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ORIGINAL ARTICLE

Adoption challenges of environmental monitoring practices: case study of temperature data loggers in selected Australian vegetable supply chains

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Abstract
Temperature monitoring across cold chain practices is an integral component of fresh produce supply chains. Numerous temperature data loggers (TDLs) are available to reduce the significant amount of food loss and waste (FLW) (equivalent to around 50%) in vegetable supply chains; however, its widespread adoption remains a challenge for the actors along the chain. This study seeks to understand the adoption of TDLs within selected Australian vegetable supply chains to address the challenge of FLW. Three representative cases of vegetable supply chains were purposively selected, including growers, packers, transporters, distribution centres along with technology providers, and industry experts. Data were collected through semi-structured interviews and analysed utilising thematic analysis. The findings indicate that members of vegetable supply chains recognise temperature management as one of the key factors for preserving quality and extending shelf life of their produce; however, they are not proactively seeking to utilise TDLs in their supply chain operations. Resistance to adoption of TDLs is deeply rooted in product-based challenges such as cost and compatibility, and process-based challenges including information sharing and product mixing. Additionally, presence of an individual's undesirable behavioural aspects such as status-quo bias and responsibility shirking as well as prevailing social norms within the industry influence the adoption of TDLs.

Keywords Environmental monitoring practices · Temperature data loggers · Australian vegetable supply chains · Technology adoption behaviours

Introduction

Agri-food supply chains (ASCs) around the world have been challenged with the rapidly evolving economic, social, and environmental issues. World population is expected to reach nine billion by 2050 (UNDESA 2019), and ensuring food security is the defining challenge for agriculture (UNICEF 2020). Urbanisation is expected to increase with an accelerating speed, and it is anticipated that urban areas will account for around 60% of the world's population in year 2050 (an increase from 54% in 2016) (Fróna et al. 2019). At the same time, global economic growth is projected to increase by around 3% annually which would lead to a significant reduction in economic poverty in developing countries leading to rise in the purchasing power of consumers (FAO 2009). Parallel to the global food demand challenges, there are also problems of disruptions across ASCs due to pandemics like COVID-19 (Das and Roy 2022), and continued environmental degradation and climate change (Malhi et al. 2021). To meet these challenges, increasing production levels of food is essential but reducing the existing significant amount of food loss and waste (FLW)[1] across different

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[1] Food loss refers to decrease in the quality or quantity of edible food along supply chain operations. Food loss typically occurs during initial stages of supply chain such as in production and post-harvest processing. Food waste, a subset of food loss refers to produce that is not consumed at the end of the chain such as at retail or household level Rezaei, M. and B. Liu (2017). "Food loss and waste in the food supply chain". International Nut and Dried Fruit Council: Reus, Spain: 26–27.

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echelons of existing perishable food supply chains is a more pertinent solution which can be achieved through the adoption of modern technologies (Benyam et al. 2021; Trevisan and Formentini 2023).

FLW is an overarching challenge for ASCs in which approximately one third of the food produced for human consumption–equivalent to around 1.3 billion tonnes each year–is discarded (Munesue et al. 2015; Xue et al. 2017). The extent of food loss is similar across the globe, but stages and causes differ (Dou et al. 2016). For instance, USA loses up to 40% of its food from production to consumption (Gunders and Bloom 2017), and approximately 10% of fresh produce is lost annually in Europe from farm to fork (Jedermann et al. 2014). Similarly, in Australia, it is estimated that around 50% of fresh produce is lost across different stages of the supply chain (DCCEEW 2023).

The problem of FLW has been categorically mentioned as one of the key issues for Australian agri-food supply chains (Sanad Alsbu et al. 2023). The study of Commonwealth Scientific and Industrial Research Organisation (CSIRO) found that 18 to 22% of horticultural fresh produce is lost during production and processing stage. Thereafter, 7 to 10% of fresh produce is lost during packing stage (Juliano et al. 2019). Similarly, FIAL[2] estimated that 37% of total food waste comes from the loss and waste of horticultural products in primary production and processing stage (FIAL 2021).

Numerous reasons for this significant amount of FLW in Australian ASCs are presented in extant literature. For instance, Messner et al. (2021) stipulated that overproduction is a prevalent feature in Australian horticultural supply chains. Surplus food production is considered to be a common practice which leads to a high amount of FLW at the end. Private quality standards[3] and its enforcement by the supermarkets are also considered as one of the dominant factors for FLW in Australian horticultural supply chains (Devin and Richards 2018). McKenzie et al. (2017) found that around 68 to 87% of undamaged, edible harvested tomatoes were rejected as not meeting certain cosmetic grounds[4] set by the retailers. The Australian fresh produce market is concentrated with two supermarket chains (Coles and Woolworths) holding over 70% of market share (Tonkin 2016).

Ineffective management of cold chains and temperature abuse along different stages of fresh produce chains are also termed to be one of the key factors for significant amount of FLW (Raffo et al. 2021; Schudel et al. 2023). The study of Australia's department of Agriculture, Water and the Environment and Refrigerants estimated that around 25% of annual production of fruits and vegetables loss is attributable to breaks and deficiencies in the food cold chains (DAWEFA 2020). Temperature management across different stages of the chain (post-harvest to consumption) is considered integral to maintain quality and to extend the shelf life of fresh produce (Göransson et al. 2018). Recent technological advancements in cold chain monitoring have enabled real-time temperature tracking of produce. A fully automated real-time cloud-based cold chain monitoring system can reduce FLW, preserve the quality of produce by enhancing its shelf life, and maintain its nutritious value (Badia-Melis et al. 2018; Benyam et al. 2021). Temperature management during different stages of ASCs (harvest to distribution) by utilising advanced technologies for monitoring and detecting deterioration of produce is considered to be one of the key aspects for reducing FLW (Onwude et al. 2020; Trevisan and Formentini 2023).

Numerous temperature data loggers (TDLs) are available to monitor temperature throughout the cold chain processes (Mercier et al. 2017; Badia-Melis et al. 2018; Ndraha et al. 2018; Shashi et al. 2021); however, its widespread adoption and adaptation in perishable produce chains are still a challenge (Ndraha et al. 2020). Therefore, the main objective of this research is to understand the phenomena of lack of adoption of TDLs in selected Australian vegetable supply chains by analysing its current adoption status and relevant challenges including behavioural and psychological ones. The term behavioural and psychological refers to the spectrum of challenges and factors pertaining to perceptions and attitudes of vegetable growers along with other members of the chain.

The remainder of the article is structured as follows. Section "2 "study context" presents context of the study. Section 3 (Literature Review) provides an overview of relevant literature. Methodology of the study is outlined in section 4 (Methodology of the study). Findings are discussed in Section 4 (Findings) and Section 5 (Discussion) respectively. Finally, section 6 (conclusion) concludes the research by providing significance of the study, including its implications and future directions.

Study context

Vegetable sector in Australia encompasses a wide diversity of edible fresh produce spanning across varied climatic regions to meet mainly the demands of domestic consumers. Australia has produced 3.585,678 tonnes of fresh vegetables in 2022/23

[2] Food Innovation Australia Limited is an industry led, not for profit organisation focused on providing services to Australian food market.

[3] Private quality standards are established and owned by non-government entities for meeting certain food safety and sensory qualities of fresh produce, and these are implemented on suppliers of fresh produce. Hobbs, J. E. (2003). Incentives for the adoption of good agricultural practices (GAPs). *Food and Agriculture Organization*, *1*.

[4] Refers to the physical condition of a fresh produce including colour, look, size and other visual appeal. Dusoruth, V., & Peterson, H. H. (2020). Food waste tendencies: behavioral response to cosmetic deterioration of food. *PloS one*, *15*(5), e0233287.

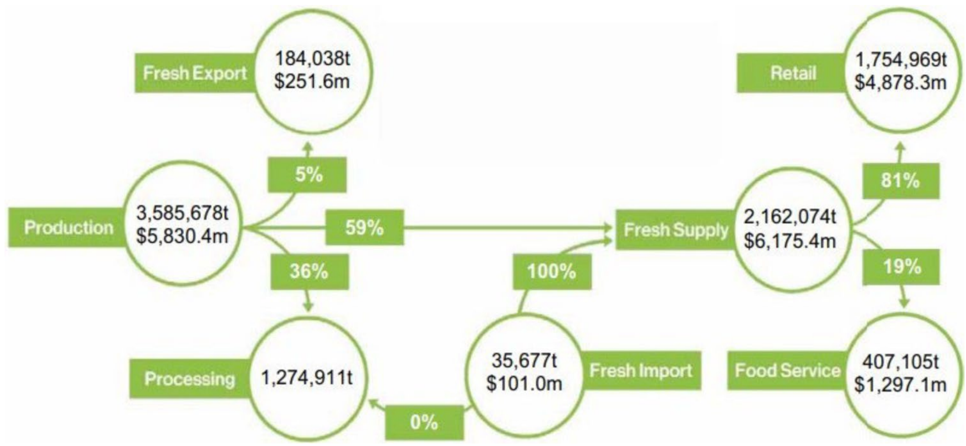

Fig. 1 Distribution of Australian vegetables into different channels. Source: (Hort Innovation 2023)

having an estimated farmgate value of around AUD5.83 billion. 59% of the total production volume were injected into domestic supply chains, 36% into processing and 5% of the total volume were exported. Figure 1 taken from the report of Hort Innovation (2023) on Australian Horticulture Statistics handbook 2022/23 illustrates an overall distribution of Australian vegetables into various market channels. This study was conducted in the Lockyer Valley Regional Council (LVRC) area located in south-east Queensland. Vegetable production is the largest agricultural commodity in LVRC, accounting for around 44.3% of whole agricultural output.

According to the handbook of Hort Innovation,[5] Australian farmers are growing 33 different types of vegetables, ranging from artichokes to zucchinis (Hort Innovation 2023). Table 1 shows top ten vegetable crops based on production volume in tonnes (t) and gross farmgate value in millions ($m) for the year 2022–23.

Significant amount of food loss and waste (FLW) exists in Australian vegetable supply chains as illustrated by the study of CSIRO and DAWEFA (Juliano et al. 2019; DAWEFA 2020). Proper monitoring of temperature across different stages of the chain (farm to fork) is important to reduce the significant amount of FLW in these chains. The adoption of real-time data collection tools including temperature data loggers (TDLs) in supply chain operations can be beneficial to achieve efficiency and to reduce high amount of FLW.

Literature review

The study explores two important elements in the field of fresh produce supply chains. These elements are cold chain technologies including TDLs and its implementation challenges in fresh produce chains. Section "Cold chains and its importance and processes in fresh produce" covers the importance and technological trends in cold chain monitoring of fresh produce. Section "Technology adoption challenges in fresh produce supply chains" provides a review of technological challenges in utilising cold chain technologies in fresh produce chains by concluding with the gaps in literature.

Cold chains and its importance and processes in fresh produce

Cold chains are becoming a significant part of the modern global perishable industries. Singh et al. (2018) define cold chain management as "the process of planning, implementing and controlling the flow and storage of perishable goods, related services and information to enhance customer value and ensure low costs". After harvest, fresh produce like vegetables and fruits remains alive and has vital signs, and to keep these in their optimum condition, maintaining suitable

Table 1 Top ten vegetables produced in Australia based on production volume and value

Rank	Production (t)		Gross value ($m)	
1	Potatoes	1,462,065	Potatoes	830.20
2	Tomatoes	436,908	Tomatoes	645.10
3	Carrots	306,394	Leafy salad vegetables	589.20
4	Onions	266,429	Mushrooms	434.20
5	Head lettuce	134,726	Broccoli	289.90
6	Pumpkins	112,895	head lettuce	266.70
7	Sweet potatoes	102,754	Onions	248.70
8	Cucumbers	88,495	Carrots	247.90
9	Leafy salad vegetables	78,495	Cucumbers	229.90
10	Cauliflower	76,944	Capsicums	211.80

Source: (Hort Innovation 2023)

[5] Hort Innovation is a non-for-profit research organisation dedicated to development of Australia's horticulture industry. Organisation also provides statistical support to the industry. More information is available on https://www.horticulture.com.au/

temperature along the supply chain is one of the integral environmental factors which have direct implications on deterioration and post-harvest shelf life (Centobelli et al. 2020), so keeping cold chain integrity is crucial to reduce FLW, maintaining the quality of fresh produce and extending its shelf life (Han et al. 2021).

In vegetables and fruits growing sector, cold chain generally starts right after harvesting fresh produce. Harvested product is precooled to bring its temperature down to appropriate food-specific storage conditions. After storage, depending on the market demand, fresh produce is then transited in refrigerated transport through land, air, or sea to other storage facilities or distribution centres. Cold chain ends when consumers get fresh produce and put it in a domestic refrigerator (Mack et al. 2014). Cold chain management processes can be broadly classified into three stages, which are: pre-cooling, storage, and transportation.

At the pre-cooling stage, field heat from harvested produce is extracted. This stage is aiming to slow down the physiochemical activities in fresh produce, minimise the destruction of nutrients, and to reduce the shocks of temperature fluctuations in subsequent cold chain operations (Han et al. 2021). There are a variety of pre-cooling techniques, including hydro-cooling (Reina et al. 1995), room cooling (Thompson 2016), vacuum cooling (McDonald and Sun 2000), forced air cooling (Thompson 2016), and cryogenic cooling (Curtis et al. 1995).

After pre-cooling stage, fresh produce is transferred to a refrigerated warehouse (RW) which serves mainly to provide a stable and long term low-temperature environment to conserve its quality (Shashi et al. 2021). RW is critical for maintaining temperature, regulating transport capacity, and sustaining a balance in demand and supply.

Refrigerated transport links upstream and downstream operations of the fresh produce supply chains and is an essential component in the post-harvest storage, handling, and distribution (Al-Dairi et al. 2022). There are numerous refrigerated transport modes, including air, marine, road, and rail. Selection of a refrigerated transport depends on the market demand, economic value, and overall cost (Nath et al. 2018). An overview of cold chain processes in fresh produce chains is presented in Fig. 2.

Technological trends in cold chain monitoring

Radio frequency (RFIDs)-based temperature data loggers (TDLs), wireless sensor networks, thermal imaging, and internet of things (IoT) are some of the evolving technological trends in cold chain management processes of fresh produce chains (Badia-Melis et al. 2018; Shashi et al. 2021).

Applications of TDLs and wireless sensor networks (WSN) in various sectors of agri-food industry, especially in cold chain management, have gained considerable interest in recent years (Pan and Liu 2021). TDLs is an emergent technology that can record product's history, including temperature, and can provide accurate information about its status throughout different stages of the chain (Costa et al. 2013). TDLs are instrumental in replacing the old bar code method and contribute to the real-time visibility of products and objects, regardless of their geographical location in food supply chains (Zhou 2021). A complete TDLs system consists of three parts: tags, readers, and antennas. Radio signals are emitted from reader to activate tag and allow the data to be received. Communication between tag and transceiver is activated through the reader which then decrypts the encrypted data and transmits it for further processing through antenna (Mosadegh Sedghy 2018). RFID-based TDLs can be passive, semi-passive, and active. Passive and semi-passive TDLs send their data by reflection or modulation of the electromagnetic field. Passive TDLs do not have a battery, while semi-passive tags have a battery but only to charge the sensor and recording logic. Active TDLs have a battery and provide real-time information upon its access, and therefore, these tags are expensive as compared to others (Badia-Melis et al. 2015).

TDLs are now widely connected through WSN, consisting spatially distributed sensors and one or more sink nodes. Researchers posit that embedding TDLs with WSN provides

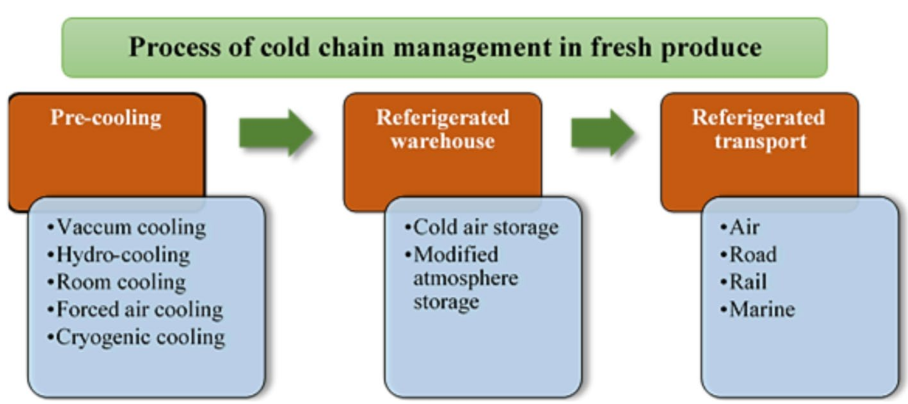

Fig. 2 Cold chain management processes in Fresh produce Chains

multiple benefits in effective cold chain management (Aung et al. 2011). Firstly, combining these two technologies offers richer information that facilitates better decision support and proactive localised management, thereby achieving higher safety of fresh produce across different cold chain activities Secondly, if TDLs is embedded into WSN, tags, and sensors can build a more intelligent network by sharing sensors and transmission capabilities. For instance, longer data transmission can be achieved, and further related information like location and other environmental conditions can be sensed, which is integral to the shelf-life estimation of fresh produce (Alfian et al. 2017). An overview of TDLs that can be utilised in cold chain monitoring of fresh produce supply chains is presented in Table 2.

Thermal imaging camera can be also utilised to record infrared radiations emitting from the produce and converts it into a visible image which can then be used to record temperature (Ishimwe et al. 2014). Thermal imaging depends on emissivity, which means that the ratio of energy emitted from an object in comparison with a black body at the same temperature can vary from 0 (perfectly white) to 1 (perfectly black) (Gowen et al. 2010). Badia-Melis et al. (2017) investigated the feasibility of temperature measurement through thermal imaging technology in pallet covers where putting sensors was not practically feasible.

Internet of things (IoT) is a network that connects objects with the ability to identify and interact to reach an agreed goal (Giusto et al. 2010). IoT has been emerged as an efficient system in cold chain monitoring of fresh produce because of the enormous number of devices connected to the internet, as well as widely availability of internet and service providers (Naeem 2019). Although applications of IoT are well established in agriculture, its utility in food supply chains has gained significant interest in operations like risk management, food traceability, and development of intelligent packaging (Tsang et al. 2018; Popa et al. 2019; Onwude et al. 2020). Fresh produce supply chains are transforming and becoming more data-driven due to the availability of advanced and cost-effective sensors (Rejeb et al. 2021). However, overall agriculture is comparatively less digitalised as compared to other sectors (Kodan et al. 2022).

Technology adoption challenges in fresh produce supply chains

Adoption refers to the decision process of an organisation or an individual to make use of an innovation. In agriculture, adoption of an innovation, new practice, or technology is predominantly affected by the decision-making process of farmers (Rogers 2010); therefore, understanding factors that are affecting farmer's decision-making process is important (Rose et al. 2018, Hayden et al. 2021). A farmer's decision-making process is extremely complex and rarely purely rational (Burli et al. 2021). Therefore, to understand this process, one needs to take into account a wide range of complex individual-level factors, socio-temporal dynamics, contextual and institutional settings (Reimer et al. 2014).

Table 2 Overview of data loggers for cold chain monitoring of fresh produce

Type	Technology	Features	Uses	Data	Examples
Conventional temperature loggers	Connected through USB or via NFC	Temperature data at a certain stage Manual collection process	Field temperature monitoring Packing sheds Cold rooms Warehouses Aircraft cabins Ship containers	Quality control Reactive approach	Sensitech Flashlink Deltatrak
Wireless temperature monitors (Non-sim based)	RFID technology and GPS technology	Real-time data Automated email notification Physical location	Remote data monitoring Weather stations Product on the go temperature monitoring	Real-time Sharing information Proactive approach	Sensitech TempTale Blulog
Wireless temperature monitors (Sim-based)	RFID + GPRS Technology	View real-time data Automated email and SMS notifications Sharing the product's physical location using SIM/Tower locations	Remote data monitoring Product on the go temperature monitoring	Real-time data about the quality Sharing information with different stakeholders across the chain Proactive approach to temperature issues across the supply chain	Vacker Emerson-Go real time Sendum

Pure economics research suggests that farmers are perfectly rational profit maximisers, and they make decisions based on careful analysis of factors leading to maximising utility from their actions (Anderson et al. 1977, Rougoor et al. 1998), to which Nuthall and Old (2018) refer as a formal decision-making process. However, considering all relevant factors in decision-making process, research suggests that majority of farmers do not tend towards this style of decision (Hardaker and Lien 2010). For instance, Hayden et al. (2021) found that decision-making process of farmers is largely influenced by factors other than economic incentives such as psychological and behavioural ones.

Understanding psychological and behavioural factors of farmers is getting more interest in recent literature on technology adoption due to its importance in explaining their decision-making process (Giua et al. 2022; Hüttel et al. 2022). Attitude of farmers, their personal values, emotions, and intuition have a critical role to play in their decision-making and technology adoption (Adnan et al. 2018; Pillai and Sivathanu 2020; Gerli et al. 2022). Despite the importance of behavioural and psychological factors in explaining the farmer's decision towards adopting a technology, little attention has been given in previous literature. For instance, a review and reflection on farmer's adoption of sustainable agricultural practices by Foguesatto et al. (2020) reported that there are very few studies to understand the psychological factors of farmers in innovation adoption.

Supply chain of fresh produce is characteristically complex due to nature of produce's quality, safety, spoilage, seasonality, shelf life, storage, and environmental conditions (Van Der Vorst and Beulens 2002). Consumers are now more interested in transparency and integrity of chains, which compels food supply chain actors to deploy technologies that can transform current practices and provide an agile information across the chain (Villalobos et al. 2019).

IoT-based temperature data loggers (TDLs) have been considered to be one of the most prevalent and essential technologies to facilitate information sharing across ASCs through maintaining quality and freshness; however, there are numerous challenges. Aamer et al. (2021) comprehensively presented the adoption challenges of IoT in fresh food supply chains by reviewing seventy-two research studies published across forty-three journals. The authors collated 15 adoption challenges of IoT in fresh produce. These challenges were classified into five main themes including, technical, financial, social, operational, educational, and governmental. Furthermore, they also identified that technical, operational, and financial are the top three researched themes while the other two have received less attention in previous studies. Another peer-reviewed article by Narwane et al. (2022) identified twenty-four different factors while studying the adoption of IoT in the context of Indian fresh produce supply chains. Annosi et al. (2021) highlighted the role of coordination mechanisms and practices among supply chain actors and how these processes impact the adoption of digital technologies in ASCs. The authors posited that coordination is one of the significant adoption challenges among different-sized firms along the supply chain of fresh produce.

Hansen et al. (2023) reviewed the current status and future of digital technologies in Australian agriculture. The authors focused on technical, governance and social factors of digital technologies adoption. They mentioned that fragmentation of digital technologies, absence of enabling legislations and policy, coordination between technology providers and users, and lack of a value proposition are the biggest challenges in deploying technologies. Furthermore, they recommended that a clear value proposition along with supportive legislation and policies can enhance digital technologies' adoption in agriculture. In the same context, Marshall et al. (2022a, b) studied agricultural technology adoption in south-eastern Queensland and found that digital divide between the rural and urban areas of the country is one of the reasons for less adoption of technologies in agriculture. Table 3 presents an overview of key challenges in adopting IoT in Australian ASCs.

Han et al. (2021) comprehensively reviewed previous research on cold chain logistics and identified Industry 4.0 adoption as a future research area that requires understanding from multi-disciplinary perspectives. Similarly, it also graphically presented the literature statistics on cold chain management between year 2002 and 2020, which suggests that cold chain management is getting attention among researchers. Aamer et al. (2021) clearly stressed a need to carry out future research in the field of IoT, its application in cold chain management, and adoption challenges in ASCs. Therefore, this study is an attempt to fill this gap by understanding psychological, behavioural, and contextual factors of the industry in this case.

Technology adoption models and theoretical framework of the study

In last five decades, there has been a proliferation of technology adoption models across different fields such as information systems, computer science, consumer behaviour, and agriculture (Tey and Brindal 2012; Liu et al. 2018). Prominent theoretical frameworks are diffusion of innovation theory (DOI) (Rogers 2003), theory of reasoned action (TRA) (Fishbein and Ajzen 1975), theory of planned behaviour (TPB) (Ajzen and Fishbein 1980), technology acceptance model (TAM) (Davis 1989), unified theory of acceptance and use of technology (UTAUT) (Venkatesh et al. 2003), and technology organisation and environment (TOE) (Tornatzky and Fleischer 1990).

Table 3 Key adoption challenges of IoT in fresh produce chains

Theme	Key challenge	References
Technical	Complexity	Marshall et al. (2022a, b)
	Interoperability	Higgins et al. (2017), Higgins and Bryant (2020), Marshall et al. (2022a, b)
	Reliability of internet/ Connectivity Issues	Salemink et al. (2017), Rennie et al. (2013)
	Technical skills	Wiseman et al. (2019)
Financial	Capital/initial investment	Higgins et al. (2017), Zuo et al. (2021)
	Operations and/or maintenance cost	(Alfian et al. 2017)
Social	Collaboration among supply chain members	Jakku et al. (2019), Ali et al. (2021), Higgins and Bryant (2020)
	Data security and trust among supply chain members	Marshall et al. (2022a, b), Jakku et al. (2019), Fleming et al. (2018)
Psychological/ Behavioural	Digital mindset	Lythreatis et al. (2022), Marshall et al. (2022a, b)
	Ease of use	Ndraha et al. (2018), Lezoche et al. (2020)
Governmental	Governmental regulations and policies	Cook et al. (2022) Wiseman et al. (2019)

Technology adoption in fresh produce supply chains is a complex phenomenon that calls for an integrated framework. For instance, Mohr and Kühl (2021) applied TAM and TPB to investigate the behavioural factors of farmers influencing the adoption of artificial intelligence. Similarly, Laksono, Irham et al. (2022) also combined TPB and TAM models to examine the psycho-behavioural perspectives of farmers in the adoption of geographical indication technology. Adnan et al. (2019) combined DOI, TPB, and TAM to examine the decisions of Malaysian farmers regarding the adoption of green fertiliser technology. Taherdoost (2018) suggests that more than one theoretical approach or model is necessary to understand the complex dilemma of human behaviour, the issue involved and related contextual factors, which this study has adopted as its theoretical framework. The framework of the study presented in Fig. 3 combines factors from the DOI, TPB, TAM, and TOE to understand current adoption status of TDLs in Australian vegetable supply chains along with underlying psychological and behavioural adoption challenges.

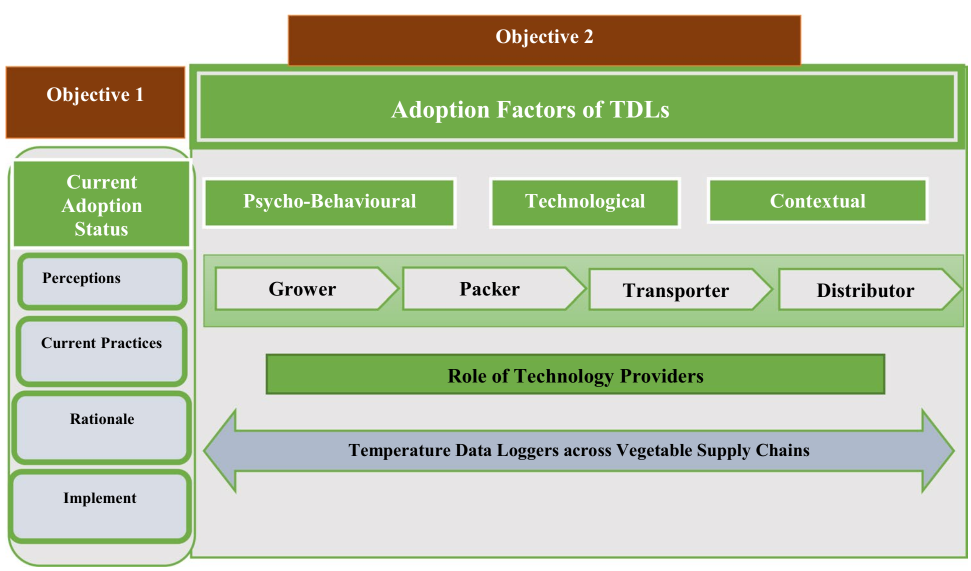

Fig. 3 Theoretical framework of the study

Methodology of the study

An explorative, qualitative case study approach was undertaken in the year 2021/22 to comprehend current practices of temperature monitoring and adoption of TDLs across vegetable supply chains in Lockyer Valley Regional Council (LVRC) situated in Southeast Queensland, Australia. LVRC is a longstanding farming region in which vegetable production is the largest agricultural commodity, accounting for 44.3% representing 5% of Queensland's total agriculture output (ID 2023).

Three case studies were undertaken in which each case consists of separate vegetable supply chains. Case study protocol was developed (attached as Appendix 1) as it enhances its research validity (Yin 2009). Each case study included grower, packer, transporter, distribution centre staff, technology provider, and relevant experts as presented in Fig. 4. The first case study was providing broccoli to central markets in Brisbane and Sydney, and some of their produce was also exported. The second supply chain was primarily providing broccoli and shallots to central markets across Australia. The third case study was supplying Asian vegetables (mainly cucumbers) to the central market in Brisbane and Sydney. Technology providers included companies who were engaged in manufacturing and marketing of TDLs. Experts included those who were directly or indirectly involved with the improvement and development of horticultural supply chains and or working with allied organisations or in research institutions. Overview of the study participants for the research is provided in Fig. 4 below.

A combination of different sampling strategies was employed to collect data from vegetable supply chain members. At the start, criterion sampling strategy (Miles and Huberman 1994) was utilised. Two criteria were followed for the selection of a case for the study. The first was that only a vegetable supply chain should be considered to be a case, and the second was that the vegetable grower should be based in southeast Queensland, mainly in the LVRC area of the state of Queensland in Australia. In the second stage, a critical stage sampling strategy (Miles and Huberman 1994) was utilised in which cases were selected that could provide rich information about the adoption of TDLs. In the third stage, during data collection, a snowballing technique (Miles and Huberman 1994) was used in which the researcher asked participants to identify and recruit other participants in the upstream operations of the chain for this study.

To achieve saturation, Marshall et al. (2013) suggested a range of fifteen to thirty respondents to be involved in the interviews for case studies. Therefore,, twenty-five interviews were conducted from different members of vegetable supply chains including technology providers as presented in Table 4.

Data were collected from multiple case study participants through a blend of different methods to grasp deeper understanding of the adoption of TDLs as suggested by (Creswell and Creswell 2017). Semi-structured interviews were employed to collect data as this method allows efficient collection of qualitative data (Roulston and Choi 2018). An interview guide (attached as Appendix 2) was developed consisting mainly open-ended questions along with probing ones to capture participant's insights (Adeoye-Olatunde and Olenik 2021). Documentary evidence was also utilised during data collection as it further enhances richness of data (Yin 2009). Documentary evidence included farm's

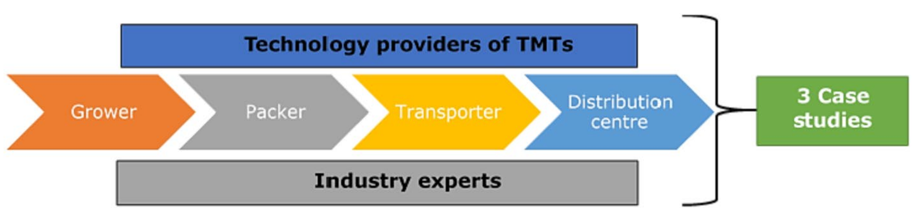

Fig. 4 Study participants

Table 4 Interview participants

Supply chain stage	Case study 1	Case study 2	Case study 3	Total	Interaction
Growers	2	2	2	6	F2F*
Packers	1	1	2	4	F2F
Transporters	2	2	2	6	F2F
Distribution centre staff	1	1	1	3	F2F
Vegetable supply chain interviews	6	6	7	19	
Technology providers	1	1	1	3	F2F & online
Experts	1	1	1	3	
Total	**7**	**7**	**8**	**25**	

*Refers to face-to-face interaction

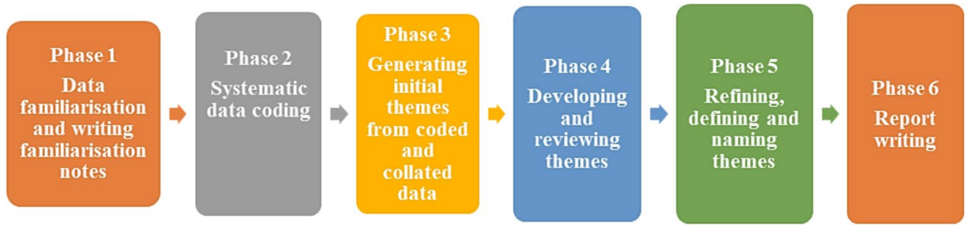

Fig. 5 Six-phase process of thematic analysis adapted from (Braun & Clarke 2020)

temperature monitoring practice memos, communication documents across the chain (recording temperature at each part of the chain), and quality assessment documentations.

Fieldwork process

There were three steps involved in the field work process. In the first step, initial approaches were made to the chief executive officer/owner of a vegetable-producing farm located in the Lockyer Valley district in Queensland, Australia. A formal engagement plan (attached as Appendix 3) was developed for each case study. During interaction, study's purpose, benefits, and design were discussed, and the company's collaboration was sought. It was also made clear to the farm management that this research strictly follows a confidentiality agreement, so their information will be only used for research purposes. The farm management was then asked to connect researcher with other chain partners such as a transporter and distribution centre.

In second step, appointments were made with the chain partners through email or phone. Information sheet and consent forms (attached as Appendix 4) were provided before the interview. Before engaging in this research, consent forms were signed by the chain partners. In addition, these chain partners were also asked to refer another partner from the upward stream operations of the chain to be part of the study. The researcher also approached technology providers through a referral from the Queensland Department of Agriculture and Fisheries' supply chain innovation team. Information sheets and consent forms were shared with the technology providers, and they were interviewed either face to face or over the phone.

In the third step, a list of experts were contacted who directly work with members of the vegetable supply chains across the region on improving practices around temperature monitoring, enhancing the quality of fresh produce, and reducing food loss. An email including details of the study, ethics, and concept plan was shared with these experts, and their participation in the study was sought (attached as Appendix 5). Some experts were unavailable; however, others agreed to be interviewed, and most of these interviews were conducted online.

Data analysis

Collected data were analysed by utilising thematic analysis and NVivo software version 12.[6] Initial transcription of interviews was carried through an online paid transcription software titled as "trint" (https://trint.com/). Six-phase method of thematic analysis suggested by Braun and Clarke (2020) was followed to develop codes and themes from data. These steps are presented in Fig. 5.

In the first step, Microsoft Word document was created by transcribing and exporting all the interviews with each member of vegetable supply chain. Recordings of interviews were again listened and tallied with the provided transcription for any error or omission. This process allowed familiarisation with the data and understands the breadth and depth of the content. At this stage, initial ideas and patterns started emerging which were recorded in each document as comments for further use in analysis.

In the second step, initial codes from the interview transcripts were developed. These initial codes assist the authors to organise interview data into meaningful groups of information (Tuckett 2005). Coding process was carried out in Microsoft Word and in NVivo software, in which data were condensed into chunks of information. These initial codes were discussed among authors for further feedback.

In the third step, initial themes were gathered from coded and collated data. After this, initial codes from each interview were exported from Microsoft Word to a single file of Microsoft Excel. Each tab in the Microsoft Excel file was representing codes from single interview. The codes were read again and succinctly labelled into groups called categories (Braun and Clarke 2006). This helps in not only reducing the pieces of data but also acts as an intermediary concept, leading to themes. Initial themes were developed and shared among authors for feedback.

The fourth step consisted of developing and reviewing initial themes. These themes were modified according to the codes and categories developed in the last step. Categories

[6] Nvivo is a qualitative data analysis computer software and is used across a diverse range of fields including social science and psychology. Further information about latest version of this software can be found on https://lumivero.com/

from each interview were carefully reviewed and their suitability with initial themes determined.

In the fifth stage, themes were defined and refined by identifying the essence of each theme and determining what aspect of the data each theme captures (Braun and Clarke 2006). For each individual theme, a detailed analysis was conducted, while identifying the story behind the theme, and how the overall story emerges from the data. In the final step, findings from the data are presented.

QSR NVivo software was also used in this study to increase the reliability of data analysis through graphical representation of codes, categories, and themes as identified in the manual thematic analysis. This graphical presentation includes hierarchy chart of codes and a snapshot of mind mapping exercise as presented in Fig. 6 below.

Fig. 6 Initial hierarchy chart of codes and mind map created through NVivo 12

Findings

Findings of the study are organised into two parts. First part (current adoption status of TDLs in vegetable supply chains) presents insights into the perceptions and existing temperature monitoring practices of vegetable supply chain members. The second part (Adoption factors of TDLs in vegetable supply chains) examines the adoption challenges of TDLs in vegetable supply chains.

Current adoption status of TDLs in vegetable supply chains

Two factors need to be considered to understand the current adoption status of TDLs in vegetable supply chains. The first factor is to comprehend the perceptions of vegetable supply chain members about temperature monitoring and its relevant technologies. This is due to the fact that perceptions play a critical role in the decision-making process of farmers (Edwards-Jones 2006). The second factor is to discuss the current practices of temperature monitoring across different stages of vegetable supply chains. Combining perceptions and practices of supply chain actors can illustrate the current adoption status of TDLs.

Temperature management and monitoring appeared universally important across all the members of the vegetable supply chains. Findings suggest that the perceptions of the chain members about temperature monitoring can be classified into four main themes presented, in Fig. 7, generated and analysed through NVivo 12.

Enhancing shelf life and maintaining quality of vegetables were quoted as the prominent dimension of temperature monitoring. Economic incentives and visibility of the chain were identified as other overarching themes of temperature tracking along the chain. Moreover, a reactive approach has been observed among the actors of vegetable supply chains regarding temperature monitoring. A reactive approach means that temperature monitoring becomes important at the time when the supply chain is facing a disruption.

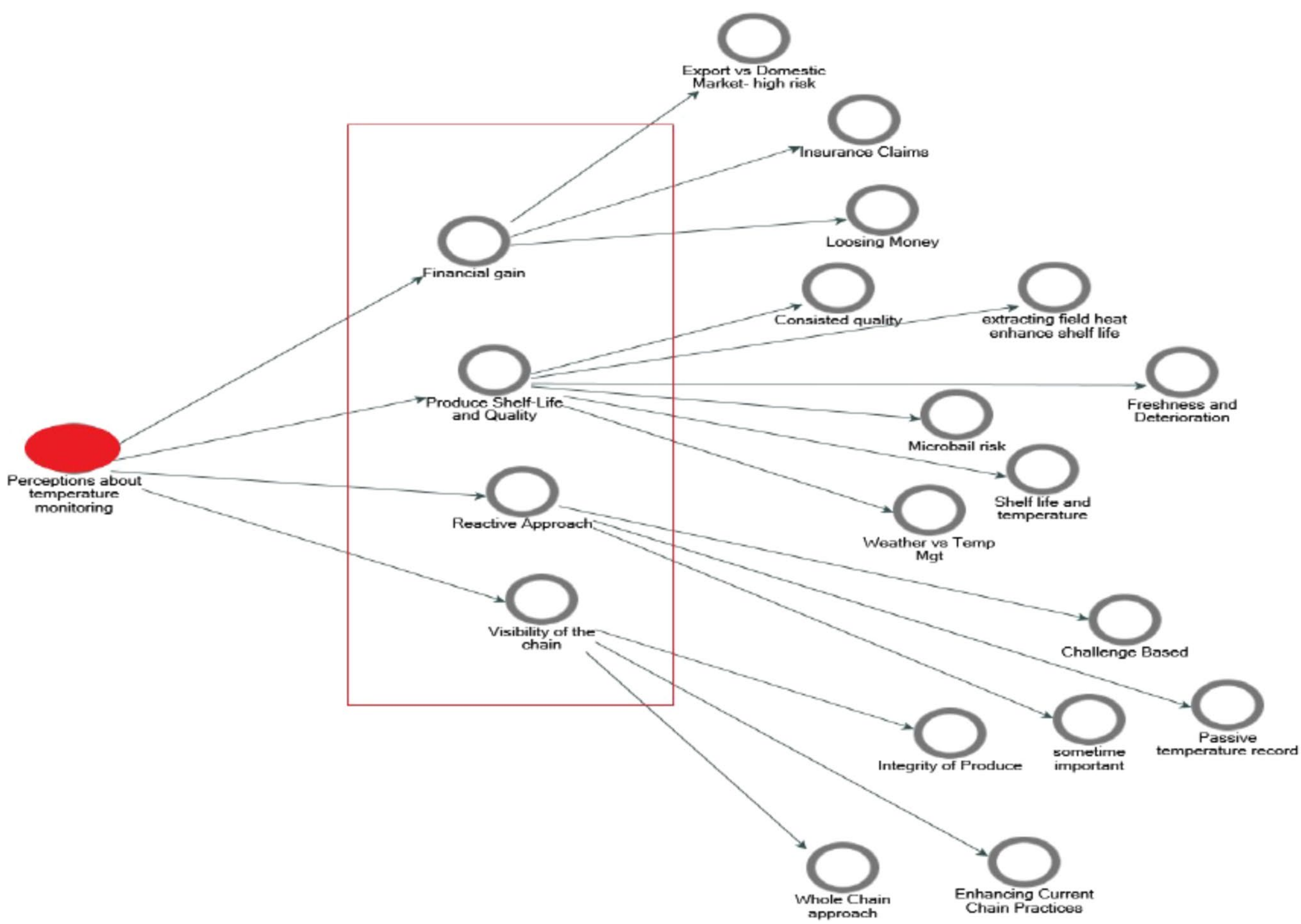

Fig. 7 Perceptions of vegetable supply chain members about temperature monitoring generated through Nvivo 12

Growers associated temperature management with the quality and shelf life of vegetables. They believed that if the temperature of produce is adequately managed right from the harvest to distribution, then they have more time to sell it and can access distant markets, including overseas. Growers described temperature management as "extracting field heat-out from their produce and linking it with the shelf-life extension" (Grower 1 Case study 1) (G1C1).

Quality of the product and prolonging its shelf life are also used interchangeably, and temperature management is deemed essential. "Yellowing of broccoli", as mentioned by grower 2 in case study 2 (G2C2), is due to not properly managing the temperature, leading to rejections at the distribution centre. Quality and shelf life are symbolically related to financial gains by every chain participant, as quoted by grower 2 in case study 1 (G2C1), "affecting bottom line when [it] reaches to [the] market".

Growers mentioned that temperature monitoring is also important for them as they endeavour to be aware of the real-time changes across the supply chain. They view TDLs as a valuable tool to check the "operations of upstream chain members" as stated by grower 1 in case study 3 (G1C3). Some growers also perceived that utilisation of these technologies could assist in verifying the suitability of transport companies for their produce to be appropriately handled.

Transport companies along the chain consider temperature monitoring more critical to their business operations as it has direct financial implications because of "insurance claims",[7] as cited by transport company 1 in case study 1 (T1C1). They use modern trailers equipped with advanced TDLs to facilitate growers in delivering their products within the required market specifications. In addition, transport companies keep temperature records as evidence to put forth to the grower in case the product is rejected by the customer (the distribution centre) due to substandard quality or persistent varied temperature. Thus, this record can be utilised to verify or deny the alleged claim.

Furthermore, a reactive approach has been perceived among vegetable supply chain members regarding cold chain monitoring. Managing product's temperature along the supply chain is considered necessary when disruption occurs, or the final product is rejected. Chain members do not see any value in proactively tracking temperature as fresh produce is transitioning from farm to plate, as quoted by grower 1 in case study 2 (G1C2), "well, it [temperature monitoring] is important, but it's when there are challenges to the supply chain, you know, when it gets to the end, realistically".

In summary, all members across the vegetable supply chain appreciate the importance of temperature monitoring to improve shelf life and quality of vegetables, to achieve higher economic outcomes at the end, and to improve visibility; however, the approach to monitoring is more reactive, especially among growers and packers.

Existing practices of temperature monitoring

Numerous temperature monitoring practices were identified along the vegetable supply chains investigated in this research. In order to understand these practices in detail, operations across vegetable supply chains are classified into three main activities including farm to packing facility, packing and grading stage, and farm gate to distribution centre. Each of these operations along with its temperature monitoring practices are explained below in detail:

Farm to packing facility

During this stage, fresh vegetable produce is harvested and shifted to the packing facility. Most of the growers and packers cited that temperature management at this stage is considered least important as they do not see any value in it. Lack of continuous temperature monitoring was found at this stage of the chain. For instance, packer 1 in case study 1 highlighted that after harvesting, produce is setting in the sun for around two hours: "we will cut like fifty bins of broccoli, and it will normally take one and half to two hours. So that means some broccolis are sitting on the paddock for more than two hours sometime".

Vegetables from farm are usually transported to the packing facility in open trucks or trailers in bins without any temperature management. Distance of the farm to the packing area is found to be one of the main determinants for non-compliance at this stage. Three growers who were found to be concerned about the quality of their produce and temperature abuse at this stage have invested in temperature-controlled trailers to shift their produce from farm to packing facility, as mentioned by grower 1 in case study 2 "when broccolini gets picked up at the farm, it goes into an air-conditioned trailer where [it] sits in trailer until it reaches to packing shed".

Our findings suggest that in-field temperature management is also linked with two other main factors which are weather and market demand. These factors are outside the control of the grower and packer. They are considering the current and predicted temperature of the day, on which they base their harvesting decision. They plan to harvest produce early in the day to get the product at low field heat, as quoted by grower 1 in case study 1 "I think there will be a particular

[7] Due to complex business nature of agri-food supply chains, insurance companies are working on providing tailor-made solutions to recover losses. For example: https://www.wfi.com.au/farm-insurance/fruit-and-vegetable

time of the day that we will stop harvesting because it is too hot". In other cases, hydro-cooling[8] or vacuum cooling[9] technologies are utilised depending on the market demand to bring the produce temperature down. They only use these technologies where it is absolutely required.

Some growers only use cold rooms to extract field heat from freshly harvested produce. Grower 2 in case study 3 explained that they are keeping harvested produce at normal room temperature and then storing it in the cold room to remove field heat: "I have been told not to put your produce straight in [the] cold room and let it cool inside the shed and then put it in the cold room".

Overall, findings show that growers point to the lack of proper processes and procedures for managing and monitoring the temperature of vegetables at this stage, which affects their quality and shelf life in later stages.

Packing and grading stage

During this stage, freshly harvested produce is inspected, cleaned, graded, and packaged. Temperature management during this stage has been found to be considerably better compared to previous one. Several practices were identified at this stage for managing the temperature of vegetables. For instance, in case study 1, packer 1 cited that produce from farm is put in the cold room and then packed on another day: "we will harvest it today and then we bang them into the cold room and pack it the next day". Cold rooms are typically set at 2–3 °C and are used to bring down the core temperature of produce.

In case study 2, temperature monitoring during packing is different and depends on the nature and sensitivity of the crop towards temperature variations. For instance, broccolini is bunched and packed in a temperature-controlled packing facility, and then shifted to a cold room where it is kept for two to three days before dispatching to the distribution centre as quoted by packer 1 in case study 2: "we have a pack room which sets at 13 to 15 °C where broccolinis are packed and then transferred to [a] cold room in bins", while temperature management practice for shallots is different. The same packer described that shallot is transferred from the farm directly to the cold room (without taking into packing area) where they stay for three to four days. Generally, packers in all case studies consider cold room checks as an alternative to overall temperature management at this stage. At the end, some packers also record the temperature of the produce pallet before loading it into the container.[10]

In summary, occasional temperature monitoring has been recorded at this stage. The packers are only considering the temperature of cold rooms as a proxy for cold chain monitoring practices.

Farmgate to distribution centre

At this leg of the supply chain, monitoring of the cold chain was found to be notably better as compared to the previous two stages, in-field farm to packing facility stage and during packing and grading stage. This is the critical point in the chain where produce is accepted or rejected based on temperature and other quality parameters such as size, colour, and maturity determined at the distribution centre. The temperature monitoring processes were found to be relatively similar across all three case studies.

Growers and packers use trailers equipped with continuous TDLs to transfer their produce from the farm gate to the distribution centre. At the farm gate, the packer and driver of the trailer randomly probe certain pallets of vegetables, and temperature is recorded manually, which is prone to errors. Thus, in the case of rejection at the distribution centre, transport companies may not find it convenient to verify the temperature at the loading point. Packer 1 in case study 1 noted, "we only check the temperature before it is dispatched. We just prop randomly, check a pallet and if a pallet is good [then] we send it to them. Drivers also do random checks on pallets. We only record unless we got some problem".

Packers and transporters also mentioned that product mixing is a persistent problem where a variety of produce with different core temperatures are loaded into a single container, leading to deterioration and possible rejection. Transport companies have also complained that packers tend to exceed the maximum safe load allowed on a container in search of saving money, which can also lead to potential damage and rejection of produce. In some cases, when they are asked to follow load rules, they then resort to arguments which lead to a business loss, as transporter 1 in case study 1 quoted: "so all of a sudden you see a different company coloured truck picking it up with the same fridge company on the front with the same capacity".

Transport companies' representatives also attributed temperature variation at this leg of the chain due to the current process of placing purchase orders by the big supermarkets.

[8] Hydro-cooling uses chilled or cold water to lower the temperature of the fresh produce before storing it in a cold room. Reina, L., Fleming, H., & Humphries, E. (1995). Microbiological control of cucumber hydrocooling water with chlorine dioxide. *Journal of Food Protection,* 58(5), 541–546.

[9] In vacuum cooling, moisture from the crop is evaporated through lowering pressure. Vacuum cooling is used when rapid cooling of the product is required. McDonald, K., & Sun, D.-W. (2000). Vacuum cooling technology for the food processing industry: a review. *Journal of Food Engineering*, 45(2), 55–65.

[10] Transport trailer in which fresh produce is transferred to distribution centre.

Table 5 Temperature management practices across vegetable supply chains

Vegetable Product Flow →

Stages	Farm to pack	During packing	Farmgate to distribution
Description of activities	• Harvesting & transporting to pack house	• Cleaning, grading and packing	• Transporting and handing over
Temperature monitoring status	• No temperature monitoring	• Occasional temperature monitoring	• Continuous temperature monitoring
Temperature monitoring practices	• No-monitoring on farm • produce setting in open environment • Shifting produce through open trucks • Occasional Hydro-cooling and vacuum-cooling depending on weather and market demand	• Controlled packing environment in some instances • Temperature control equipped cold rooms	• Temperature-controlled transport • Product mixing on trailer as a challenge • Small window for order affect temperature practices • Temperature historical data is not considered at DC • Different tools for temperature monitoring at DC • Ineffective feedback mechanism

Growers are given a very small window (usually less than 24 h) to fulfil an order which leads to improper temperature management and certain cooling practices such as hydro-cooling and adequate time in a cold room are compromised, as quoted by transporter 1 in case study 1, "supermarket chain places order in no-time which does not provide enough time to the grower to properly perform temperature management practices before sending it out".

At the distribution centre, the current temperature of fresh produce is used as a proxy of quality, and they are not concerned with the history of temperature spikes throughout the chain. Transport companies claimed that if supermarkets resorted to rigorous temperature monitoring (including spikes), it might lead to mass rejection and empty shelves. Consequently, when the product arrives at the distribution centre, some parameters are recorded along with temperature while ignoring temperature history as quoted by the distribution centre staff 1 in case study 2: "we don't [monitor temperature] upstream from us, but certainly once it becomes under our control, then yes, we do. We take product temperatures on arrival, and that's basically to determine the quality".

Different methods and tools were found to be utilised by the chain actors for temperature recording which leads to discrepancies in the data. Transport companies use simple probes[11] for checking temperature, while distribution centres employ laser guns[12] due to their efficiency. In addition to this, transport companies also claimed that in some distribution centres, drivers are allowed to record delivery temperature data, while in others they do not have access to do it, as quoted by transporter 1 in case studies 2 and 3: "in some depot, drivers can probe it whereas in others our driver cannot probe it as its their [distribution centre] requirements". This means that distribution centres across the three vegetable supply chains studied in this research, lack uniform policies regarding provenance of temperature information to related stakeholders.

Finally, temperature data are not communicated effectively throughout the supply chain as a matter of routine despite its critical nature. In fact, it is only shared in case of

[11] It is a type of sensor which can be used to measure surface temperature of fresh produce by physically touching a product or pallet of fresh produce.

[12] Infrared thermometers called laser guns are utilised for measuring temperature of objects without physically touching the product by calculating the amount of reflected and emitted energy from the object. Diwanji, M. M., Hisvankar, S. M., & Khandelwal, C. S. (2020). Temperature Measurement using Infrared Contactless Thermal Gun. 2020 International Conference on Smart Innovations in Design, Environment, Management, Planning and Computing (ICSIDEMPC).

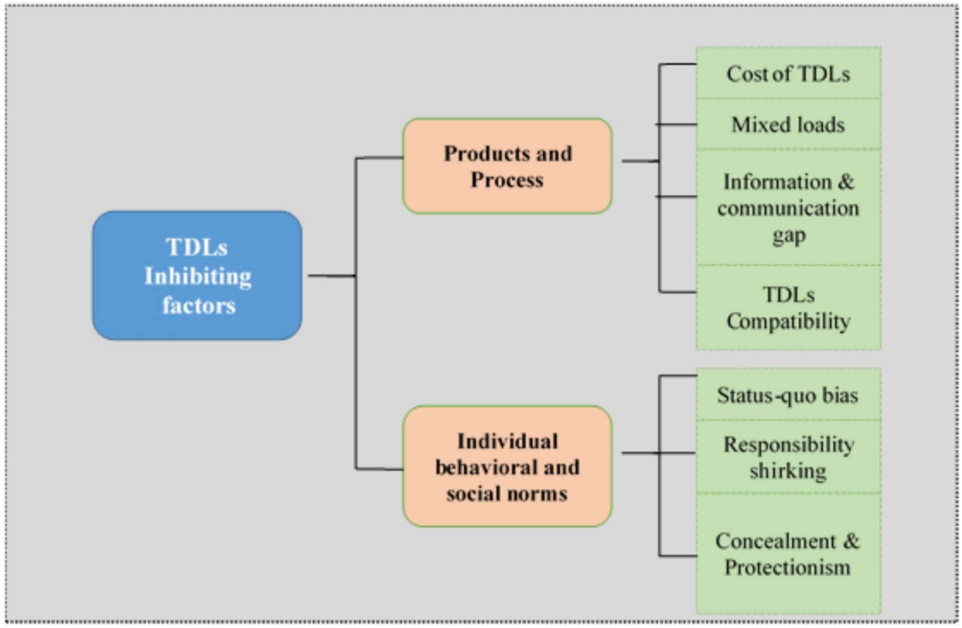

Fig. 8 Overview of inhibiting factors of TDLs adoption in vegetable supply chains

product rejection at the end of the supply chain, as quoted by packer 2 in case study 2, "we don't get any feedback unless it's negative". In other words, temperature data are least utilised in making decisions regarding improving product quality and overall supply chain performance. Details of vegetable supply chain processes along with temperature monitoring practices are presented in Table 5.

Overall, from the above discussion on the perceptions about the importance of temperature monitoring and current practices of the chain actors, it can be observed that there is presence of a perception-practice chasm among vegetable supply chain members about existing temperature monitoring practices.

Adoption factors of TDLs in vegetable supply chains

Adoption factors of TDLs in vegetable supply chains can be primarily divided into two types. The first one is related to existing practices and products, and the other one is related to the behaviour and social norms of the industry as presented in Fig. 8.

Product and process-based inhibitors

Four key product and process-based factors were identified from the interviews of vegetable supply chain members. The first factor is that vegetable supply chain members perceive the expenditure on TDLs as a cost rather than an investment and there is a lack of guaranteed return from the uptake of these technologies. The second adoption factor identified from the interviews was that multiple types of vegetables having different temperature requirements are stored or transited simultaneously throughout the chain, which deters the uptake of TDLs. Lack of information sharing and ineffective coordination between TDLs technology providers and vegetable supply chain members was recognised as the third adoption factor affecting the utilisation of TDLs. Growers were found to be sceptical about TDLs technology providers and argued that they do not endeavour to understand the complex nature of modern fresh produce supply chains. Each of these factors is explained below, along with quotations from interview transcripts. Further direct quotes from interviewees regarding each theme are given in Appendix 6.

Cost of TDLs and uncertain return on investment

All members of the vegetable supply chains interviewed as part of this study argued that the cost of TDLs is an inhibiting factor in its uptake. Findings show two key underlying reasons that relate to the viability of TDLs in vegetable supply chains.

Firstly, the upfront and associated cost of TDLs is mentioned as the primary reason for their low adoption in vegetable supply chains. Average price of a disposable data logger is around AUD30 to AUD80 depending on its monitoring capabilities including features like live temperature tracking and location information. Growers argue that marginal profits in vegetable industry make the present TDLs unjustifiable from a business standpoint; before data are used for decision-making, it must be retrieved and analysed, which incurs cost. Grower 1 in case study 2 argued: "it is not only the cost of [the] data logger but other costs to get something out from the technology which I [grower] can understand and use". Effectively utilising TDLs requires more labour as well as more units of TDLs in each shipment which requires additional things to worry about, such as the retrieval and analysis of collected data. Interviews were conducted at the time when agricultural supply chains were experiencing a tight workforce market and struggling to recruit and retain staff. Although labour inputs are sometimes reduced by TDLs and other technologies, their usage has resulted in increased workloads for vegetable farmers at the expense of minimal financial benefit.

Secondly, it was captured from the interviews of the supply chain members that growers perceive the expenditure on TDLs as a cost rather than an investment. The primary reason they shared for this behaviour is that they are not entitled to gain extra monetary benefits or potential market preference for continuously maintaining temperature of their product across different stages of the chain. Fresh produce at the distribution centre is not necessarily inspected for the remainder of its shelf life, let alone the history of temperature's readings from the paddock to consumer as argued by the grower 2 in case study 1: "as long as you deliver it within 5 °C [centigrade][13] and the broccoli is green, then no problem, you will get your money, and no one ever wants to know what happened before". This acceptance criterion of vegetables at the distribution centre renders a challenge to justify a return on investment from TDLs for growers.

TDLs technology providers and experts also emphasised that the cost of the data logger and its associated expenses, including labour and data handling is one of the principal inhibiting factors for its adoption. Experts interviewed as part of this research mentioned that farmers are rational decision-makers, and they want to ensure and invest in a technology that has a clear return on investment, as quoted by expert 3 in case study 3: "farmers are not stupid and they are very pragmatic […] and very focused around the dollars that they are going to make". Utilisation of TDLs was found to be based on market value of produce and potential target market including domestic high-value product or export markets. Some vegetable growers interviewed as part of this research had previously exported internationally to Singapore and Hong Kong. These growers were of the view that due to a high return on investment along with the challenge of product recalling[14] in case the produce is rejected in an overseas market, makes us more sensitive and compels us to use TDLs in our shipments—as stated by grower 2 in case study 1: "That is why the export market is so tricky [due to the above reasons], you need to make sure to stick with the proper protocols of temperature monitoring".

In summary, not only the initial cost of TDLs but also its overheads are considered to be one of the key obstacles to their adoption across the domestic vegetable supply chains. Every member of the chain, including technology providers and experts, perceived that the cost of TDLs was a key challenge to their wider acceptance. However, in the export market, vegetable growers were found to justify the business case for the adoption of TDLs due to expected higher profit margins and logistical challenges related to product recalls.

Practice of produce mixing (mixed loads)

Produce mixing refers to the practice of combining different types of produce through various stages of the vegetable supply chain. While this practice offers certain benefits such as reducing logistic cost and ensuring consistent supply to different markets, it emerged as another important inhibiting factor in the adoption of TDLs. Findings suggest that the issue of mixed loads during transport, storage, and logistics parts of the vegetable supply chain is attributed to low level of uptake of TDLs.

Two critical practices related to mixed loads were identified in this study. First, combining a variety of multiple products in one container or cold room requires different transit or storage temperatures, which makes it difficult to establish accurate temperature traceability. Second, loading vegetables into a trailer that is not adequately cooled down results in an overall temperature spike[15] in the container. A combination of these practices posed a challenge to the adoption of TDLs in vegetable supply chains.

Transport companies in the chain explained that they have to load different types of vegetables into one trailer. A dedicated trailer for a single product is not feasible for several reasons, including cost, volume of market demand, product's delivery within a suitable timeframe, and utilisation of maximum trailer space. They found that these reasons are very challenging to overcome, and thus, it is quite often that a diverse variety of vegetables ends up in a single container with varied temperatures. Consequently, some vegetables are bound to be over-chilled while others will be exposed to a higher than desired temperature. For example, interviewee from distribution centre 1 in case study 1 quoted that: "very seldom you have dedicated trucks, you might have potatoes, avocados, capsicums on one truck which require different temperatures".

It was also found that even within the same product category, vegetables having different temperature readings are normally being loaded into the same trailer. This mixing of produce in a trailer disturbs the air temperature in the container and exposes all the produce to a higher temperature

[13] 5 °C is the current market specification for fresh vegetables to be accepted at the distribution centre as stated in the FSANZ Food Standards Australia New Zealand FSANZ. (2016). Food standards code. In: Food Standards Australia New Zealand.

[14] The risk of product recalling is high in export markets as horticulture produce has a very low level of insurance.

[15] Spike is characterised with a recurrent and abrupt rise in the temperature monitoring log.

spike. The interviews from transport companies also highlighted misalignment of motivation due to the need to satisfy different customers in the chain. For instance, a transport company is looking to satisfy growers while the primary concern of growers is the distribution centre that they are selling their produce to on an almost weekly basis. Therefore, transport companies are accepting overheated products from the farms due to the presence of tough competition among stakeholders in the industry, as quoted by transport company 1 in case study 1, "unfortunately in this industry [transport], the opposition is always there to grab opportunities and if we do not accept hot produce from a grower, then we lose business". Moreover, growers mistakenly view trailers as a replacement for cooling devices, however, these transport methods (containers) are only installed with enough air conditioning capacity to maintain temperature of the produce during transit i.e. they do not bring temperature down rather they maintain temperature, as stated by the transport company 1 in case study 2, "growers are thinking that our trailers can bring down the temperature [;] however, these things are designed to keep the temperature stable [but] not to cool it down".

In summary, mixing diverse products and its provenance along different stages of the supply chain including post-harvest and logistics makes it difficult for the members to adopt best temperature monitoring practices. As a result of this, some of the more progressive and larger corporate growers are looking to invest in their own transport capabilities. As stated by packer 1 in case study 2: "so that is why we are trying to have our own transport […] to deliver our produce directly from our cold room to the distribution centre".

Information and communication gap

Findings show that technology providers and vegetable supply chain members have different perceptions about the utilities of TDLs in fresh produce chains. Information asymmetry and communication gaps exist between technology providers and vegetable supply chain members. Technology providers are more focused on improving the existing capabilities of TDLs rather than understanding the specific challenges and complexities involved in fresh produce supply chains. This results in the development of technological solutions that do not align with the actual needs of the vegetable supply chain members. In addition, technology providers also struggle to make an argument and provide a clear understanding about the financial benefits of the uptake of TDLs to potential adopters.

Most vegetable growers recognised that technology providers are predominantly investing in the hardware side of existing TDLs, such as improving their sensory qualities and data reliability. However, there is a limited focus on understanding the complex nature of fresh produce supply chains, which results in developing technological solutions that do not cater to the diverse needs of the members of contemporary fresh produce supply chains. Some vegetable growers even maintained that technology providers are working in silos and are not usually open to integrate their perspectives into the product development process of TDLs, as stated by grower 1 in case study 2: "technology providers [of TDLs] do not know what we are doing and what they are trying to resolve".

Growers were found to be unaware of potential TDLs solutions and reluctant to consider their uptake which highlights the lack of information sharing between technology providers and vegetable supply chain members. Interviews captured that some supply chain members suspected that technology providers are more focused on pursuing their sales target by pitching their products to be one of the best available technological solutions for temperature monitoring. For instance, transport company 1 in case study 1 highlighted that: "there are a lot of snake oil salesmen having mostly a monetary interest. All they want is to sell you a data logger that we do not need". Similarly, experts interviewed for this research agreed with the growers' views and cited that most technology providers do not endeavour to comprehend the underlying dynamics and unique requirements of the sector, which impacts the uptake of TDLs in fresh produce chains.

On the other hand, TDLs providers mentioned that vegetable supply chain members are not generally receptive to information, and their approach to temperature monitoring is for the most part a reactive response. Technology providers also believed that availability of different types of TDLs, combined with the growers' scepticism about technologies, makes it difficult for them to demonstrate the potential value of their technologies. For example, technology provider 1 in case study 3 stated that, "growers are very cynical about us. If I go and explain to them […], they always have this sort of expression on their face that I am here with a hidden agenda which is to sell a logger".

In summary, there is an information and trust gap between technology providers and potential users of TDLs which leads to its low level of adoption in vegetable supply chains. This can be attributed to the impression of growers that technology providers lack deep understanding of the specific challenges and requirements of fresh produce sector.

Compatibility of TDLs

Interview findings also indicated that one of the other major obstacles towards TDLs adoption is that the existing technologies are not suitable for the perishable and complex nature of vegetable supply chains. For instance, existing TDLs involve a tedious process of analysing and interpreting temperature data before it can be effectively utilised during post-harvest decision-making process. In addition, this task of

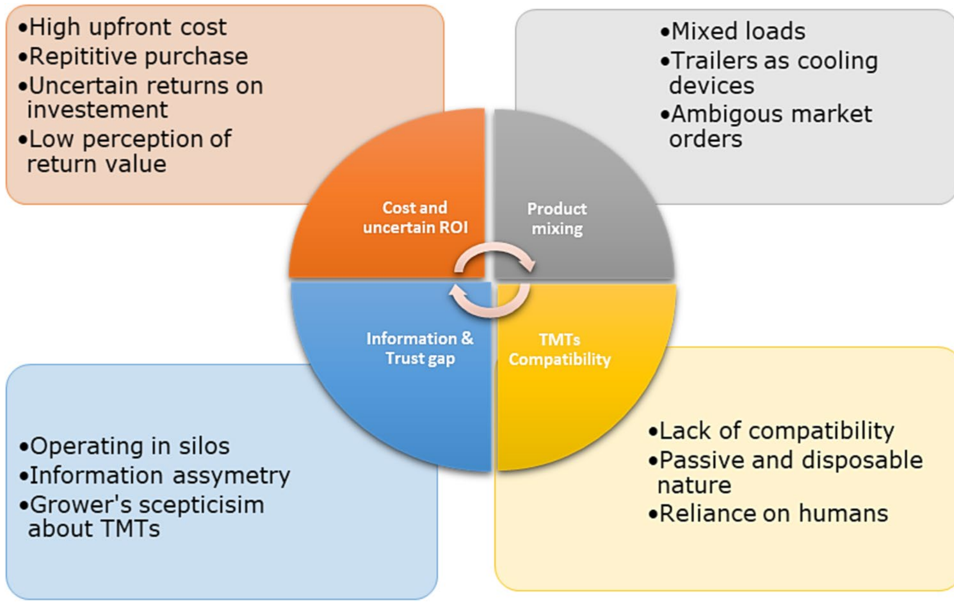

Fig. 9 Summary of product and process-based inhibiting factors of TDLs

analysing and interpreting collected data is perceived to be a highly labour-intensive process for fresh produce growers.

TDLs providers interviewed in this study acknowledged that existing TDLs for fresh produce supply chains were not explicitly developed for this sector, as stated by technology provider 1 in case study 2: "a lot of technologies [TDLs] out there which are fantastic from a technology perspective, but it has probably been developed for mining or some other sector". As a result of this, one of the significant drawbacks pointed out by various supply chain members was that the current TDLs are designed to measure the air temperature of the cold room or container rather than the core temperature of the product. Ideally, these technologies should be able to measure and provide core temperatures of each product or pallet in a cold room or container (as different types of vegetables are stored or transited in the same cold room or container simultaneously). Transport company 1 illustrates this in case study 1: "current technology only monitors return air. This won't identify if a hot pallet is there but will only identify if a hot freight is in there".

Supply chain members also exhibited that existing TDLs are disposable and passive.[16] Most data loggers are suitable for one-time use which means that it needs to be purchased separately for each shipment. In terms of the passive nature of these data loggers, temperature data are only available to the supply chain members after the delivery of produce to a distribution centre. Therefore, it requires a person at the end of the supply chain to reclaim TDL and send it back to the point of origin for data retrieval. Thus, these data can be only useful in developing a best practice for the future, but have no value in controlling any potential damage to the ongoing shipment, as illustrated by packer 1 in case study 1: "alright if we use a data logger to monitor our produce and if something is wrong and we found out once it reaches to the customer, then it is too late to fix, so there is no point of using a technology". In other words, disposable and passive nature of existing data loggers makes it difficult for the supply chain members to ensure temperature control at every stage of the chain.

Additionally, findings show that current TDLs are highly reliant on human interventions and are labour-intensive. For instance, probing[17] is involved at each stage of the supply chain which makes it more laborious and dependent on humans, as explained by grower 2 in case study 2: "probing on and off is the most challenging thing for us and for the upstream members as resources like the staff are tight up to this". This results in two major issues. Firstly, staff involved in this process require proper training and handling knowledge which may not be easily achievable given their low level of education and exposure. Secondly, and more importantly, it becomes very labour-intensive and costly for the supply chain members to effectively acquire value from utilising existing TDLs in their operations. This factor is highly relevant to growers in these chains who are

[16] Temperature monitoring technologies usually come in active and passive formats. Active data loggers continuously collect data and convey it in real time while passive ones do not convey data in real time and require an action to be performed to retrieve data.

[17] Probing is a process of placing a temperature probe on the surface of a product or inserted into a pallet of fresh produce to measure its temperature at different stages of the vegetable supply chain.

simultaneously dealing with numerous other challenges, such as labour shortages and timely delivery of their products to markets. Figure 9 provides a summary of product and process-based inhibiting factors affecting the adoption of TDLs in vegetable supply chains.

Individual behavioural and social norms-based inhibiting factors

From the interviews of vegetable supply chain members, including technology providers and experts, three major individual behaviours and social norms were identified that impede the adoption of TDLs. Firstly, status-quo bias behaviour was exhibited as a prominent individual behaviour among the supply chain members. Growers were found to be more complacent as compared to other members of the supply chain. Secondly, averting and diffusion of responsibility and sense of accountability were also found to be a social norm across the vegetable supply chains. Findings suggest that due to lack of accountability, chain members are able to avoid their responsibilities. Absence of integration and ineffective sharing of information was also considered to be a social norm which affects the adoption of TDLs in vegetable supply chains. Thirdly, the behaviour of concealing information about non-compliance practices across the vegetable supply chains was also found to be one of the main deterrents to the adoption of TDLs. These are discussed in detail below along with extracts from interview transcripts of supply chain members.

Status-quo bias behaviour

Complacency emerged as one of the dominant behaviours among vegetable supply chain members interviewed in this study. Numerous members of the chain demonstrated this behaviour and were found to be satisfied with their current established practices of temperature management and monitoring. As a result, they were resistant to the uptake of TDLs in their existing supply chain operations.

Interviewees indicated that growers were found to be more complacent as compared to other members of the chain. This is due to their assumption that temperature is adequately maintained during storage, transportation, and handling of produce along the chain. They believe that their product will hold its post-harvest form and quality throughout the supply chain activities. As a result, growers, who are supposed to be the predominant users of TDLs, do not perceive potential risks associated with temperature variations in vegetables along the chain. This was evident from the interview of grower 1 in case study 1: “Oh, I know that broccoli will be alright, and it will be fine […] at the other end”.

In addition to growers, findings also revealed that staff members working in different parts of the chain also exhibit similar behaviour regarding temperature management. For instance, drivers in the logistics part of vegetable supply chain were described as usually more careless and lacking due diligence while handling fresh products during transit stage. As distributor 1 in case study 1 quoted about the behaviour of a truck driver: “the truck driver will come here to pick up my two pallets, shoot from here with the fridge running and doors of the trailer wide open, and will go to another place to pick up some more pallets”.

Vegetable supply chain experts and technology providers interviewed as part of this research also mentioned that generally growers and staff members along the fresh produce supply chains also demonstrate negligent behaviour about temperature monitoring. They explained that this behaviour of growers is typically result of their experiential knowledge that they had acquired over generations. Technology provider 1 in case study 2 highlighted that, “the biggest challenge that we face with the growers is that they do not see temperature as a big thing due to [sticking to] their practices [growing and selling to market] as they are engaged for the last 30 or 40 years”.

The ingrained culture of “responsibilities shirking”

Responsibilities diffusion[18] by the supply chain members including blame-shifting[19] and shirking[20] across different parts of the chain was emerged as a prominent behaviour exhibited by interviewed participants. Presence of unclear accountability and ineffective integration at each stage of the chain were considered to be critical challenges that lead to the behaviour of responsibility shirking among different members of the chain. For instance, growers were found to be blaming transport companies for temperature related issues, and similarly, transport company’s interviewees were blaming growers or distribution centres for their negligence.

Findings suggested that there was an active presence of an accountability gap at each stage of the vegetable supply chain. As a result of this, behaviour of responsibility diffusion among different actors of the chain was commonly found. Consequently, supply chain members are reluctant to utilise TDLs in their business operations as this will make everyone accountable for their actions at each step of the

[18] The diffusion of responsibility defined as a sociopsychological phenomenon of an individual to feel decreased responsibility in a group while being part of the group. Darley, J. M. (1970). The unresponsive bystander: Why doesn't he help?

[19] Blaming other members of the chain for not adequately handling produce with the aim of making them responsible for the losses in case the product is rejected at the end of the supply chain.

[20] Shirking is intentionally underperforming one's agreed upon duties (Clemons et al., 1993; Wathne & Heide, 2000).

chain. This behaviour is demonstrated from the interview of distribution centre 1 in case study 1: "I think everyone thinks it is everyone else problem, [the] grower thinks [that] once it leaves my gate, my job is done. But he [she] still owns that product until it is received by the customer".

Experts and technology providers interviewed in this study explained that lack of vertical integration and information asymmetry at each stage of the vegetable supply chain are also inhibiting the uptake of TDLs. This leads to a behaviour of animosity between chain members, and they start blaming each other for not adequately handling their produce. This friction was best exemplified from the interview of technology provider 1 in case study 1: "the main reason for [non-adoption of TDLs] is that everyone has their own data and does not want to share. The practice of growers blaming the transport companies for mishandling their produce or the transport company blaming the grower is prevalent. So, they have this animosity that grew up among them". In summary, an accountability gap and lack of vertical integration make it difficult for the existing supply chains to utilise TDLs in their business operations.

Culture of concealment and protectionism

Intent of supply chain members to use TDLs in their business operations was also found to be affected by their behaviour of concealment and protectionism. Information asymmetry led to this behaviour that was deeply entrenched across the supply chain. For example, variation in the interpretation and application of required standard operating practices existed among the members of the chain. Protectionist behaviour was also exhibited by some supply chain members and was concerned that TDLs might disclose non-compliance temperature management standards practices.

As mentioned above, responsibility avoidance and blame shifting were found as a prominent social norm across the supply chain. However, due to the use of TDLs, vegetable supply chains will become more transparent which is considered to be a challenge for some members of the chain due to presence of bad practices and supply chain opacity.[21] This was evident from the interview of grower 1 in case study 2 who stated that: "transparency is considered as a challenge as certain customers do not necessarily want it because they felt transparency is alike opening a can of worms".

Technology providers interviewed as part of this study were more sceptical about shirking behaviour of certain members of vegetable supply chains, especially growers. They believed that vegetable growers are not adopting TDLs due to their motivation to hide non-compliant practices. For example, technology provider 1 in case study 1 explained that: "one of the growers actually told me that you are selling "devil tools" [TDLs] as some of the farmers and even other supply chain members see this as a real threat to their business".

Vegetable supply chain experts interviewed in this study also revealed that TDLs adoption is also impacted by the secretive nature of vegetable supply chain members. Every participant across the chain feels that due to the use of TDLs, other members of the chain will have access to their business secrets and proprietary practices. As a result of this, enhancing the use of TDLs in vegetable supply chains is considered to be a challenge. This is evident from the view of expert 1 in case study 2, "In the domestic market and export market, they [growers] are very secretive of their growing practices and also maybe some of the ways that they treat their produce in the supply chain which they do not want to share it with the guy who's going to be on the farm just across the road".

In summary, the social norm of concealing information about non-standard practices of the supply chain members is impacting their TDLs adoption. In addition, supply chain members also resist the uptake of TDLs to protect their proprietary practices. Figure 10 provides an overview of the individual and behavioural perspectives regarding the adoption of TDLs in vegetable supply chains.

Discussion

Findings from the interviews of vegetable supply chain members highlighted that temperature management and monitoring have an integral role in enhancing shelf life and maintaining quality of their produce. This perception agrees with the previous literature on the importance of temperature and its relationship with shelf life and quality of fresh produce (Mercier et al. 2017; Ndraha et al. 2018; Shashi et al. 2021). Similarly, actors of the vegetable supply chain also perceived that TDLs could improve visibility and provenance of produce which are consistent with extant literature (Costa et al. 2013; Óskarsdóttir and Oddsson 2019).

Financial gain was also perceived as a significant outcome from the adoption of TDLs. Maintaining integrity of cold chain from farm to fork was seen to lead to higher profits by improving chain efficiency and product pricing. Perceptions of supply chain members in this study agree with the previous research in terms of achieving financial benefits from adopting TDLs (Lim and Song 2021, Shashi et al. 2021). However, members of the vegetable supply chains were unable to translate the above-mentioned perceived benefits from TDLs into financial gains. This led

[21] This refers to the lack of transparency and non-disclosure of information across different stages of the supply chain. Chaoyong, Z., & Aiqiang, D. (2018). The coordination mechanism of supply chain finance based on block chain. IOP Conference Series: Earth and Environmental Science.

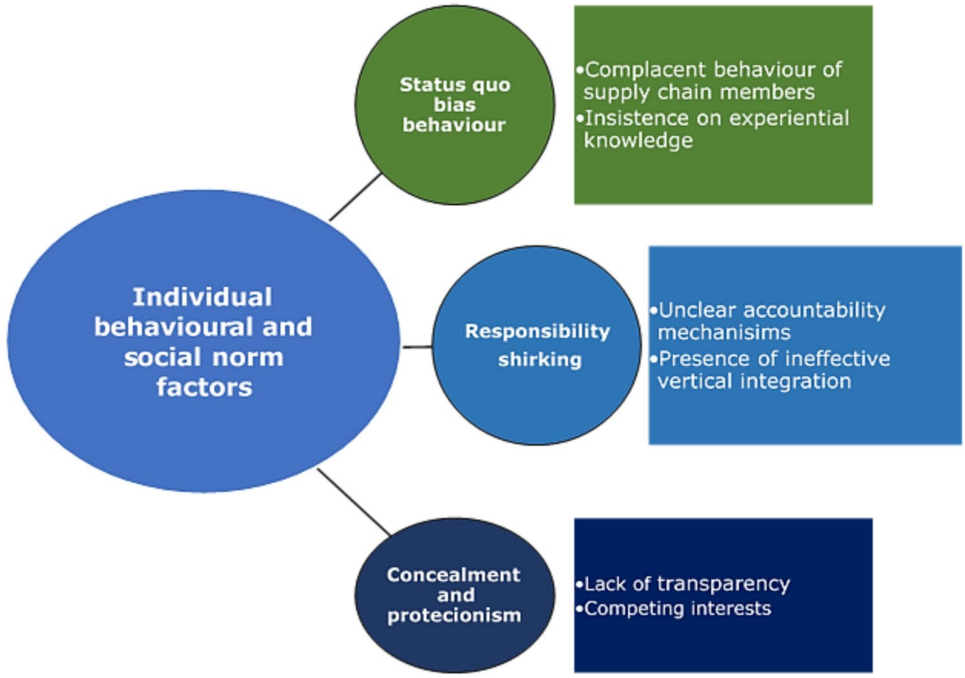

Fig. 10 Summary of individual behaviour and social norm-based factors

them to exhibit a reactive behaviour towards the utilisation of modern temperature monitoring and controlling technologies in their business operations. This aligns with the findings of Cook et al. (2022) who confirmed that clear financial benefits from the adoption of digital technologies in Australian agri-food industry can enhance its uptake. Despite recognised and proven potential of TDLs in vegetable supply chains, adoption of cold chain monitoring technologies is still a challenge. Several reasons have been put forward for this phenomenon in extant research (Tey and Brindal 2012; Pillai and Sivathanu 2020, Kodan et al. 2022); however, this study is unique as its focus on vegetable supply chains.

Currently available TDLs exhibit low compatibility with the complex nature of vegetable supply chains. Members of the chain interviewed in this study considered it to be an overarching challenge. They reported that existing TDLs are not built for purpose to effectively integrate the complex needs and requirements of these chains. Four key issues were identified including design problems, disposable and passive nature of current TDLs, heavy reliance on human interventions, and use of different temperature monitoring tools along the cold chain.

Existing TDLs in vegetable supply chains are designed to record ambient temperature of the environment without providing any precise reading about the core temperature of the produce (Weston et al. 2021). As such, quality and remaining shelf life of a produce depend on the management of its core temperature (Zhao et al. 2022). The challenge in existing TDLs is that it is installed either at pallet or container level which provides a general overview of overall surface temperature (Mosadegh Sedghy 2018). To effectively monitor the temperature, readings from different parts of the pallet or container are vital. Thus, current TDLs fail to deliver precise data about the core temperature of a produce, which diminishes its utility for vegetable supply chain members. Mosadegh Sedghy (2018) also highlighted these challenges in their review article on RFID tags in context of agricultural cold chain monitoring. Current research is focusing on developing smart pallets and containers to achieve full environmental sensing solutions by integrating IoT into fresh produce supply chain operations (Saffari et al. 2022).

Passive[22] nature of existing data loggers (TDLs) reduces their utility in current processes of vegetable supply chains and increases its reliance on human interventions at each stage (Kumar et al. 2009). Data loggers record temperature throughout logistic operations which are usually available for retrieval at the end of the chain—typically at the distribution centre. Additionally, most of the existing TDLs are for one-time use only and therefore require repeated purchase of new data loggers (Roberts 2006). They are usually thrown away at the end of supply chain operations. It is challenging for the actors along the chain especially growers to retake possession of these data loggers from the end destination (Kapoor et al. 2009). They have to make special arrangements for retrieval and further analysis of collected data

[22] Temperature monitoring technologies are usually coming in active and passive formats. Active data loggers continuously collect data and convey it in real time while passive ones do not convey data in real time and require an action to be performed to retrieve data. Details about different types of TDLs are available in chapter 2.

which act as a deterrent for them to actively track temperature of their produce.

Findings of the study also indicate that use of diverse temperature monitoring and recording tools at different stages of the supply chain acts as a deterrent for the uptake of TDLs. For instance, growers embed RFID tags with their produce that records its surface temperature while the staff at distribution centres use infrared laser guns to monitor temperature of pallets as it often proves to be more commercially viable approach. Variation in TDLs produce different results which acts as a major limiting factor in their implementation. Similar results for temperature monitoring of vegetables (cucumber and chard) were also found by (Badia-Melis et al. 2017) who confirmed that "temperature measured by thermal imaging showed a differential between 1.9 and 6 °C compared to temperature measured by thermal sensors".

This study also suggests that one of the key reasons for low compatibility of existing TDLs is the presence of information asymmetry among potential users and its providers. Vegetable growers reported that a "silo" mentality is present among technology providers as they are currently driven by technological advancements rather than understanding ground realities of the overall ecosystem of fresh produce supply chains (Mahdad et al. 2022). As a result of this, there is a lack of coordination and trust among technology providers and potential users (growers) which leads to developing TDLs in which users demands are not embedded.

Vegetable producers argued that TDLs do not yield any additional financial benefit to them from wholesalers (distribution centres). Use of TDLs is considered to be a supplementary quality attribute as it is neither financially incentivised nor given any specific preference by supermarkets. Currently, temperature requirements for fresh produce at the distribution centre are 5 °C or below, as specified by the Food Safety and Australia New Zealand Standards[23] (FSANZ 2016). There is no requirement by any supply chain actors interviewed in this study to prove temperature provenance of their produce from farm to pack.

The trajectory of farmer's resistance to change and its relationship with the uptake of technologies in agri-food supply chains is well represented in prior literature (Newton et al. 2020; Conti et al. 2021). Insistence on experiential knowledge and old age practices transferred through generations among farmers is considered to be one of the factors for resistance to new developments or processes. The findings of this study suggest that numerous underlying factors are responsible for the complacent behaviour of actors along vegetable supply chains. These factors are a lack of trust on TDLs and its providers (Canavari et al. 2010), ineffective information sharing among supply chain actors (Teese et al. 2022), uncertain returns on investment (Long et al. 2016), and lack of strict regulatory requirements on temperature monitoring.

Complacent behaviour of logistic staff, especially truck drivers along the vegetable supply chain operations, was also cited as one of the inhibiting factors for the uptake of TDLs. Truck drivers were not generally well trained or informed about the sensitivity of vegetables towards temperature abuse. The study of Rendon-Benavides et al. (2023) on the berry supply chains in Australia revealed the same attitude of truck drivers during logistic operations.

Responsibility diffusion[24] by the actors of vegetable supply chains was observed as one of the deterrents to the uptake of TDLs. Presence of blame-shifting[25] and responsibility shirking[26] was exhibited as a prominent behaviour among members of the chain. Findings suggest that lack of accountability and ineffective integration along the chain are key precursors of the above behaviours. Study also found that due to the prevalent culture of blame shifting, growers blame transporters while they in turn put the responsibility on growers and in some cases on distribution centres and supermarkets when a shipment is not accepted at the downstream operations. The underlying reason for this kind of behaviour among the vegetable supply chain actors is due to absence or lack of accountability at each stage of the chain. Prior literature has reflected the challenge of accountability in the agri-food chains. For example, Frankish et al. (2021) studied the food safety culture in Australia. The authors found that due to the presence of weak accountability mechanisms in horticulture supply chains, blaming each other for ineffective food quality is a dominant behaviour.

Concealment and protectionism behaviour was also observed among the members of vegetable supply chains. They were found to be reluctant to share data with other stakeholders for effective integration and collaboration. Previous research suggests that due to the complex nature of perishable food supply chains (Panetto et al. 2020), sharing of information is imperative for the enhancement of collaboration among stakeholders (Lee 2000; Taylor and Fearne 2006). However, in the case of Australian fresh produce

[23] Food Standards Australia New Zealand (FSANZ) is an independent statutory agency established by the Food Standards Australia New Zealand Act 1991 (FSANZ Act). Safe temperatures are 5 °C or colder, or 60 °C or hotter.

[24] The diffusion of responsibility defined as a sociopsychological phenomenon of an individual to feel decreased responsibility in a group while being part of the group. Darley, J. M. (1970). The unresponsive bystander: Why doesn't he help?

[25] Blaming other members of the chain for not adequately handling produce with the aim of making them responsible for the losses in case the product is rejected at the end of the supply chain.

[26] Shirking is intentionally underperforming one's agreed upon duties (Clemons et al., 1993; Wathne & Heide, 2000).

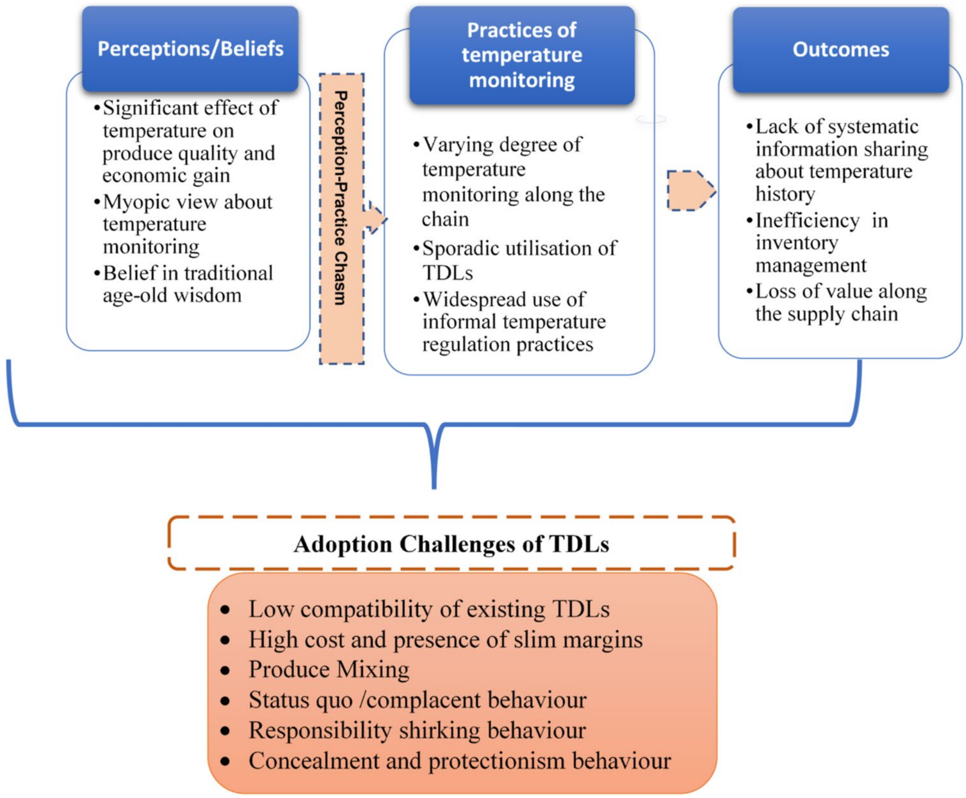

Fig. 11 Consolidated conceptual model of the study

supply chains, actors are not usually open to information sharing (Teese et al. 2022).

Vegetable supply chain members, especially growers, were feeling vulnerable to the uptake of TDLs. They believed that due to use of TDLs, some of their practices (which are not up to mark) will be exposed to the other members of the chain, and hence, they will lose business with them. For instance, if the produce is not cooled down properly during harvesting and packing stage, TDLs will expose it throughout the transit and distribution centre operations. Prior research has studied the issue of information transparency in cold chains through the lens of the power and business strategy of stakeholders (Hsiao and Huang 2016). However, the behaviour of stakeholders towards the adoption of technologies in fresh produce cold chains is an extension of this study. Figure 11 provides a brief overview of the study by revealing relationships between insights gained from the discussion on findings. Three domains are present in this figure.

First domain is related to the perceptions and beliefs of vegetable supply chain members about temperature monitoring. It clearly indicates that supply chain members, especially vegetable growers, consider temperature maintenance to be an essential component for maintaining produce quality, extending shelf life and achieving financial gains. However, they hold myopic views about TDLs and rely mainly on their experiential knowledge and age-old beliefs. Second domain represents the consequent practices of temperature monitoring that are currently in vogue among supply chain members. It shows that vegetable supply chains sporadically utilise TDLs as well as informal practices to varying degrees in controlling and monitoring temperature. There is a clear presence of a perception–practice chasm among the supply chain members about temperature monitoring. Final domain shows the outcomes of deeply held beliefs and the consequent practices. There is a clear lack of integrated use of TDLs in vegetable supply chains. This causes various forms of inefficiencies such as inventory management and loss of produce during supply chain operations. Current TDLs suffer from various compatibility issues while vegetable supply chain members are not able to undertake risky investments as they suffer from slim profit margins. Keeping a diverse range of produce with varying temperature requirements leads to the issue of product mixing in cold rooms and transport containers. Various behaviours including status quo and complacency, responsibility shirking, and concealment and protectionism further reinforce the substantial roadblock towards higher adoption of TDLs.

Conclusion

Temperature monitoring across cold chains is becoming a significant part of modern global perishable food industries. Management and control of temperature along vegetable supply chains are indispensable in maintaining its quality and reducing existing significant amount of food loss and waste. Numerous technologies are available for cold chain tracking; however, their widespread uptake by supply chain members is still considered as a challenge. This study has addressed a knowledge gap by providing a comprehensive overview of the adoption of temperature data loggers (TDLs) in vegetable supply chains, by focusing on understanding the underlying reasons, including psycho-behavioural aspects of supply chain members and existing practices and technologies.

By undertaking qualitative thematic analysis of the data collected, it was identified that temperature monitoring by utilising TDLs is considered essential for preserving quality and enhancing the shelf life of fresh produce; however, its uptake by the members of the vegetable supply chain is low due to insistence on their experiential knowledge and age-old practices. The factors affecting the adoption of TDLs in vegetable supply chains were found to be mainly related to the existing cold chain practices, currently available technologies, and ingrained individual behavioural and social norms in the industry. The study contributes broadly to the understanding of the adoption of technologies in fresh produce supply chains by providing insights to managers, directors, and business owners of technology providers, along with other firms engaged directly or indirectly with fresh produce supply chains in Australia. Further research may be conducted to understand factors that can enhance the adoption of TDLs in vegetable supply chains.

Appendix 1: Case study protocol

Overview of the study

Temperature management along the chain enhances quality and shelf life of fresh produce. Therefore, traceability of temperature during different stages of the chain is an integral component of supply chain operations. Numerous technologies are currently available to trace temperature monitoring in the chain; however, the adoption of these temperature monitoring gadgets along the chain is still an issue. Therefore, the purpose of this research is to investigate the process of adoption of temperature monitoring technologies across the vegetable supply chain

Research participants

- Vegetable supply chain members—Growers, packers, transporters and staff of the distribution centre engaged in quality monitoring of vegetables
- Technology providers of temperature monitoring technologies
- Industry experts who are working on improving efficiencies of existing supply chains

Data collection procedure

Semi-structured interviews by following the interview guide of the study. Interviewing growers of the chain, then packers, transporters and staff of the distribution centre. Snowball sampling procedure will be followed. References of technology providers to be interviewed will be collected from members of vegetable supply chains. Industry experts will be shortlisted on the basis of their experiences with fresh produce supply chains and specifically developing capacity of growers on the adoption of agriculture technologies

Expected outcome of the study for participants

A key outcome of the research is the design and development of a "tool box" which may, for example, include procedures or processes to identify key blocks to the adoption of temperature monitoring technologies in the vegetable value chain and to signpost approaches to overcome these and improve the use of these technologies

Appendix 2: Interview guide

Interview Guide

Grower interview guide

The purpose of this guide is to keep the researcher in line with the theoretical framework of the study.

Estimated time:

45 to 50 minutes for the entire duration of the interview session

The interview session consists of five parts (A, B, C, D, E)

A. **Introduction to the interview (5 min)**
   - Greetings
   - Introducing the research/project
     In this part, the researcher introduces the research topic and explains the importance of the research in terms of reducing food wastage, increasing customer satisfaction, creating more value for the business, including how this research can enhance a positive image of their business in customer's mind (viz., goodwill). The researcher informs the grower that this process will be extended to the other stakeholders along the vegetable chain.
   - Describing the purpose of the interview
   - Expressing that the discussion will be completely confidential and will be used only for the research purpose
   - Asking for permission to record the interview
   - Obtaining consent (signing consent form) from the interviewee

B. **Background info: (5 min)**

Farmer information	Farm information
Please tell me about yourself **Prompts:** age experience in growing vegetables education level (Masters, Bachelor, Diploma, Certificate, etc.) time commitment to the farm operations (part time or full time)	Please tell me about your farming business **Prompts:** Farm structure; e.g., family farm, how much is used for cropping? Farm size Main crops Operational level of the business (growing, growing & harvesting, growing, harvesting& packing) Number of employees on the farm (Permanent and part-time/casual)

C. **Main/essential interview questions (30 min)**
   (The researcher will involve the participant in a casual discussion to understand the current practices the organization/grower is undertaking regarding temperature monitoring in their current process)

1. In your opinion, do you think that temperature monitoring along the supply chain of your produce is important?
   (This question investigates basic understanding of the participant about the importance of temperature monitoring in the supply chain of their product and realizes its importance in terms of the prompts below).
   The intention is to bring the researcher and participant on one page about the importance of temperature monitoring in the chain
   Prompts:
   - Less wastage
   - Retaining freshness of the produce
   - More value for the customers and happy customers at the end
   - More value for the business
   - Food quality and safety
   - More distant markets

2. Which temperature monitoring methods/procedures are you currently using in your farm operations like in the field before harvest, at the harvest and in the packing shed
   Prompts:
   - Recording temperature at the field, pack house
   - Reason behind it for keeping a record of it
   - Temperature monitoring devices at different stages
   - Communication process with the other chain member like transport company, distribution centre staff or any other
   - Motivation to use the current system
   - Challenges in the current method/procedure (Any complaint about the temperature monitoring issue from the customer)

3. Do you have any idea/information on what technologies can be used to monitor the temperature of the produce in your farm/business operations?
   Prompts:
   - Probing about the technologies to understand more about the level of information the participant has

4. Have you started / or do you think of initiating any technology in the improvement of temperature monitoring on your farm operations? (If yes, then subsequent questions. If no, then probing the reasons to understand the factors of not initiating it like cost, lack of skilled labor, attitude towards not using it)
5. Subsequent questions: What are that technology? How it has been initiated and why the selected ones?
   Prompts:
   - Information source (technology provider, field day, other growers, extension officer, internet etc)
   - Factors to evaluate the information
   - Procedural adjustments to make it more operationalized

6. What are the most important things that you will consider and want to initiate/adopt with regard to the temperature monitoring technology in your farm operations
   Prompts:
   - Less effort
   - Adding value to the business
   - Compatible with your business operations
   - Easy to understand
   - Level of risk
   - Quality monitoring
7. In your opinion, what are the main barriers that you can think of in adopting a temperature monitoring technology in your farm operations?
   Prompts:
   - Staff behaviour
   - Lack of organization commitment
   - Communication process along the chain members
   - Getting information sent back to me on farm

D. Other questions
If time allows and the participant is showing interest, I will also probe the following questions for more understanding

8. In your view, what role the other chain members can play to successfully adopt the temperature monitoring technologies?
9. What future role do you see technologies in temperature monitoring will play in your farming operations and industry in the next 5/10 years?
10. In your opinion, what actions can be taken to improve the acceptability of temperature monitoring technologies in your business and also across the chain?

E. Closing of interview (10 min)
- State what will happen next in the research; i.e. transcribing and analysing the interview data
- Ask from the participant to identify other colleague who could be potential participant in this research
- Thanks participant

Appendix 3: Engagement plan

Improving adoption of temperature monitoring technologies in the vegetable value chains: a case study of Southeast Queensland

The researcher will work in collaboration with the management of XXX Produce to work through the whole chain participants such as growers, logistic companies, and technology providers, service providers such as technical expertise as well as general and distribution centres. The researcher will work according to the management protocols of the company and all the information will be kept confidential and will be used only for this research purpose.

Selection of innovation and supply chain

The selection of value chain and temperature monitoring technology will be carried out by mutual understanding of the XXX Produce management and the researcher.

Activities in the research

This research is based on a case study approach in which the researcher will interview participants along a specific vegetable supply chain to understand dynamics in the cold chain management and adoption of cold chain management technologies.

Significance to firm

Cold chain management is critical to the maintenance of the quality of perishable horticultural commodities and minimises deterioration after harvest. However, the adoption of cold management and temperature monitoring technologies is still an issue. Therefore, the main objective of this research project is to understand the behaviours and factors which cause less adoption and how businesses can develop procedures to increase its adoption. This project will study firm's vegetable chain from harvesting till distribution centre to understand cold chain management technology adoption issues and then recommend actions and procedures to improve the processes along the chain.

Overview of the activities and timeline

This is a tentative plan outlining the collaboration of RECoE-USQ with XXX throughout the project duration, however, it can be re-arranged upon the availability, access and at the disposal of the management.

Chain actors	Activity and # of activities	Nov-20	Dec-20
Grower, packing and quality control in XXX	Interview with growers (2 growers)		
	Interview with farm manager (1 farm manager)		
	Interview quality control staff (1)		
	Interview packing shed manager(1)		
Transport providers	Logistic company providers quality control staff (2)		
Technology providers	Cold chain management technology providers (2)		
End of chain	Distribution centre quality staff (2)		

Appendix 4: Information sheet and consent form

University of Southern Queensland

Participant Information for USQ Research Project Interview

Project Details	
Title of Project:	An investigation into Australian Vegetable Value Chains: Enhancing adoption of temperature monitoring technologies
Human Research Ethics Approval Number:	H19REA097

Research Team Contact Details

Principal Investigator Details
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Description

The main purpose of this project is to explore and understand the behavioral aspects of adoption of temperature monitoring technologies along the vegetable value chain in Queensland, Australia.

While many technical and decision-making innovations in temperature monitoring are available in vegetable value chains, the adoption of these practices is still generally low. This project will investigate the current status of adoption of these practices in the vegetable value chain in Southern Queensland and will explore the factors for enhancing the adoption of it in the vegetable value chains.

Participation

Your participation will involve contributing your thoughts and ideas in an interview which will take no more than an hour and a half of your time. The interview will take place at a time and venue that is convenient for you.

Your participation is entirely voluntary and you are free to withdraw from the project at any stage. If you decide to take part and later change your mind, you are free to withdraw. If you wish to withdraw at any time, please contact the Research Team (contact details at the top of this form).You have the opportunity to know about the outcome of the research. If you wish to receive a summary report will be sent to your email. The report will also be available on the website: http://eprints.usq.edu.au/view/type/thesis.html.

Expected Benefits of Your Participation in this Project

The benefit from the research will be greater understanding of the barriers and incentives to the adoption of innovation. The outcome of the project will also include developing a "Tool Box" including procedures and practices to enhance adoption of innovation in vegetable value chains. The outcome may also provide inputs to the government entities in formulating policy decisions for effective uptake of new innovative practices.

Risks Involved in Your Participation in this Project

There are no anticipated risks beyond normal day-to-day living associated with your participation in this project.

Privacy and Confidentiality

All comments and responses will be treated absolutely confidential

- Only the investigator will have access to the interview responses
- Please advise the investigator if you do not want the interview to be recorded. In this case, the interview may take longer as the researcher will need more time to take notes during the interview.
- Any data collected as a part of this project will be stored securely as per the University of Southern Queensland's Research Data Management policy.

Concerns or Complaints Regarding the Conduct of the Project

If you have any concerns or complaints about the ethical conduct of the project you may contact the University of Southern Queensland Manager of Research Integrity and Ethics on +61 7 4631 2214 or email researchintegrity@usq.edu.au. The Manager of Research Integrity and Ethics is not connected with the research project and can facilitate a resolution to your concern in an unbiased manner.

Thank you for taking the time to help with this research project. Please keep this sheet for your information.

University of Southern Queensland

Consent Form

Project Details

Title of Project:	An investigation into Australian Vegetable Value Chain: Enhancing adoption of temperature monitoring technologies
Human Research Ethics Approval Number:	H19REA097

Research Team Contact Details

Principal Investigator Details
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Statement of Consent

By signing below, you are indicating that you:

- Have read and understood the information document regarding this project
- Have had any questions answered to your satisfaction
- Understand that if you have any additional questions you can contact the research team
- Are over 18 years of age
- Understand that all the data collected will be confidential and de-identifiable
- Agree to participate in the project

Participant Name	
Participant Signature	
Date	

Please return this sheet to a Research Team member prior to participation

Appendix 5: Ethics approval

Dear Habib

I am pleased to confirm your Human Research Ethics (HRE) application has now been reviewed by the University's Expedited Review process. As your research proposal has been deemed to meet the requirements of the National Statement on Ethical Conduct in Human Research (2007),
ethical approval is granted as follows:

USQ HREC ID: H19REA097
Project title: An investigation into Australian Vegetable Value Chains: Enhancing adoption of innovative practices
Approval date: 18/04/2019
Expiry date: 18/04/2022
USQ HREC status: Approved

The standard conditions of this approval are:

a) Responsibly conduct the project strictly in accordance with the proposal submitted and granted ethics approval, including any amendments made to the proposal;.

(b) Advise the University (email:ResearchIntegrity@usq.edu.au) immediately of any complaint pertaining to the conduct of the research or any other issues in relation to the project which may warrant review of the ethical approval of the project;

(c) Promptly report any adverse events or unexpected outcomes to the University (email: ResearchIntegrity@usq.edu.au) and take prompt action to deal with any unexpected risks;

(d) Make submission for any amendments to the project and obtain approval prior to implementing such changes;

(e) Provide a progress 'milestone report' when requested and at least for every year of approval.

(f) Provide a final 'milestone report' when the project is complete;

(g) Promptly advise the University if the project has been discontinued, using a final 'milestone report'.

The additional conditionals of approval for this project are:

(a) Nil.

Please note that failure to comply with the conditions of this approval or requirements of the Australian Code for the Responsible Conduct of Research, 2018, and the National Statement on Ethical Conduct in Human Research, 2007 may result in withdrawal of approval for the project.
Congratulations on your ethical approval! Wishing you all the best for success!

If you have any questions or concerns, please don't hesitate to make contact with an Ethics Officer.

Kind regards

Human Research Ethics

University of Southern Queensland
Toowoomba – Queensland – 4350 – Australia
Phone: (07) 4631 2690
Email: human.ethics@usq.edu.au

Appendix 6: Respondent quotes on adoption factors of TDLs in vegetable supply chains

Main theme	Sub-themes	Respondent	Quotes
Product and process-based inhibitors	Cost of TDLs and uncertain return on investment	Grower 1 Case study 2	*If there is a cost, then there has to be value in it*
		Transport 1 Case study 2	*I think the perceived cost, whether it's right or wrong and it's like everything. It may have long term benefit, but people want to see their money back in three or four years*
		Technology Provider 1 case study 1	*In my opinion, it's not only the one-time cost but repetitive cost of this when they are repeating it again and again*
	Practice of produce mixing	Grower 1 Case study 1	*It comes hard [to use data logger] when you have different products in one container which happens all the time*
		Packer 1 Case study 2	*Load mixing is another issue with transport companies as they put down our stuff, which is cold, but they put another stuff next to it, that's sitting at 20 °C, obviously it heats up and so it's hard to sort of control that*

Main theme	Sub-themes	Respondent	Quotes
	Information and Communication gap	Expert 1 Case study 3	*There are a lot of people who go in saying, you know, I've got drones, and I can do this, and I can do that. Whether it is actually what the producer is prepared for which is always a question mark*
		Packer 2 Case study 2	*No one came to me to explain it [TDLs] like we have fertiliser companies coming in and explaining their products, but I haven't seen anyone coming and explaining about these gadgets*
	Compatibility of TDLs	Grower 2 Case study 2	*Human factor in current technology is a big challenge for us. Farmers don't really want to interact with the technology. The current one is very labour-intensive*
		Packer 1 Case study 3	*The loggers [TMTs] are not friendly to our business and in general to the fresh produce industry*
Individual behavioural and social norms-based inhibiting factors	Status-quo bias behaviour	Transporter 1 Case study 2	*This is the nature of the farmers that they are more complacent about their produce*
		Expert 1 Case study 3	*There is a culture among growers that does not support adoption of new technologies in fresh produce chains generally*
	The ingrained culture of "responsibilities shirking"	Technology provider 1 case study 2	*Growers do not have a really good relationship with most people in the supply chain, so they do not want to share information that makes it difficult for this technology to be used to its full potential*
		Distribution centre 1 case study 2	*It is the nature of the farmer to get away with something that is not making issue for them*
	Culture of concealment and protectionism	Grower 1 Case study 3	*Because it may expose a lot of things here and there that maybe we've been doing incorrectly or anything like that. Yeah, it could be a possible barrier as well that maybe I do not want to be monitored*
		Grower 2 Case study 1	*Because of the nature of the beast, nobody really wants to know what is happening in the supply chain*

Author contributions All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Dr Moudassir Habib, Dr Ben Lyons, and Dr Chad Renando. The first draft of the manuscript was written by Dr Moudassir Habib, and the other two authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Declarations

Conflict of interests The authors have no competing interests to declare that are relevant to the content of this article.

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