcodes.

Box 4 Barcode Usage in Australia

2.2.2 Traceable Parties and Locations

In any traceability system, it is important to distinguish the various actors, who play a role in the chain of custody or ownership of a supply chain. Examples of parties in the supply chain might include a farm, packing house, distributor, carrier, or a retailer. In order to understand the full context of traceability, understanding WHO played a role and sometimes their relationship to each other in the chain is essential.

A traceability location is a designated physical area that has been selected to be in the scope of a traceability system.

2.2.2.1 Application by Industry

Property identifiers including Property Identification Codes (PICs) currently in use serve different purposes in Australian states and territories. They have different meanings and different rules apply to their use. In some states, they are assigned to individuals and in others to locations or land parcels. Land parcels in some cases are non-contiguous properties. This creates logical and administrative issues for regulators – especially for food quality and safety management, biosecurity incident response and to enable robust and rapid traceability.

An illustration of how the use of Global Location Numbers (GLN) provides useful functional benefit for producers beyond property identification for regulatory purposes is provided below.

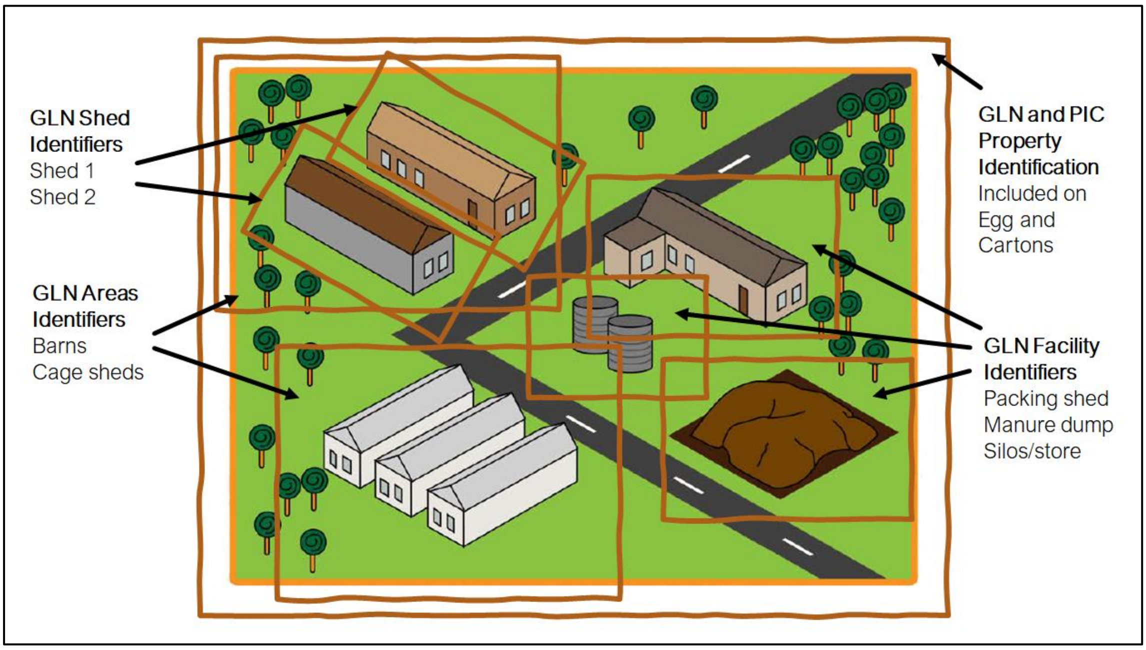


Figure 5 Illustration of Global Location Number

It is up to producers how they choose to define areas inside the property using a consistent and logical numbering system to define areas, facilities, sheds and other locations. This provides practical benefits for third party instructions including delivery and store addresses.

2.2.2.2 Opportunity

A unified national standardised approach to identifying both traceable parties and locations should be considered. The objective here is not to suggest that existing PIC systems be replaced; rather than a national unique numbering approach may provide a mechanism to harmonise existing systems; delivering consistency, simplicity and reducing compliance burdens for industries as well as governments.

Consideration for a national database and identification scheme is an option for Australian agriculture to investigate.

2.2.3 Traceability Data

Egg traceability data is needed to provide parties downstream with information on what happened upstream. These data need to be recorded by each individual party and are defined below as Key Data Elements and Critical Tracking Events.

2.2.3.1 Key Data Elements and Critical Tracking Events

Key Data Elements (KDE) ensure that captured and recorded data can be interpreted by all supply chain partners. Key Data Elements define Who, What, Where and Why.

Critical Tracking Events are records of the completion of a step in the business process in a supply chain, that is critical to record and share, in order to ensure end-to-end traceability. Critical Tracking Events provide a precise and granular view of the physical events, including the final sale to the end consumer. It goes beyond recording of commercial transactions between trading partners.

2.2.3.2 Application by industry

Key Data Elements and Critical Tracking events have been defined and are currently used in egg traceability systems. The FSANZ Traceability standard 4.2.5 and Eggs Standards Australia criteria have defined data collection requirements across all stages of the egg supply chain (Food Standards Australia New Zealand Act 1991).

2.2.3.3 Opportunity

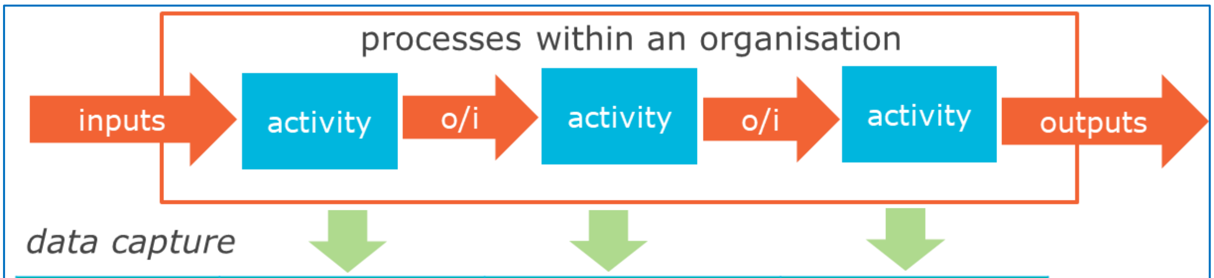
Whilst requirements have been defined, there is an opportunity for the egg industry to review current events and data standards to define a nationally agreed set of Key Data Elements to define the Who, What, Where and Why and Critical Tracking Events to ensure consistency of data capture across the whole supply chain. Specifically, it would be critical to define the following:

- The Who represents the traceability party such as the egg farm, grading/packing house, distributor, retailer etc..
- The What represents eggs down to batch/lot level. Other input materials such as stock feed should also be considered.
- The Where represents the location where a specific event took place e.g. farm (could be down to field), warehouse, packing house etc..
- The Why represents the business process that was undertaken, e.g. egg grading, egg marking, egg packing, or transportation.

Defining an agreed set of Critical Tracking Events nationally ensures that information required is captured in a consistent manner to enable, in conjunction with Key Data Elements, full end to end traceability of eggs.

The diagram below illustrates a generic diagram for the capture of information along a supply chain incorporating Critical Tracking Events and Key Data Elements.

Figure 6 shows how the use of unique identifiers for products (GTIN) and locations (GLN) can be used.



KDE:	CTE 1	CTE 2	CTE 3
Who	gln	gln	gln
What	gtin+lot	gtin+lot	sscc
Where	gln	gln	gln
When	date+time	date+time	date+time
Why	business process	business process	business process

Figure 6 Processes within an organisation

2.2.4 Traceability Systems for Data Sharing

The key to implementing a Traceability system and set of agreed standards is to ensure that information can be shared across the supply chain.

The diagram below (Fig 7) provides an overview of what a potential egg traceability system would look like if CTE's and KDE's were to be implemented.

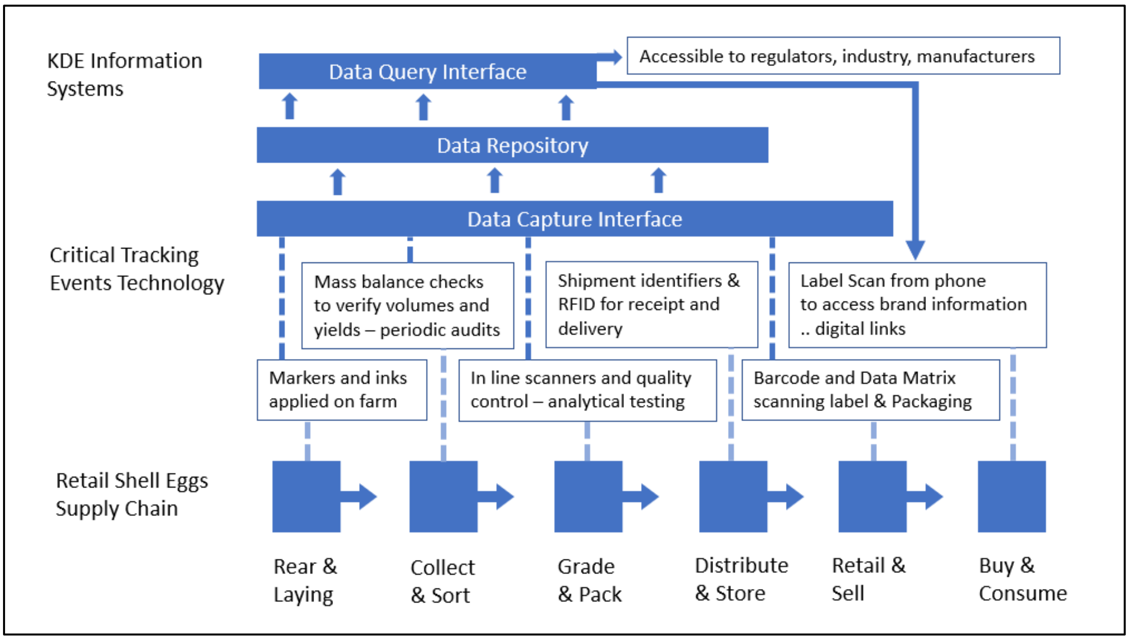


Figure 7 Industry Traceability Systems and Data Sharing

Alignment and collaboration with supply chain partners are essential. This is where standards come into play. Open supply chain standards enable interoperability between parties by establishing a common set of rules for identification, data capture, data sharing and data usage.

Organisations can identify products and locations using a standardised product identification and standardised location identification methodology. Additionally, companies can capture the standardised identification in a common approach – barcodes and /or other data carriers. Finally, once organisations are using a common language to identify and capture product data, the information can be shared in a standardised format, ensuring data completeness and accuracy.

The collection of traceability data from other parties and the provision of data to other parties are essential components in distributed traceability systems. This is achieved by applying a set of standards for the capture and sharing of traceability data.

A standards-based event and data capture service facilitate interoperability of data among trading partners in a supply chain.

2.2.4.1 Application by industry

Many proprietary and some open systems have been deployed to capture event-based data in specific supply chains. Based on open global standards, these systems can provide a full end to end visibility of product movements and facilitate full traceability across all parties in the supply chain.

In Europe, the tracking of fish is captured using the fTRACE system.

https://www.ftrace.com/en/gb

fTRACE improves efficiency and trust of the entire supply chain by standardizing industries and enabling companies to share transparency information on a batch level: A cross-sector traceability solution fully based on GS1 standards. fTRACE is an end-to-end traceability community solution provided by the fTRACE GmbH, a 100% subsidiary of GS1 Germany. The core of the fTRACE approach is to capture and share event based traceability data. Based on this, a variety of value-adding applications such as fresh counter traceability, end consumer information and BI dashboards are provided for retailers, brand owners and manufacturer.

Locally and across the globe, IBM has developed its IBM Foodtrust solution.

https://www.ibm.com/au-en/blockchain/solutions/food-trust

IBM Food Trust™ is the cloud-based blockchain solution providing an open, flexible and trusted way for members to share food data, derive value from the contributions of others, develop breakthrough functionality – and soon – choose where and how they deploy.

Partnering with industry leaders like GFSI (Global Food Safety Initiative), IBM Food Trust upholds current leading supply chain practices and paves the way for new ones. The exchange of clear and accurate information to any network user is built into our technology. Also built-in is compliance with GS1, the global standard for business communication.

https://www.gs1.org/docs/news/GS1-Open-Standards-Promote-Interoperability-Blockchain-Applications.pdf

Box 5 Examples of Traceability Solutions

2.2.4.2 Opportunity

The sharing of traceability information across the supply chain in a standardised format and making this accessible to participants in the egg supply chain would enable improved identification of eggs to the source. This would reduce the reliance on receiving and entering data manually and eliminating data errors. A national approach would improve interstate and intrastate egg movements and further strengthen consumer confidence in proving the source of their eggs (e.g. free-range versus caged).

2.3 Verification and Authentication Technologies

The following section provides a summary of the current methods used to trace food products and their potential opportunity for the Australian egg industry. Our focus is to explore the current science which provides an opportunity for enhanced product and supply chain integrity rather than specific in-market solutions. Examples of industry applications and solutions are provided for the purpose of technical maturity and readiness only.

Traceability in food industry value chains is increasingly being underwritten by innovations in forensic authentication systems and tools. Authentication and verification tools have historically been the domain of food safety testing, science and research. Industry threat of food fraud and unintentional adulteration of the product has focused businesses on forensic methods to protect brand reputation and secure niche markets. The trust in food supply chains from farmers to industry and regulators is varied according to the actors within the supply chain (Henderson et al. 2010, Henderson et al. 2011, Wilson et al. 2013, Charlebois et al. 2016, Huck et al. 2016, Tonkin et al. 2019). When food supply chain records are broken, records are inaccurate, or data is not symmetrical across the supply chain, the whole supply chain can suffer consequences, as in the case of food outbreak disease (Davidson et al. 2017, Meyer et al. 2017).

The value associated with a food product is a combination of its intrinsic characteristics, such as determining species or genotype and constituent ingredients; extrinsic characteristics, such as country of origin, method of production (organic vs traditional; grain vs pasture-fed; wild vs farmed), welfare standards and compliance with assurance standards, and the path with which it travels from producer to consumer and all the steps in between (supply chain) (Canavari et al. 2010, Lau et al. 2018). Taken together, these characteristics make up a product's provenance. Verification of these characteristics along the supply chain can involve high testing costs and long sample turnover times, which conflict with a just-in-time driven food supply system. An effective traceability system not only manages food quality and safety risks but also promotes the development of effective supply chain management (Ringsberg 2014).

Increased availability, reduced costs, and miniaturisation of equipment and systems previously restricted to laboratories have created a new market opportunity for testing services, traceability software and certification systems. Consumers' willingness to use technology to authenticate food labels is directly and positivity related to mistrust in the food industry and regulators (Charlebois et al 2016). Information in food supply chains is vital for consumers to choose products that match their desired qualities. By providing points of authentication, consumers could potentially feel more confident with the information provided on food labels. From an economic point of view, methods to control food authenticity are therefore essential and have become a focus area in food research (Stranieri et al. 2017, Sun et al. 2017). Quality, safety, credibility and reputation are inter-related aspects of food choices. Traceability methods which provide data that increase food safety communication and reduce data asymmetry will provide more value for both the supplier and customer. Analytical methods have a lower potential for fraud or falsification and are useful as complementary tools to prevent or investigate fraud and ensure customer confidence. Methods which were considered here were based on their ability to differentiate between egg production types. While sample destruction is not the preferred option, consideration was given to all current methods which can be used to differentiate eggs based on production and geography. It must be noted that any analytical method used should be robust enough to capture the inherent variability associated with breeding system diversity. No individual marker will be able to provide evidence to discern between the number of variables.

Authentication technologies summarised below include:

1. Isotope ratio mass spectroscopy (IRMS)

2. Elemental profiling
3. Trace element labelling
4. Rapid Evaporative Ionization mass spectroscopy (REIMS)
5. Nuclear magnetic resonance (NMR)
6. Infrared (IR) spectroscopy
7. Chromatography
8. Omic methods

Best attempts are made to avoid excessive jargon and to describe methods in ways that are useful for industry.

2.3.1 Isotope Ratio Mass Spectroscopy (IRMS)

2.3.1.1 Method description

Isotopes are atoms of the same element that differ by mass from each other. Isotopic signatures of hydrogen, carbon, oxygen and nitrogen vary in natural systems reflecting the dynamics of Earth System processes. These elements are found everywhere and are actively cycled within and between the atmosphere, hydrosphere, biosphere, and lithosphere. The isotopic ratios are applied to food traceability because stable isotope ratios change with climatic conditions, geographic origin, soil type and composition, and geological conditions of the locations of production (Kelly et al 2005). These methods have been used extensively to verify geographical origin and pathways through food supply chains and environmental systems. As the isotope ratio of food products is determined by geographic, climatic, physiological, and food chain positions, the inverse is also true. Knowing the isotopic ratio of a food product can be used to determine those parameters.

Hydrogen and oxygen ratios occur in patterns which relate to the geographical distribution of precipitation based on distance from the ocean, prevailing weather patterns, and altitude (Krivachy et al 2015). Therefore, they can be related to drinking water and the diet of animals and available water to plants. The correlation of the oxygen value of animal body water and drinking water depends on species and the rates of drinking and respiration. Generally, these are in a linear relationship which can vary between carnivores and vegetarians (Chesson et al 2011). The hydrogen isotopes are also correlated with the oxygen ratios derived from precipitation, they are also used in relation to individual metabolites as the basis for authentication of spices, aromas, and fragrances. Nitrogen isotope ratios can indicate the production method and can be used to differentiate between conventional and organic production methods (Choi et al 2017; Bontempo et al 2016; Inacio et al 2017; Inacio et al 2015; Schmidt et al 2005). Carbon isotope ratios can indicate a product's constituent ingredients based on the photosynthetic pathway used by those ingredients. For example, identifying products which have been adulterated with corn or cane syrup as in the case of honey (Vetrova et al 2017) or beverages (Magdas et al 2012; Adami et al 2010).

Strontium isotopes (87Sr/86Sr) are formed through the radiogenic decay of 87Rb and are used as a geological tracer. The measured 87Sr/86Sr ratio can correspond to the sum of the minerals derived from bedrock and their respective ages. Therefore, the 87Sr/86Sr ratio used in conjunction with other light stable isotopes (O, H, C, and N) provides a different scope to support the determination of provenance. Ideally, materials coming from either similar δ2H‰ and δ18O‰ values would have varying 87Sr/86Sr ratios or vice versa. The 87Sr/86Sr ratio of plant tissues may be directly related to the cations taken up from the soil, as isotopic fractionation is assumed to be very small (Petrini et al. 2015)

2.3.1.2 Current and potential application by industry

Stable isotope ratios are among the officially recognized methods for determining food origin as outlined in European regulations and international standards (Christoph et al. 2015, Carrera and Gallardo 2017). A requirement for food authentication and traceability is a database of authentic samples of known origin for comparison (Camin 2017), which could also be used for geographic origin determination. There are databases in existence which contain stable isotope information, for example, food of animal origin (Camin et al 2016), beverages (Carter 2015, Rossman 2008), and cereal crops (LI et al 2015), with wine being the most developed industrial database (Christoph et al 2015).

As a first indicator, hydrogen and oxygen isotope ratios in eggs (primarily in eggshells), are linked to the hydrogen and oxygen isotope of the water from the source region. The nitrogen and carbon isotope ratios are related to the climate and production practices (Rock et al 2012). Previous studies (Rogers 2009 and Denadai et al., 2008, 2009) were able to differentiate hens' diets based on the isotope ratios of eggs. Most recently, Dutch and New Zealand eggs demonstrated the promise of using nitrogen isotopes to screen and authenticate organically produced eggs from conventional feeds (Rogers et al 2015). The isotope fingerprint of eggs is a promising tool to authenticate and monitor labelling within markets and to identify instances when feeding practices may not be consistent with a specified farming regimen (Rogers 2009, Boner 2003, Rock 2012, Rock 2013).

2.3.1.3 Opportunity

In order to further develop the use of stable isotope techniques in egg traceability and authenticity systems, additional studies are needed to expand the available dataset. Having a larger, regionally diverse dataset from eggs is necessary and essential to identify potential regional to global trends in the isotopic composition of eggs with regards to geographic origin, as well as production systems. Elements other than H, O, C, N and S that could potentially provide information about the origin of eggs and should be investigated include Sr and Ca. IRMS techniques offer a complementary tool besides current egg labelling approaches.

2.3.2 Elemental Profiling

2.3.2.1 Method description

Elemental profiling is increasingly applied to determining food provenance. This refers to the macro-elements (sodium, calcium, and potassium), microelements (copper, zinc and selenium), rare earth elements (lanthanum, cerium, and samarium) or other elements occurring at very low abundances (gold, iridium). Plants derive their mineral content from the soil, which is impacted by not only the geological or geographic regions they are grown in, but also derived by fertilization, harvesting time, pollution exposure and production year. However, these latter variations are smaller than the variation observed between production areas and geographic regions.

Rare earth elements, as well as certain macro- and micro-elements are directly linked to the geology of the area and are minimally influenced by different production methods and harvest year. Therefore, the elemental profile, which is both the concentration of elements and the ratios between them, measured in any agricultural product will reflect the composition of the bioavailable and mobilized nutrients present in the underlying soils where they were grown (Danezis et al. 2016).

The elemental composition of foods from animal organs additionally reflects the fodder and vegetation they eat. The combination of elements characterizing products from a particular region should be different in each region. These methods are often coupled with isotope ratio measurements to strengthen provenance determination.

Elemental fingerprints of food are measured by a variety of laboratory based analytical techniques. Inductively Coupled Plasma Mass Spectrometry (ICP-MS), Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) and Inductively coupled plasma atomic emission spectroscopy (ICP-AES) are generally used due to their ability for multi-elemental measurements (Aceto 2016). This method has been successfully applied to vegetables (Drivelos and Georgiou 2012), beef (Heaton et al 2008), coffee (Worku et al 2019), and wines (Almeida and Vasconcelos 2001, Mercurio et al 2014). New rapid and non-destructive methods to quantify elemental fingerprints are being developed are discussed in section 2.3.6.

2.3.2.2 Current and potential application by industry

Elemental profiling is used in food analysis for both the authentication and traceability of food. The production chain of eggs is dominated by animal metabolisms; therefore, their elemental composition is mostly influenced by the diet of the production animals and the features of their fodder.

Elemental profiling of eggs is limited in the scientific literature, although the concentration of trace elements (Se, Zn, Mn, Co, Cu, Mo, V, Cr, Ni, Tl, As, and Cd) in both yolks and whites, distinct production systems, namely conventional, organic, and courtyard (family scale) where differentiated (Giannenas et al 2009). rom feed to egg, inorganic compounds undergo a fast transfer, which should reflect the environmental conditions to which the animal is exposed to, including soil, water and diet.

The milk industry has a comparable production chain. Multivariate analysis of the elemental composition of milk products, for example, found that Ca, Na, Fe, Zn, Mn, K, Ba and Mg were the most discriminative elements for geographical origin separation (Zain et al 2016).

2.3.2.3 Opportunity

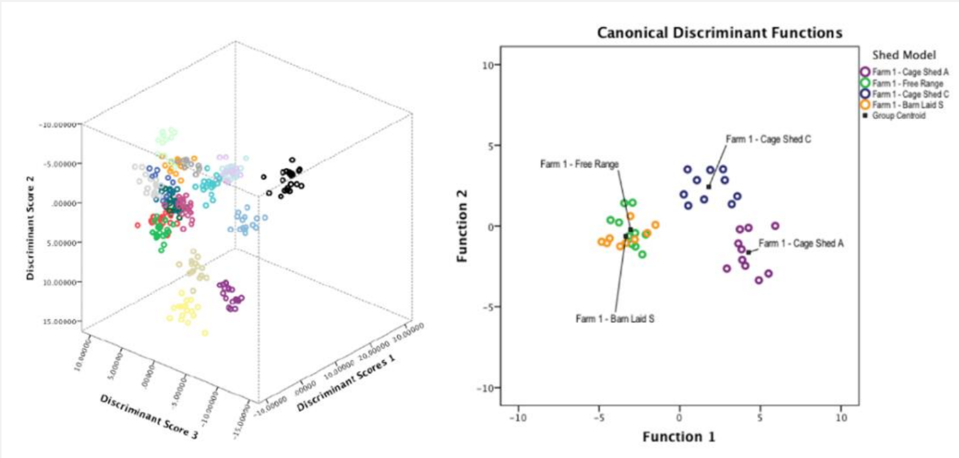
Studies focusing solely on elemental profiling are rare, the more common approach is to use these fingerprints in tandem with other methods, such as isotope ratios or NMR techniques. Similarly having a larger, regionally diverse dataset from eggs is necessary and essential to identify potential regional to global trends in the elemental distribution of eggs with regards to geographic origin, as well as production systems. Development of reliable proxies and rapid means to determine the presence or otherwise of trace element is likely to make chemical profiling an attractive proposition for enhancing traceability of product through complex supply chains in the future.

Trace Element and Isotopic Analysis – Source Certain

Chemical profiling of products is a well-established forensic science that assists to verify the geographical location of where a product was grown and/or the system by which it was produced. Trace element and stable isotope concentrations provide unique signatures that have been used to validate provenance claims and provide evidence-based support for case law.

Source Certain (Perth, WA) has successfully applied the technique to verify the origin of Australian eggs to a state, farm and shed level. The methods also provide the capability to verify farming methods based on chemical constituents of inputs used.

This means sourcing the eggs back to their farm of production and laying sheds. Eggs sourced from 100 farms across several geographical areas throughout all Australian egg-producing states (WA, QLD, VIC, NSW, SA, TAS and ACT) were collected. These samples were subject to lab analysis and the determined data were interrogated. Unique profiles for all eggs sourced from 100 different locations (i.e. separate farms) were developed. Classification models were also constructed to visually illustrate the statistical differences – as shown in the example provided.



Chemical profiling of produce is one of the most robust methods available to enhance supply chain traceability for organic and inorganic products. The process is however complex and limited facilities, availability of skilled technicians to operate sophisticated equipment means that the capability has historically be limited to laboratory and research facilities.

Development of reliable proxies and rapid means to determine the presence or otherwise of trace element is likely to make chemical profiling an attractive proposition for enhancing traceability of product through complex supply chains in the future.

Box 6 Example of Trace Element and Isotopic Analysis

2.3.3 Trace Element Labelling

Food products that have a direct relationship to the local soil reflect the regional distribution of trace elements, through absorption from the soil into the plant or by feed intake into the animal. Thus, the use of trace element fingerprinting, combined with statistical methods, is suitable for classification of such food products according to their origin. In contrast, for food products from conventional agriculture, in many cases, this close connection between soil, plant, and animal is not given. Animals which are fed commercial complete feed it is not possible to completely verify the origin of such products based on a region-specific trace element fingerprint. Artificially introducing a trace element pattern (e.x. using rare earth elements) which can be detected by suitable measurement methods can be applied to label eggs produced in certain regions or under certain production methods (I.e. organic vs conventional) (Bandoniene et al 2018). Rare earth elements are 16 elements ranging in atomic numbers 57-63 (light) and 64-71 (heavy). The natural background levels in plants and animals is very low, allowing small quantities to be detected through labelling techniques.

2.3.3.1 Current and potential application by industry

Application of trace element labelling through spiked chicken feed was found to be successful in a recent study (Bandoniene et al 2018). While this method makes it possible to ensure the origin of any poultry products, practical concerns by industry must be addressed before this is widely applied.

2.3.3.2 Opportunity

There is an opportunity to delineate feed standards for production practices to consider trace element labelling using naturally occurring elements. By applying known ratios of rare elements, rapid assessment methods can be developed to improve both traceability and geographic origin. There are high upfront costs to creating these standards as poultry feed and adoption, but measurement costs would lower over time.

2.3.4 REIMS – Rapid Evaporative Ionisation Mass Spectrometry

2.3.4.1 Method description

Rapid evaporative ionization mass spectrometry (REIMS) is a recent form of ambient mass spectrometry (AMS) which allows for in situ, real-time analysis of tissue samples. A surgical device called the intelligent knife (iKnife) is coupled to a mass spectrometer and it heats and evaporates samples with electric current (Balog et al 2013, Schaefer et al 2009). REIMS analysis takes a few seconds to gain accurate identification of tissues and allows in vivo and in situ tissue analysis. This methodology was originally developed for the medical and bacterial identification applications but has recently been applied to identify the species, origin, or quality of meat and fish products (Balog et al 2016, Black et al 2017).

2.3.4.2 Current and potential application by industry

This is a very new technology in the area of food analysis. Meat and fish studies have been the first application as they are solid, easy to cut, juicy and conductive. The spectral profiles of authentic food samples can be used to train and validate chemometric models using multivariate statistical analysis algorithms. However, the variety of food forms and their different physical properties is a challenge for the evaporation mechanism of REIMS. REIMS was applied to honey samples, but due to the low conductivity of the honey matrix, not enough aerosol vapours were generated. Contact heating, however, was applied successfully to liquid and non-conductive samples and was able to discriminate between botanical origins and adulterated honey samples (Wang 2019). REIMS was used to differentiate the geographic origin of pistachios after they were shelled and turned into a conductive paste (Rigano et al 2019).

2.3.4.3 Opportunity

This technology is currently being explored and shows very high promise for food provenance applications. However, more research needs to be done to test the applicability for eggs. Given that both whole egg and egg whites are conductive (Amiali et al 2006), this method has promise, but technological scoping studies must be done.

2.3.5 Nuclear Magnetic Resonance Spectroscopy (NMR)

2.3.5.1 Method description

Nuclear magnetic resonance (NMR) spectroscopy produces rich spectral information and the possibility of establishing the structure of compounds. The basic principle of NMR is that all nuclei are electrically charged, and many have an associated spin. In the presence of an applied external magnetic field, an energy transfer occurs that can be measured at different wavelengths.

NMR enables determination of complex matrices with high analytical precision. Thus, almost all the macro components of a mixture can be detected in one spectrum. Therefore, NMR spectra of food products can be considered as fingerprints, which contain the entire information on the composition of a product and on its qualitative characteristics. This information can be used for the comparison, discrimination, or classification of samples.

The spectrum in NMR spectroscopy usually contains tens of thousands of variables—chemical shifts. As NMR spectroscopy can measure many samples quickly, chemometric techniques such as multivariate data analysis can be applied to large datasets.

Two types of NMR are applied for food analyses low-resolution NMR (LR-NMR) and high-resolution NMR (HR-NMR). LR-NMR instruments are smaller, easy to use but require reference materials to carry out quantitative analyses, which is the limiting factor of their use. HR-NMR is one of the most expensive methods, in terms of capital and running costs, but it provides the most detailed information regarding the molecular structure of a sample, although sensitivity without complicated sample preparation is poor (Luykx et al 2008).

One application of HR-NMR is Site-Specific Natural Isotopic Fractionation (SNIF-NMR) which enables robust fingerprinting of natural molecules and is commonly used to differentiate geographic regions.

2.3.5.2 Current and potential application by industry

Despite its increasing popularity among food authentication methods, NMR is still an underutilised methodology in this area, mainly due to its high cost and the lack of NMR expertise in the domain. NMR is cited in EU regulations for the geographic origin determination of wine (EU regulation 2670/90, 2347/91, and 2348/91) as a recognized method for determining geographic origin or adulteration of products (Monakhova et al 2013).

NMR in combination with chemometrics has been used to classify Italian cherries (Longobardi et al 2013), cocoa beans (Caligiani et al 2014), and honey (Dinca et al 2014). NMR and chemometrics were used to distinguish farm and wild-caught salmon (Martinez et al 2009).

2.3.5.3 Opportunity

NMR spectroscopy in combination with multivariate data analysis is a suitable tool to screen eggs according to the different production regimes. NMR spectroscopy possesses a number of unique properties, which makes it promising for the analysis of eggs. NMR spectroscopy requires highly specialized equipment and operators to prepare, run, and interpret the results correctly. Sample preparation must carefully consider extraction and homogenization for the transfer of the sample into a solution which can be measured.

The measurement of the NMR spectrum is not trivial. Overlapping signals and signal suppression must be considered before the NMR spectra can be transformed into useful data.

Despite these hurdles, NMR spectroscopy is successfully applied to identify eggs based on their production method (Ackermann et al 2019). The water, protein, lipid composition of eggs may vary specifically depending on the hens' feeding regime, which is further influenced by the production method. For example, the fatty acid profile of the yolk varies depending on the intake amount of grass pasture (Mugnai et al 2014).

2.3.6 Infrared Spectroscopy

2.3.6.1 Method description

The infrared (IR) region measures the vibrations of molecules, where each functional group, or structural characteristic, of a molecule, has a unique vibrational frequency that can be used to determine what functional groups are present in a sample. When the different functional groups are taken together, the result is a unique molecular "fingerprint" that can be used to confirm the identity of a sample.

The IR portion of the electromagnetic spectrum is divided into three regions—the near-, mid-, and far-infrared—named for their relation to the visible spectrum. The mid-infrared (MIR; approximately 4000–400 cm−1) is traditionally used to study the fundamental vibrations and associated rotational–vibrational structure, whereas the higher energy near-infrared (NIR; 14,000–4000 cm−1) can excite overtones or harmonic vibrations. This means that NIR can provide more complex structural information than MIR. Raman vibrational spectroscopy is high-intensity and laser operated where the vibrational information is retrieved from light that is scattered from the sample. Hyperspectral imaging is a non-destructive testing technology, which contains both spectral information and image information The complex patters of signals are correlated to the contents of the different chemical constituents.

Multivariate data analyses can determine more than one component at a time in a sample and be used as a support to establish links to the food's origin. If the components have enough discriminatory power, the set of their concentrations will form a characteristic pattern, or fingerprint, relating to the geographical origin of the sample. Multivariate data analysis or other data mining procedures provide the ability to detect these patterns and are essentially helpful when the number of components necessary to differentiate samples from different geographical origins increases (Cozzolino 2012).

Handheld devices that allow consumers to self-authenticate labels are meeting increasing consumer demand (Charlesbois et al 2016). Consumer-friendly devices could be helpful in educating consumers about food processes and potential fraud, but regulators should carefully consider the monitoring and enforcement ramifications.

As technology is becoming more efficient and data processing algorithms are improved, handheld devices offer the promise of high sample throughput, resulting in easy handling, short analysis time, non-invasiveness, with qualitative and quantitative analyses (Huck et al 2016).

2.3.6.2 Current and potential application by industry

Virtually any type of food in any state (fresh or processed) can be analysed by spectroscopic methods. Spectroscopy has commonly been applied to measure food quality in a variety of products (Cozzolino 2012, Pustjens et al 2016). Egg freshness is assessed with fluorescence spectroscopy (Karoui et al 2009). With regards to geographic origin, the success of these methods relies on the selection of the sample set, type of spectroscopic technique used, type of data pre-treatment, and type of chemometric algorithm used.

The chemical specificity and ease of IR make it an attractive tool for rapid and comprehensive food analysis. However, there are limitations to scale of determination that IR techniques can provide. As in the case of cocoa bean shells, correlations between geographic origins were possible to a low level of specificity (Mandrile et al 2019). In other words, samples were distinguishable into classes based on geographical origins, with adequate precision and accuracy, but it was not possible to discriminate the chemical species driving that classification.

Demands are increasing for non-destructive, rapid, accurate, portable or handheld devices, which has resulted in several types of portable and/or handheld available devices, for which a detailed review has recently been published (Abasi et al 2018). These fall under the broad categories of image processing technology; acoustic, ultrasound and impact force methods; and electronic or optical methods. Most of the methods have been developed for horticultural and meat products and are generally lower in accuracy than their research-grade counterparts. Fish and pasta have been used to demonstrate the application of handheld NIR devices to authenticate species (Grassi et al 2018, Neves et al 2019).

2.3.6.3 Opportunity

Spectroscopic techniques as non-destructive, rapid and safe approaches have been successfully applied to the quantitative determination of major egg constituents (i.e. fat, moisture, and protein content). Most studies on these applications have assessed the quality of eggs and their products in terms of storage time, air cell height, albumen pH, egg fertility and sexing (Zhao et al 2019). A recent study has shown that NIR spectroscopy combined with class-modelling is a potential tool for distinguishing egg production (Chen et al 2019) but this study was very limited in scope.

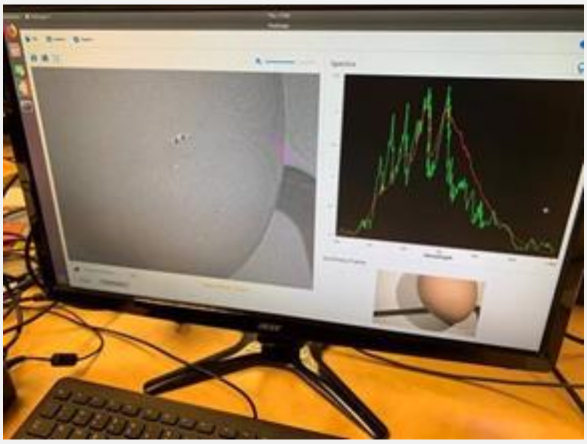
Hyperspectral imaging with chemometrics was used to classify eggs based on production method in a non-destructive method (Sun et al 2017). The natural variability of food materials is high, but IR techniques offer the possibility to identify leading variables, common trends, and general indications, which could be coupled to more robust analytics for further investigation.

With non-destructive spectroscopic techniques and cloud-based computing having developed rapidly over the years, there is potential for use of these devices for self-authentication by customers, in the future.

Microtags – TruTag Technology

Silica microtags developed by TruTag Technologies are about the size of a dust particle and smaller than the width of a human hair. Tags may be applied to packaging and labels and can be integrated directly onto the product – via a simple spray-on method. Silica is one of the most abundant materials on earth and is an ingredient already found in many foods, including sweeteners.

Using an ultra-fine laser, the silica is etched with a signature for batch level identification of products. A library of unique codes allows for tracking and authentication of the product. Each tag's coded, micro-scale pattern can be scanned using the company's proprietary instruments. These patterns are like ID numbers that can be associated with a variety of information, such as country or region, farming system or brand owner.



Hyperspectral imaging technology enables a wide range of light wavelengths to be processed rapidly making micro-tagging a relatively economical and easy to use solution. Advances in mobile phone imaging and data processing capability will further increase the likelihood that microtags and nanoparticles will be used by industry for enhanced product traceability. Egg industry applications to date have been limited, however successful trials have been reported for red meat products in Australia.

Box 7 Example of Silica Microtags

2.3.7 Chromatography

2.3.7.1 Method description

Chromatographic analyses provide rapid, reliable separation and quantitative determination of macro- and micro-components of highly similar chemical structures in complicated matrices of foods and food products (Cserháti et al 2005).

As food substrates contain several compounds, which are chemically diverse, ranging in both size and polarity, chromatographic techniques must take into consideration the sample matrix of interest. These methods produce chemical fingerprints that can be applied to differentiate and authenticate foods, based on the identification of minimal analytical differences between patterns or identification of unique marker compounds.

Several high-resolution techniques have been developed, including gas (GC) or liquid chromatography (LC) which are sometimes coupled to mass spectrometers. LC separation targets polarity, electrical charge, and molecular size and is used to detect proteins, amino acids, carbohydrates among other compounds. GC is more suited to the naturally volatile or semi-volatile compounds. Authentication by chromatography is based on the profile of specific compound profiles for each food product which form profile characteristics for food origin identity. HPLC (High-performance liquid chromatography) use a UV-visible light absorbance detector, a fluorescence detector, and electrochemical detector and diffractometer. HPLC has been used commonly in food analysis as it is straightforward, robust, and reproducible with a modest initial capital cost.

Chromatographic techniques can produce both a fingerprint and a profile. The principal difference between chromatographic fingerprint and chromatographic profile is related to the type of analytical information they concerned. A chromatographic profile contains specific information relating to particular chemical compounds or metabolites while a chromatographic fingerprint contains many peaks with non-specific and non-evident information which represents many of the food products. The most useful aspect of such results is to create a specific and reliable differentiating tool rather than provide explicit information about the source compound.

2.3.7.2 Current and potential application by industry

Chromatographic techniques have been used to determine the adulteration of high-quality foods with substandard or inexpensive ingredients, such as honey, wines, vegetable and olive oils, coffee, milk, and saffron (Di Stefano et al 2012, Esteki et al 2019). These methods are robust and reproducible and are often combined with other complementary methods.

Broadly, the applications can be split into a few main categories, phytonutrients measured by LC and semi/volatiles and fatty acids using GC. These classical approaches of separation techniques are widely used and the costs associated with measurement reflect this. However, time and care must be given to determining which compounds are of interest and provide the strongest case for determining provenance or adulteration.

2.3.7.3 Opportunity

HPLC-UV chromatography was used to create fingerprints for eggs based on their production method (organic, free-range, barn, and caged) when combined with appropriate chemometrics. Highest levels of discrimination were between organic and non-organic eggs based on whole egg measurement (Campmajo et al 2019). Specific markers were not used, but rather overall fingerprint profiles were created, demonstrating the robustness of these methods. Egg yolk compounds were analysed and compared across breeds to differentiate eggs (Bunea et al 2017), which demonstrates the genetic component of classification, which can be detected with fingerprint profiles.

DNA Biomarker - SafeTraces

DNA has been used as an 'on-food' safety solution to provide provenance signatures and protect food brands from recalls, adulteration, and fraud.

SafeTraces was founded in 2013 and has focused on first-mile (fam to processing) traceability solutions for conventional and organic food crops including bulk commodities like grain. The solution involves the spray-on application of edible, flavourless, odourless DNA-based signatures directly to food, not the packaging, to deliver enhanced traceability.

The DNA-based solution leverages the company's patented, FDA affirmed GRAS materials, currently being implemented across the fresh produce industry. The method involves encoding and decoding digital information to and from DNA strands drawn from seaweed.

SafeTraces product is available on a limited basis and has only recently become commercially available in late 2019. Inventors of this technology claim billions of signature permutations can be created, and food treated with these DNA strands can be inspected with a proprietary reader similar to the device shown.

Subject to industry acceptance of DNA markers, the method offers the potential for low cost, ease of use and innocuous management of brand fraud and measurement of product co-mingling through the value chain.

Box 8 Example of DNA Biomarkers

2.3.8 Omic methods

2.3.8.1 Method and maturity

Omic methods describe a suite of methods which are used to differentiating sample populations, based on the entirety of the genome (genomic), the proteins (proteome), or the metabolic products (metabolome). Generally, omic methods refer to the group of technologies which are used to qualify or quantify a distinct sub/-molecular level. Other techniques, including mass spectrometry or NMR may be used in tandem to detect compounds of interest.

The results of omic methods are highly resolved, unambiguous molecular fingerprints, making it possible to distinguish between a reference and an unknown sample. While fingerprinting is possible (i.e. screening as many analytes as possible) it is also possible to apply preferential, ultra-high-resolution instrument-based methods to increase the likelihood of discrimination and maximize the quality of data.

Omic tools produce large amounts of data which must be reduced through either bioinformatic or chemometric algorithms to the key components with the greatest variance between different sample populations. By aligning and assessing that data with other databases, additional information can be gained. Currently, there are only limited standards for non-targeted approaches, which limit commercial applicability. Marker compounds can be extracted from experimental data and be used to develop routine approaches, which can be standardised.

The polymerase chain reaction (PCR) is a technique which detects very low amounts of nucleic acid probes and determines their sequence via the amplification of DNA or RNA individual strains. This technique is used extensively to identify the species of origin in foods. The techniques are mature and have broad application to a range of industries including animal and vegetative farming systems. However, the selection of the most suitable method depends on the amount of genetic variation of the analysed species.

Genomic methods are highly species-specific and therefore require access to the correct DNA sequence of the organism, either as strains, varieties, or ecotypes. DNA barcoding uses a single gene sequence to differentiate most animal species (Herbert et al 2003). For a barcoding approach to species identification to succeed, within-species DNA sequences need to be more like one another than to sequences in different species. Therefore, the application of these methods is limited to a comparison between single taxon or closely related taxa. In other words, these methods are highly useful for fraud when substitutions of one species or linage for another is suspected.

Proteomics is used to assess the quality and quantity of peptides and proteins which are derived from either the genome or exogenous factors. Therefore, proteomics can be used to ascertain the genetic origin as well as the geographic origin, cultivation, production, or storage processes (Creydt and Fischer 2018). These methods are predominantly used for quality assurance of protein-rich foods.

Metabolites are intermediates and end products of metabolic pathways, categorized into exogenous and endogenous compounds. The metabolome is strongly influenced by external factors, such as weather, soil composition or storage conditions. Metabolomic methods include mass spectrometry, fluorescence spectroscopy, NIR and MIR and other vibrational spectroscopy. The main advantage of metabolomic approaches is the un-targeted nature, which can detect a variety of fraud or adulteration compounds (Cubero-Leon et al 2014).

2.3.8.2 Application by Industry

The polymerase chain reaction (PCR) to analyse the genetic origin of food products is widely used and has been applied to determine geographical origin in meat, cheese, fish, fruit, and marine salts (Pustjens et al 2016).

Whole Genome Sequencing (WGS) based investigation identified the root cause of a Salmonella outbreak and preventing future outbreaks, Public Health England began real-time sequencing of all presumptive Salmonella spp. received from April 2014. In June 2014, a large multi-national outbreak of Salmonella enterica ser. Enteritidis was linked to the consumption of eggs. Over 350 cases were reported in several European countries.

A clear statistical correlation between the UK egg distribution network and distribution of the outbreak-related patients was revealed by WGS. This indicated that the outbreak of Salmonella related to the source of the eggs. WGS showed that five restaurants in England associated with point source outbreaks were distinct but linked. Clinical, food and environmental samples in several European countries showed that separate introductions of contamination had occurred from at least two premises owned by a single European egg producer with broad product distribution.

This case shows the power of WGS in revealing the epidemiology behind an outbreak, which allowed the definitive source of the outbreak — a single egg producer — to be identified and targeted for intervention, rather than just the restaurants where the contamination reached the population.

Targeted intervention further up the food production chain can be additionally effective in reducing further risks. This case also highlights the importance of the availability of genome sequencing data from multiple countries, demonstrating how global sharing of WGS data could enhance the response to a foodborne outbreak, to further protect public health and identify a particular source of contamination.

2.3.8.3 Opportunity

Omic methods require validation of potential biomarkers and certified reference materials for validating methods. Future work to apply omic methods should consider representative sampling which includes all sources of variability (e.g. population type, development state, pathological conditions, production methods, location) and multiplexing the identification and quantification of several authenticity markers into one assay.

DNA barcoding could be combined with other technologies, but in the case of eggs, species substitutions are rare and therefore DNA-based methods will have limited applicability. More research is needed to understand the effect of production method on egg metabolites or proteome.

2.3.9 Comparative Analysis and Summary

With a view to providing practical benefits, capabilities are compared using a simple comparative analysis based on (Table 4):

- Cost, including whether costs may drop with industrial uptake or remain high due to the nature of the method,
- Accuracy, with reference to the type of information offered
- Processing time, referring to in-line with production or off the production line
- Accessibility of the capability described as either in the research space or current industry adoption and,
- Commercial readiness – offerings in market as services to industry
- Measurement – does the method require destructive or non-destructive measurement

Table 4 Method comparison and potential for industry adoption

Method	Cost	Accuracy	Time	Access	Commercial readiness	Measurement
IRMS	High	High	Long	Specialised		Destructive
Elemental Profiling	Low	Moderate - high	Middle	Specialised	Ready	Destructive
REIMS	High Upfront Low Long-term	High	Fast	Specialised, but can be routinised	Ready	Non-destructive

NMR	High	High	Long	Specialised		Non-destructive
IR and NIR	Low	Moderate - high	Fast	Specialised, but can be routinised	Ready	Non-destructive
Chromatography	Mid	Moderate	Middle	Routine	Ready	Destructive
Trace element	High Upfront Low Longterm	High	Middle	Scientific (current) Widespread (opportunity)		Destructive
Omic	High	Moderate - high	Middle	Specialised, but can be routinised		Destructive

2.3.9.1 Implications for Industry

As stated previously, there is not one individual marker which can solely provide refutable evidence of production methods or geographic origin. Rather a series or suite of measurements can be used to refine current egg labelling standards (i.e. isotopes or trace elements). There is no single best solution for food products, due to the availability of a large variety of techniques and progress in technique development.

A system which involves screening and further testing if results of the first screen may be considered. Such a system would involve the development of rapid, robust, non-destructive screening followed by a destructive measurement for confirmation or refutation of the egg. There are multiple drivers of supply chain fraud, but ultimately, the integrity of a product is maintained by the strength of its supply chain. However, as the risk is situational and characterised by the wider environment in which the products move, it is necessary to use robust methods that can provide the appropriate level of information for the claim. The value associated with a food product is a combination of its intrinsic characteristics, such as determining chemical constituents (i.e. water, protein, lipids); extrinsic characteristics, such as region of origin, method of production, welfare standards and compliance with assurance standards, and the path with which it travels from producer to consumer and all the steps in between (supply chain).

All the methods described require standards and comparisons. Data management is a large consideration regarding all the methods presented here. How databases are assembled, managed, and shared can either limit or increase the available information for egg production and the applicability for any tracking or tracing technology. There is a large opportunity to design a system which includes as many sources of variability as possible, while considering how eggs are moving either inter- or intrastate, possible sources of substitution based on the production method, and where non-aligned farmers are located within the supply chain.

Consumer demand is driving demand for devices which allow self-authentication of labels (Huck et al 2016; Charlebois et al 2016). Several prototypes based on DNA-based tags and IR methods are on the market and in development (refer to previous sections). Due to the lack of national regulation, self-authentication is becoming more important. But consumers are left to trust the development of the underlying algorithms and data. Developing the underlying database and management of data contained within, in a transparent and at a broad scale is critical for increasing the trust and therefore the value of this technology.

3 Conclusions

The Australian egg industry, and egg industries globally, are experiencing a premiumisation of their products caused predominantly by a shift in production practices.

Consistent with this premiumisation across the egg and other agricultural industries is an expectation that the agriculture sector develops a world-class traceability system that firstly, enhances the level of trust that consumers have for the sector by guaranteeing products being purchased are authentic and as described, and secondly, there is an ability to conduct rapid, targeted recalls should the need arise.

3.1 Conclusions

There is potential and enabling science to support enhanced egg traceability systems from farm to packing and grading facilities in Australia. Technology and solution availability, cost or performance are not, however, critical factors limiting the ability of the industry to achieve higher levels of transparency and supply chain integrity.

Not unlike other agricultural supply chains in Australia, the egg industry currently relies on codes of conduct or the industry QA standard to ensure safe management of produce from farm to consumer. This is especially true for 'first-mile' product movement from egg-laying through to packing. While Australia's national traceability review and framework (Traceability Working Group 2018) has highlighted the adequacy of many traceability systems, it also notes the opportunity to modernise systems in response to changing consumer preferences; including the desire for greater transparency along the food supply chain which is driving worldwide demand for greater traceability.

To enable enhanced traceability, there are fundamental and foundational elements to be considered. This includes national standards for, and harmonisation of, property (farms) locations and products (eggs and egg product) identification systems. Existing traceability system components have evolved in different ways and rates with a primary objective of state and territory-based biosecurity risk management. Consequently, it is difficult for consumers to access product information or make sense of labelling/stamping systems and for these systems to deliver value through premiumisation to producers.

In order to fully explore the potential and opportunity for the Australian egg industry, future work should focus on four main areas:

1. **Foundational elements – property and product identifiers**

Traceability analysis often focuses on traceable items (in this case, eggs and cartons etc.) and makes assumptions that standards are in place and working to manage property/farm and other identifiers critical to delivering supply chain transparency and efficiency. Traceability solutions, food safety and quality assurance systems and biosecurity risk management policy objectives of government are defeated or unnecessarily complicated and costly in the absence of a consistent and national approach to property and product identification and labelling.

A nationally coherent approach will greatly improve the effectiveness of egg traceability systems. This will deliver enhanced food safety and quality assurance systems and biosecurity risk management.

2. Standards and a framework for industry

The challenge of enhanced product traceability is not new, and the Australian egg industry stands to benefit from the application rather than the invention or development of systems and tools. Traceability standards are used worldwide and provide a powerful tool kit for industry and government implementation of enhanced traceability systems that are independent of technology and systems that continually change. Drawing upon elements of international frameworks and standards, the Australian egg industry can modernize and better position itself and provide broader market access.

3. Affordable and reliable product verification and authentication systems

Evolving and emerging technologies may provide new solutions for tracing and authentication of product through the supply chain. This research contributes to industry understanding of the maturity of enabling science and potential application to the egg industry. Without having to change any existing industry processes, solutions are currently available to trace a product from farm to the packhouse. Micro-tags and other low-cost applications including DNA are showing potential for rapid and reliable verification. There is an opportunity and likely value for the industry to test these emerging technologies alongside established forensic measures including element and isotopic profiling to strengthen system integrity and re-enforce existing assurance systems.

The Australian egg industry traceability challenge cannot be addressed in isolation. A national (perhaps generic) and multi-sector approach to both regulated and commercial traceability systems across all agricultural supply chains will likely benefit the industry. A generic model has potential for benefits through consistent, coordinated regulation across jurisdictions, and the sharing of information and experiences between industries.

Alongside the commercial benefits and opportunities provided by a national approach to traceability systems, it is also clear that a food safety or biosecurity incidents have economy-wide impacts and damage domestic consumer confidence and Australia's brand reputation abroad. Reputational damage can take some time to repair, possibly years. Increasing global production and movement of agricultural products and food means that the risk of such an incident occurring is also increasing. Many of the required tools, systems and standards and supporting national infrastructure are generic and can likely support the agriculture and food sector.

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Plain English Summary

Project Title:	**Australian Eggs Traceability Technology Desktop Review**
Australian Eggs Limited Project No	1FS001
Researchers Involved	John Szabo, Peter Carter, Dr Robert Barlow and Dr Nina Welti
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Objectives	To review current egg traceability systems and available technologies to support enhance traceability in the Australian egg industry
Background	Good traceability systems are critical to keeping our food safe, tracking and, if needed, recalling contaminated food quickly. Traceability allows the tracking of products and all inputs into those products in the event of an animal disease outbreak. Recent Salmonella Enteritidis (SE) outbreaks in New South Wales and Victoria, has further highlighted the importance of supply chain transparency and system integrity. This project aims to define available technologies and methods to support enhanced traceability in the egg industry: bringing together national research capability and global perspectives on supply chain and traceability standards. It has been funded from industry revenue which is matched by funds provided by the Australian Government.
Research	The desk-based research scope includes considers current domestic and international approaches to egg traceability. It provides examples of digital and biological verification and authentication technologies that may address existing supply chain traceability vulnerabilities. Verification and authentication technologies are evaluated only to the extent that underlying capabilities can assist the egg industry to address issues of traceability of products through the supply chain. This project is not focused on certification processes or schemes adopted by industry to manage quality. Neither does it consider techniques or measures to identify product defects or the presence of disease, pathogens or contaminants.
Outcomes	The Australian egg industry needs practical solutions: • To know where eggs, especially ungraded eggs are moving (inter or iintrastate and how they move; • For simple and effective technology and processes that can help prevent egg substitution – especially cage eggs sold as free-range / organic; and

	• To know how eggs can be traced back to their origin from any point of the supply chain.
Implications	Key outcomes and benefits to industry, customers, community and government include: 1. Improved industry health and safety 2. Reduced cost to industry of recall or incident response 3. Enhanced consumer trust and confidence in product quality and value.
Key Words	Traceability, verification and authentication, supply chain, food provenance, supply chain integrity, trust
Publications	This report only