

Towards zero-loss agriculture: addressing strawberry food loss in North Karelia, Finland

OSWALD SYDD

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Food loss poses multifaceted challenges for environmental sustainability, food security, and economic efficiency across agri-food systems. This study explores the spatially interrelated dimensions of food loss in the Finnish strawberry value chain, highlighting the intricate interactions and dynamics among various stakeholders and processes. It examines how multiple actors are embedded in regional agro-economies and the socio-material tensions that influence their practices. While each entity holds a different position within the system, they collectively confront a common challenge: the complex, interdependent nature of the Finnish strawberry value chain, which shapes their roles and strategies for addressing food loss. The study employs a qualitative, multi-scalar case study design of the North-Karelian strawberry value chain, grounded on semi-structured interviews, document analysis and field observations. The paper provides a nuanced understanding of how various institutional, infrastructural, and temporal complexities influence food loss outcomes. It highlights how these factors can either hinder or facilitate the advancement towards zero-loss agriculture trajectories. By providing a spatially sensitive perspective on economic stakeholder engagements, it highlights bottlenecks and offers potential solutions to effectively reduce food loss. The case illustrates how active engagement with these complexities is required to create strategic opportunities to develop more sustainable strawberry value chains that align with EU policy goals.

Keywords: Farm to Fork, food loss complexities, zero-loss agriculture, sustainable strawberry production, Finland

Oswald Sydd (<https://orcid.org/0000-0002-4732-987X>), Department of Geographical and Historical Studies, University of Eastern Finland, Finland.
E-Mail: oswald.sydd@uef.fi

Introduction

Food loss is a widespread problem that poses serious challenges to global food security, environmental sustainability, and efficient resource management, as food produced is often lost before reaching consumers (FAO 2013). EU policies aim to address this issue, following ambitious goals set out in the EU Green Deal (European Commission 2023) and, in particular, the Farm to Fork (F2F) initiative (European Commission 2021), targeted at significant environmental and economic transformations across the agri-food sectors.

The European Union Green Deal (EU GD) is a comprehensive set of policy initiatives promoting sustainable resource management and circular economies (European Commission 2020). It aims to foster forward-thinking policies, technological advances, infrastructure development, and a skilled workforce to assure a sustainable transformation of the EU's production and consumption systems (European Commission 2023). As a key component of the EU GD, the F2F aims for sustainable food systems by promoting environmentally friendly agricultural practices and minimising ecological impacts (European Commission 2021). Through policy reforms, stakeholder engagement, and technological innovation, the F2F aims to support the transition to more resilient, equitable, and sustainable food systems, including ambitious "zero-loss agriculture" goals to address food loss in Europe (Sydd 2025, 1). Yet, at this stage, it remains unclear whether these policy aims are met and, in particular, how current policies materialise in specific socio-spatial settings (Wei 2015).

Extensive research within the European Union has highlighted food loss as a challenge in the horticultural sectors, particularly fruits and vegetables, which are highly vulnerable to food loss. Yet, research is often fragmented and inconsistent, containing significant gaps across regions, sectors, and timeframes (Lukman *et al.* 2016). Nevertheless, efforts to address food loss across agricultural sectors emphasise its occurrence at the early stages of food supply chains and henceforth point to a need to focus on it (Hartikainen *et al.* 2018). This is critical for Finland, where food loss remains a persistent challenge, especially for perishable goods such as strawberries (Joensuu *et al.* 2021). Consequently, in Finland, particularly in rural areas, where strawberries form a culturally and economically significant part of the food sector, there is a need to scrutinise how food loss reduction can be addressed by identifying infrastructure bottlenecks, financial constraints, and socio-economic disparities (Muilu 2010).

By analysing the complexity of the strawberry value chain, this research enhances understanding of the socio-spatial relations of food loss in Finnish agriculture. It further provides crucial insights into sustainable transition policies outlined in the Finnish circular economy frameworks, and EU strategies, highlighting the need for a holistic, multifaceted approach (Sarkis *et al.* 2011; Truffer & Coenen 2012; Ympäristöministeriö 2022). Such a novel understanding supports the creation of diverse pathways for managing risks, enhancing capacity, and fostering stakeholder relationships, enabling improved, coordinated collaboration among stakeholders, moving beyond reactive measures that focus solely on reducing food loss.

By examining definitions, causes, and solutions, this study addresses gaps in policy and mitigation strategies. It identifies shared interests among stakeholders while emphasising the intricate connections between economic, ecological, and social dimensions to promote sustainability and resilience (Marjamaa *et al.* 2021). Hence, food loss is viewed through intricate relational dynamics, shaped by contexts and complexities, institutional rigidity, labour shortages, technological fragmentation, and the delicate balance of sustainability trade-offs (Pike *et al.* 2024). These multi-level interactions drawn from relational economic geography, hereafter, help to define zero-loss agriculture, demonstrating their extent beyond inadequate processes in logistics or production (Yeung 2005; Buschke & Brownlie 2020; Sydd 2025).

Accordingly, the study raises the question: How do farming practices, climate-smart technologies, pickers' behavioural shifts, and policy frameworks interact to reduce food loss in Finnish agricultural value chains? Additionally, it highlights the multifaceted challenge posed by ensuring economic, ecological, and social sustainability within these practices and relations (Geels 2011; Springmann *et al.* 2018; Sutherland & Marchand 2021).

The remainder of the paper will engage with analysing these complexities with the intricate aim of providing spatially sensitive knowledge for designing effective policies and collaborative measures to prevent food loss towards zero-loss aims.

Framing the complexity of strawberry food loss: a multi-theoretical lens

Exploring the complexities of food loss is intricately linked to economic, social, policy and environmental issues. This paper is structured around three theoretical pillars that, taken together, capture the socio-spatial dynamics of food loss. Such perspectives unmask food loss not as a discrete problem, but as a complex outcome shaped by climate risk, labour precarity, institutional dependencies, and fragmented governance.

Relational economic geography emphasises the spatial sensitivity of stakeholders who shape economic processes and influence outcomes (Yeung 2005). It emphasises that value-chain performance hinges on the density and quality of network ties across scales (Paasi 1986; Wilson 2009).

The influence of *institutional theory* highlights path-dependent routines and spatial relationships, explaining how formal regulations, standards, informal norms, and business culture co-evolve to provide guidelines and rationales for stakeholders (Bathelt & Glückler 2003).

It alone examines the interplay between these mismatches with formal and informal practices, and foregrounds the tension between micro-level operational logics and macro-level sustainability targets (Amin 2001; McPherson & Sauder 2013; Bathelt & Glückler 2014; Currie & Spyridonidis 2016). As a supporting theory, institutional theory highlights the evolution of socio-technical systems, the importance of spatial and place-specific factors (Fuenfschilling & Truffer 2014; Hansen & Coenen 2015; Fastenrath & Braun 2018). It operates at cultural-cognitive, normative, regulatory, and material levels, explaining the complexity of risk-sharing, labour constraints, and quality thresholds that determine whether a product is marketed, processed, or results in food loss.

Adopting a *stakeholder-centric approach* integrates insights from stakeholders, positioning farmers, policymakers, migrant workers, processors, and retailers as co-producers of practical outcomes (Ababio *et al.* 2025). This perspective clarifies how risk perceptions and resource accessibility influence decision-making challenges in food loss mitigation activities (Jones 2014).

While F2F assumes strengthening collaboration along the value chain, food loss mitigation is viewed as a complex transition, where technological privileges and rural constraints create differentiated adaptations: some successful, others not (Soode-Schimonsky *et al.* 2017). These may include efficient cold chain logistics, packaging, and sorting strategies, and advanced post-harvest innovations (Wikström *et al.* 2019). In practice, farmers, who lack economies of scale, reliable assets, and tailored financial instruments, struggle to access such capital-intensive, infrastructure-dependent solutions. Such a technological approach requires a broader framework of social norms and regional networks that encompass not only stakeholder engagement, innovation, and governance, but also clear pathways toward sustainability (Geels 2011).

For instance, industry leaders involved in long-distance deliveries often utilise advanced technological solutions and focus on intricate logistics. Smaller farmers do concentrate on place-specific alternatives, where on-farm processing can effectively address vulnerabilities such as cosmetic imperfections, harvesting methods, and storage conditions. The conversion of food loss into added value can be achieved through processing, utilising imperfect berries for juices and jams, known as “side flow”, or through freezing, which bypasses technological lock-ins (Hartikainen *et al.* 2018, 502; Simkova *et al.* 2024). Alternative perspectives of agritourism, such as self-picking options, extend the life cycle of imperfect berries, thereby enhancing the economic sustainability of strawberry farming (Mahaliyanaarachchi *et al.* 2019). Mitigation activities here are viewed as a form of sustainability of rural entrepreneurship, focusing on material and cultural practices rather than solely logistics optimisation.

Consequently, to effectively address food loss in the Finnish strawberry value chains, it is essential to differentiate not only between innovative technological advancements but also between the nuanced needs of stakeholders, the flexibility of institutions, and the variegated socio-spatial relations that generate food loss or provide avenues for it. Therefore, food loss mitigation should be viewed not as an endpoint but as a continuous process of thoughtful decision-making that reflects the crucial balance between the perishable nature of strawberries, socio-economic considerations, and the specific spatial contexts involved.

Case study of the Finnish strawberry sector

This paper employs an explanatory case study method that integrates both semi-structured interviews with farmers and unstructured interviews with pickers (Yin 2018). These in-depth interviews explore individual reasoning through detailed experiences and nuanced discussions (Osborne & Grant-Smith 2021). Participatory research is employed in this study through direct engagement with farmers and processors, who co-designed interview questions by identifying relevant issues and provided a seasonally adjusted research timeline (Bergold & Thomas 2012). Data interpretation has been developed collaboratively by validating findings through repeated rounds of feedback.

The participatory approach faced limitations due to time constraints and varying levels of engagement among participants. To improve contextual relevance and interaction, a range of open-ended questions to boost participant storytelling was created. Narrative analysis deepened understanding of the complexities by capturing the context-specific ways in which interviewees mobilise within their social networks (Naughton 2014). Principles of slow interviewing maintained comfortable dialogues, encouraging participants to express their thoughts and feelings openly and freely (Young *et al.* 2021).

The interview guide was theory driven. A multi-theoretical lens shaped topic domains and probes that foregrounded spatial embeddedness and dynamics (relational economic geography), rule systems and exception handling (institutional theory), and multi-actor coordination, discretion, and accountability (stakeholder approach), thereby aligning questions with mechanisms expected to produce loss.

The analysis employed an abductive approach, dividing interviews and field notes into episodes that focused on specific moments, nodes, and operations (Thompson 2022). First, actors, practices, and decision points were identified. Secondly, groups were analysed according to theoretical constructs. Finally, cross-analysis interpreted the narratives across stakeholder categories, compiling temporal and spatial disparities of alternative explanations for the observed findings.

In total, 12 interviews were conducted with different stakeholder groups between 2023 and 2025. Stakeholders' experiences were interpreted as practical narratives structured by stakeholders' categories, including policymakers, local institutions, associations, unique actors, and a set of farmers (top leaders, small companies, organic, and distant/peripheral). This multifaceted stakeholder spectrum highlights the need for a nuanced understanding of how spatiality operates across diverse geographical contexts (Wilson 2009).

First, face-to-face interviews were conducted with strawberry farmers and processors in the North Karelia region, picked from the European financial database Amadeus (Bureau van Dijk 2023). Interviews were conducted in Finnish and English during farm visits throughout 2023–2024 and lasted between one and five hours. Altogether, five interviews with farmers/processors from North Karelia were conducted, including one organic farm, one family farm, one multi-berry farm, one juice producer, and one self-picking farm with strong local focus and market dominance in their region.

Second, interviews were conducted with strawberry pickers in the summer of 2024 in English, Finnish, Surzhyk, and Russian, lasting 20–40 minutes. Interviews were carried out during picking breaks with five pickers, aged between 23 and 60, across three visits. The interviews provided insights into the labour, immigration, technologies, and social issues affecting their roles. The respondent group showed significant heterogeneity across gender, age, and place of residence. Respondents included an immigrant couple, a local male student, a local female newcomer, and a second-time female immigrant visitor to Finland.

Third, interviews were conducted with institutional actors and experts, including a local policymaker, a research group studying strawberry farming technologies, a niche side-product producer, and a representative from a bio-waste plant. Taken together, the responses from these three groups offer valuable insights into the dynamic and complex phenomenon of strawberry food loss, thereby highlighting spatial and relational dimensions that reveal inefficiencies through analysis of these intricate narratives.

Assessing food loss prevention in Finnish strawberry production

Rethinking challenges and opportunities

Finland's National Waste Plan to 2027 outlines a framework for achieving prevention and circularity targets, incorporating standardised food-loss metrics like pick rates, cull weights, and cold-chain temperatures. This aligns with EU standards for measuring food loss in the value chain and with the Central Union of Agricultural Producers and Forest Owners (MTK), ensuring compliance with F2F policies (MTK 2020). By aggregating anonymised farm data into standardised indicators for planning and oversight, ELY Centres (Centre for Economic Development, Transport and the Environment) align these indicators with Finland's Circular Economy strategy (Ympäristöministeriö 2022). These enhance EU GD Circular Economy policies through the EU Circular Economy Monitoring Framework (European Commission 2023; Eurostat 2024).

Farm-level resilience involves the interplay of work rhythms, weather conditions, labour regimes and coordination challenges within value chains as examined through spatial and systemic relationships (Coenen *et al.* 2012; Guthman 2017). Food loss mitigation strategies are mainly hindered by financial constraints, barriers to policy enforcement, resistance to change, and climate-related issues, and require more than technical solutions, demanding nonlinear and path-dependent dynamics (Joensuu *et al.* 2021). This cascade connects micro-level evidence, meso-level governance, and EU-level monitoring, thereby promoting compliance with complex, adaptive regional initiatives (Martin & Sunley 2007).

In Finland, strawberry farming represents a significant cultural-horticultural activity, largely dependent on the farmer's goals and resources (Kuhmonen & Siltäoja 2022). At the same time, it faces considerable food loss risks due to short harvest windows, weather variability, labour shortages, quality requirements, and logistical issues, resulting in unharvested, downgraded, or discarded berries. However, food loss is not seen as inefficiency, but rather as a result of practical trade-offs and market realities. Mitigation, therefore, turns on how stakeholders frame rules, interpret obligations, and implement agricultural policies in everyday operations.

This complexity is examined in the subsequent sections through five analytical lenses, highlighting the primary constraints faced by stakeholders, which are organised into various dimensions:

1. The policy and institutional lens mobilises institutional theory to trace how regulatory frameworks, certification schemes, monitoring practices, and market standards shape what is rendered marketable, downgraded, or lost.
2. The technological and innovation lens connects relational economic geography to the uneven embedding of cold-chain infrastructures, tunnels, packaging solutions, and on-farm processing. This highlights the importance of each stakeholder making strategically targeted investments to mitigate food loss.
3. The labour and migration lens examines how seasonal labour regimes, recruitment channels, skill development, and payment models mediate the practical distinctions between harvested, rejected, and unpicked berries, thereby making visible the negotiated nature of food loss.
4. The sustainability lens consolidates environmental conditions, value chain collaboration, and sustainable farming practices to show how attempts to reduce food loss intersect with regional variations in climate, soil conditions, and ecological constraints.
5. The food loss mitigation lens integrates these dimensions as interacting strategies for reducing food loss, focusing on climatic, logistical, and market pressures.

When combined, these five lenses provide a well-structured, interconnected framework for understanding the complexity of food loss as a socio-spatial process. They illustrate how food loss in the Finnish strawberry industry arises from the complex interplay of relationships, institutions, and stakeholder dynamics, rather than simply from decisions made at the farm level.

Institutional and policy dimensions: challenges and opportunities

The success of mitigation in strawberry production requires a range of well-defined regulations and definitions that provide timely, pertinent signals for specific locations. The essential role of governance shapes agricultural practices, particularly during critical harvest periods, when clear guidelines and prompt feedback empower farmers to adapt their harvesting quickly, helping them navigate the challenges posed by unavoidable weather and labour fluctuations.

Respondent 1 acknowledges a significant gap in practical implementation, hindering progress towards these standards:

While farmers should keep a focus on minimising food loss, the absence of handy tools to quantify their reductions undermines this task. Difficulties in measurement include quantifying costs and benefits, as well as deep collaboration within the food value chain, which is at low levels.

This underscores a critical issue: the gap in policy implementation, driven by the lack of practical instruments and measurement metrics, prevents translating top-down goals into actionable steps.

In the strawberry sector, where perishability and urgency play crucial roles, a robust framework to measure food loss and motivate mitigation is the primary task of the EU strategies. Otherwise, these strategies are just a formality. (Respondent 1)

Environmental frameworks, especially those regulating organic farming, pose another layer of institutional disputes. Rigorous reporting requirements are widely seen as bureaucratic challenges: "Strict deadlines coincide with peak seasons, leaving little time for the necessary paperwork", notes Respondent 1. While these regulations aim to enhance accountability, they hinder effective farm operations, reducing farmers' capacities to actively engage in food loss mitigation practices during a short harvesting window.

A clear understanding of food loss definitions is crucial for effective policy alignment, as "The lack of a unified approach to food loss and related terminology presents initial challenges" (Respondent 1). The varied perspectives among farmers highlight this fragmentation as

some farmers see food loss mitigation as a critical issue, while others view it as a natural part of strawberry farming ... and some neglect both entirely. Nonetheless, the financial consequences of food loss are sensitive to every farmer. (Respondent 1)

Farmer 1 briefly captures this reality: "When we don't pick strawberries and pay salaries, there is neither food nor financial loss". This statement underscores the importance of clarity in policy instruments to avoid ambiguity that can jeopardise practical (policy) implementation.

Investing in farmers' technical development, education, and research opens a promising avenue for mitigation measures in Finland. According to Respondent 1, such investments

...not only ensure a steady supply of high-quality strawberries but also strengthen Finland's market stability... [and]... agricultural resilience ... effectively mitigating risks associated with severe weather, pests, and diseases.

Research-driven approaches, including tailored nutrient management and

...controlled-environment agriculture techniques safeguarding crops against unpredictable weather, such as tunnels and greenhouses, and integrating automated monitoring systems for temperature, humidity, and soil moisture... (Respondent 1)

exemplify concrete pathways towards efficiency and resilience in Finnish strawberry farming.

The framework of policies and institutions significantly influences behaviour at critical moments by establishing definitions, exception protocols, and reporting timelines. Together with the relational economic geography, it frames spatial governance that aligns picking and cooling with territorial exposure. Finally, from a technological and innovation lens, it is evident that investments realise their full potential when rules align with the effective use of equipment and educational initiatives.

Complexities and strategies of harvesting processes: technological adaptations

Technologies can reduce food loss when integrated into socio-technical routines that consider factors such as time, distance, and workforce variability. Practical methods, such as tunnel cultivation, careful packaging, and cold storage, must be coordinated with activities like picking, sorting, loading, and transport, to achieve more consistent quality without needing to control external shocks. Technological adaptations are viewed as a complex perspective that can mitigate non-linear loss dynamics, rather than as a straightforward solution.

Harvesting practices are influenced by environmental and physical viability, as farmers adapt their harvesting behaviours towards soil variability, microclimatic conditions, weather unpredictability, and even the landscape. As Farmer 2 explains:

My farmlands consist of swampy soils and rocky terrain. We space the rows and alternate the planting directions. This approach helps to improve drainage and employ winds to dry during heavy rains.

Such adaptive strategies are influenced not by farmers' marginal choices but rather by fundamental interventions aimed at improving environmental adjustments and reducing food loss by aligning place and time.

The process of strawberry harvesting consists of three fundamental steps: picking, sorting, and packing, each of which poses the potential for food loss. Farmer 4 explains:

We provide thorough supervision to our pickers, offering clear daily instructions regarding which berries to collect, the specific fields to target, and the desired size, colour, and quality. These guidelines, however adjusted in response to weather forecasts, [...] help us control the food loss.

The first step in the process involves categorising strawberries into three distinctive classes: A, B, and C. Class A berries represent the highest-quality selections, as they are large and entirely red; Class B includes ripe, undamaged berries of varying size and colour; and Class C comprises smaller, irregularly shaped berries that are typically less marketable. Class C berries are picked only after the Class A and Class B collections are completed. As Farmer 3 remarks, "Class C strawberries are often used for making jams or juices. We have introduced a self-picking option when the weather permits and Class C berries are still available on the bushes."

Next, strawberries are ideally sorted close to processing facilities to maintain quality. Farmer 2 emphasises the importance of immediately sorting after picking:

We sort the berries right in the fields. Initially, we assess quality to guide our pickers and remove any low-quality berries. Finally, we pack half-kilo containers into cardboard boxes for shipping, ensuring fresh berries reach the market twice daily.

This reflects a logistical model that maximises freshness but is also highly vulnerable to timing disruptions. Re-sorting is discouraged due to its potential for bruising and spoilage, as Farmer 4 adds:

Re-sorting can harm crops, especially when transferring berries between containers. We carefully remove any spoiled berries and gently transfer the strawberries from the picking baskets, known as 'kopka,' into ventilated plastic containers.

At this stage, food loss mitigation is a matter of balancing processes, where technology relies on human skills under time pressure.

The third step, storage, is often undervalued by small-scale farmers and is crucial for enhancing survival rates and yields. Larger farmers integrate cold storage facilities directly into their harvesting systems.

Our cold warehouse efficiently sorts, packs, and sells while maintaining optimal temperature conditions. It also provides space for pickers to stack strawberries, record their work, and resume field activities without unnecessary delays. (Farmer 3)

Minimising transportation loss becomes strategic at this point: strawberries are transported only once and handled carefully by using appropriate cushioning materials to avoid mechanical damage and harmful vibrations.

The use of protective cultivation methods, such as plastic tunnels, marks the adoption of technology in Finnish strawberry farming. They shield crops from weather uncertainty and extend the ripening window, enabling farmers to better manage labour shortages during harvest peaks. Farmer 3 explains the importance of tunnel investment:

We financed the tunnel technology through a loan, which enables us to accurately predict output and ensure a steady supply of fresh strawberries for the capital region, regardless of the weather.

Such infrastructure entails considerable investment and requires institutional support for mid- and small-sized farmers.

Moreover, the wide variety of over 2,000 strawberry cultivars in Finland influences harvesting practices, as different cultivars thrive under various conditions. As Respondent 2 notes,

I find it intriguing how Finnish farmers prefer June-bearing cultivars in tunnels instead of everbearing ones. Combining tunnel-raising with everbearing strawberries can yield up to 1.5 kg per bush, allowing for continuous production over 2–3 months. This method, combined with an advanced watering system and suitable fertilisers, mitigates the risk of diseases that can devastate entire crops.

Thus, integrating varietal choice, vertical growth systems, and precise environmental control demonstrates how food loss can be mitigated not only in the post-harvest stages but also within the production system itself. Disease control, humidity regulations, and air and sunlight control become embedded within this strategy: “These advanced techniques necessitate a skilled approach, typically developed through extensive training, trials, and instruction”, continues Respondent 2.

More advanced post-harvest techniques, such as individually quick freezing (IQF), freeze drying, modified atmosphere packaging (MAP), irradiation, or slicing, aim to extend shelf life, improve quality, and ensure product safety downstream the value chain. However, they remain inaccessible for many due to cost, regulatory, or knowledge barriers. Small-scale stakeholders struggle to adopt new technologies due to land constraints, fluctuating market demands, and limited access.

Organic producers, more than others, face rigorous trade-offs between maintaining organic standards and adopting preservation technologies. Respondent 4 states, “We concentrate on top-quality organic strawberries and continuously search for the best raw berry suppliers.” Meanwhile, Farmer 6 expresses scepticism about conventional post-harvest technologies: “We are the only organic farm in this area, and we believe that tunnels, freezing facilities, and extensive storage degrade organic products.” This underscores a spatial-political paradox: the technologies positioned as a solution to food loss contradict organic principles, especially at the point where product authenticity and integrity are crucial to market positioning.

Food loss mitigation is not the result of a single technical fix, but rather the outcome of a complex strategic adaptation that encompasses terrain, timing, technological integration, and product philosophy. Understanding these complexities requires moving beyond the blind application of intricate solutions towards a clear concept of food loss in distinct farming practices.

The technology and innovation lens views these elements as part of coordinated systems, rather than isolated solutions. The relational economic geography lens emphasises that effectiveness depends on factors such as spatial reach, corridor design, and interdependence among nodes. Through the lens of labour and migration, it becomes visible that the benefits of technology depend on routines that align diverse skills with varying levels of availability. Moreover, the sustainability perspective reveals the need for mitigation measures to align with the realistic use of resources.

Workforce adaptation and migration constraints

Seasonal labour plays a crucial role in managing the complexities of climate variability and value chain design. Farmers face vulnerable workforce issues, such as unexpected recruitment and migration patterns, particularly when training, communication, and expectations are handled informally. Implementing multilingual, standardised procedures and incentive programs stabilises farm performance, even with varying crew compositions. This stability is enhanced by predictable

scheduling, timely quality feedback, and practical technological support. Ultimately, labour is seen as a vital area for skill development, enabling coordinated responses to manageable uncertainties.

Comparative experience shows that strawberry industries in Spain and Sweden routinely recruit temporary workers from abroad to cover short, weather-compressed harvest windows (Hedberg 2021; Gavin & Jongerden 2025). In Finland, seasonal agricultural labour migration is primarily influenced by its ties to non-EU Eastern European countries. North-western Russia and eastern Ukraine supply migrant workers seeking better wages and temporary jobs. Recent global shocks, such as the COVID-19 pandemic and the Russian invasion of Ukraine, have disrupted this flow and significantly reduced the labour pool (United Nations 2022). Visa restrictions now complicate workforce planning for Finnish farmers, who rely on migrant labour due to a shortage of domestic workers in agriculture. Picker 4 noted: "This year, I arrived in Finland alone because my husband was not allowed to leave our home country for seasonal work."

Farmers report that labour shortages directly threaten harvest consistency and increase post-harvest losses. Unexperienced pickers are more likely to mishandle delicate strawberries, resulting in lower product quality. Farmer 5 explains: "Negligent berry manipulation by unskilled personnel causes rapid mould, leading to unsellable berries." Food loss here is not an outcome of improper picking, but a direct consequence of mismatches in skilled labour demand. Due to socio-political constraints in migrant-dependent spheres, workforce gaps are rapidly transformed into tangible food loss.

To mitigate these skill gaps, farmers adopt peer-to-peer learning to enhance product quality by sharing experiences and knowledge. Farmer 2 explains: "Mature pickers share their skills with newcomers until they gain confidence as regards maintaining a similar quality: picking red, leaving green, and generating zero loss." This collaboration is both practical and relational, fostering networks that occur in parallel to the picking process. Picker 1 adds: "Newcomers learn techniques from experienced pickers, such as using knee pads, adopting comfortable postures, sitting on low seats, or bending their knees." However, peer pressure can have downsides: "When newcomers outnumber skilled pickers during a quick harvesting season, the average quality suffers, leading to increased food loss and potential reputational damage," warns Farmer 1. In this sense, peer learning is a temporary solution rather than a systemic one.

Labour conditions and picker welfare also play an indirect but significant role in food loss outcomes. Farmers continuously improve working conditions to attract and retain qualified labour. Farmer 4 says:

We have improved the accommodation for pickers, offering comfortable huts, air conditioning, and kitchens. Along with meals and recreational amenities, we encourage individual time-rest ... by stimulating with bonus-based salaries.

Picker 3 adds: "Our employer provides lunches, allowing us to eat and rest during breaks, which helps us to recharge our batteries. I repay this care with my picking accuracy." It exemplifies not only a moral feedback but also a strategic adaptation to maintain efficiency, highlighting the socio-economic reciprocity between labour care and harvest quality. Such monetary incentives involve a financial arrangement that increases productivity. The use of performance-based compensation, per-basket payments, and so-called bonus-based salaries is viewed as a tool for aligning economic incentives with product quality.

Farmers do not lower the minimum hourly wage but instead implement per-basket payments to empower pickers to increase their daily earnings based on their performance, thereby focusing on optimising both quality and quantity while reducing food loss. (Respondent 1)

This approach ties payment to output and quality, aligning pickers' incentives with farmers' efforts to mitigate food loss. Food loss mitigation is then exemplified not only as a technological or environmental issue, but also as a factor of workforce capacity, labour training, and workers' treatment.

The labour and migration lens highlights the crucial role that labour regimes play in navigating complex issues effectively. Meanwhile, the technology and innovation perspective underscores the importance of well-trained, seamlessly integrated workers within established routines. Relational economic geography emphasises that vulnerabilities arise not only from specific local conditions but also from the organisation of processes across value chains. In this context, labour actors play a

crucial role in shaping regional outcomes, making labour and skills central to developing coordinated responses (Yeung 2005). Lastly, sustainability and food-loss mitigation perspectives stress the importance of socially responsible labour arrangements, which are crucial for developing and implementing reliable, lasting mitigation strategies.

Building resilient farming systems

The resilience of the Finnish strawberry value chain is shaped by a complex interplay of local embeddedness, shifting agricultural models, and vulnerabilities tied to external dependences. This transition not only enhances integration sustainability but also implements vital measures such as climate-smart agriculture, agrotourism, precision farming, organic farming, and cutting-edge supply chain management. This diversity is crucial for reducing food loss and strengthening the food value chain in the long term. Ultimately, achieving this success requires a balanced approach to ecological and economic needs among all stakeholders.

The strawberry value chain primarily comprises large-scale commercial growers who cultivate strawberries and produce side-products such as juices and jams, small-scale farmers serving nearby communities, and hobby farmers who cultivate strawberries for personal use and sell any surplus. As noted by Farmer 4: "My grandparents lived here, then my parents cultivated new plots, my brother bought nearby areas, and, recently, my married sister returned to grow strawberries with her new family." On the one hand, such generational continuity strengthens social resilience by fostering place-based knowledge. On the other — it contends with modern realities and systemic challenges by slowing down growth.

Building resilience across such diverse value chains is a complex endeavour. Farmers observe that simply replicating effective practical techniques from one context to another can lead to critical issues such as food and water loss, soil degradation, and labour imbalances, particularly when conditions vary significantly. As Farmer 2 notes: "Our strategy was copying the behaviour of our neighbour, who is a bigger farmer, by adding to mutual outputs. Last year's results showed that the gap between us has widened."

Protected from seasonal and weather fluctuations, ceiling-raising technology significantly enhances the value chain by effectively preventing food loss. Respondent 2 states:

Ceiling-raising technology allows year-round berry cultivation. In experiments with a limited number of bushes, we achieved precise control over crop growth and feeding, including water and nutrient inputs. This approach is highly manageable and minimises both food loss and resource use.

When these methods are not fully integrated into the value chain, they create significant, unforeseen challenges that lead to substantial food loss. Respondent 2 confidently asserts, "...only systemic results effectively achieved the desired outcomes by learning through trial and error."

These issues clearly demonstrate that collaboration efforts may be sensitive to regional differences, varying farm sizes, access to technology, the availability of fertilisers, and personnel skill levels. Thus, resilience is best understood as a collective quality that encompasses the entire value chain rather than being solely a characteristic of well-equipped individual farms. Blind copying does not automatically lead to 'best solutions' suitable for everyone.

The Relational Economic Geography lens emphasises how disparities in infrastructure and governance affect individuals' and communities' ability to adapt, the speed of their responses, and the specific conditions under which they operate. The policy and institutional lens fosters coordination, reinforcing norms and commitments that help formalise this resilience framework. Sustainability frameworks and food-loss mitigation emphasise that robust value chains are essential for achieving positive outcomes across diverse locations and seasons, not just in ideal scenarios.

Towards resilient coordination: temporal-spatial disparities in strawberry value chains

Technologies and labour practices become effective within mitigation strategies that consider the complexities of food loss, recognising it as a systemic issue shaped by interrelated factors, rather than simply a series of avoidable errors. Such a governed framework is oriented by clear rules, realistic temporal horizons, and shared responsibility for absorbing uncertainty. This framework moves the discussion beyond technical optimisation of how risk, responsibility, and adaptive capacity are spatially and institutionally distributed along the value chain.

The resilience in the Finnish strawberry is influenced by perishability, technological capacity, market orientation, and labour dynamics. The perishability of strawberries requires synchronising harvest timing with market demand, thereby imposing temporal constraints on farmers. "Early-season berries are the most profitable: they are large, strong, easy to pick, and immediately sold with zero food loss during picking", observes Farmer 6. Farmer 5 notes:

Before March ends, I will discuss strawberry volumes with recent customers. While we don't set specific delivery days, we guarantee delivery of fresh-picked strawberries within hours, ensuring nearly zero food loss for us and maximum freshness for our customers.

While Farmer 1 underscores the necessity of digital tools for pre-ordering and logistic synchronisation: "My husband contacts customers by phone and text. Last year, we implemented a Google Form for orders, which captures addresses and schedules, helping us avoid food loss."

These forms of relations based on forecasting are instrumental in mitigating food loss among farmers. However, such coordination during harvest periods develops into a broader context of socio-ecological constraints. Farmers, due to unpredictable weather and uncertain amounts of strawberry surplus, are forced to balance secondary processing. Side-product producers are more conservative, unwilling to purchase uncertain quantities of berries. Moreover, rejected by the market, the side-flow producers purchase even fewer low-quality strawberries, thus turning picked berries into food loss.

We build strong relationships based on trust with our suppliers and carefully inspect berries before freezing them. However, if we notice an increase in low-quality berries from a specific supplier, we immediately stop dealing with them. We still compost about 40 litres from several tonnes of low-quality berries to produce fertilisers for our fields. (Respondent 3)

Farmer 6, simplifying such processing results, resumes:

We separate inedible berries from those my wife uses for drinks and jams ... less than two kilograms of fresh berries daily from our 5-hectare fields, which we compost for our backyard garden.

These precise forms of control signal a shift towards thinking about food loss mitigation among Finnish farmers.

Market orientation in professional farming introduces another mitigation pathway: socialised harvesting schemes through self-picking. Finnish farmers mobilise local seasonal consumers as informal labour, especially during periods when hiring formal labour becomes unprofitable. Farmer 3 notes: "This approach allows pickers to appreciate the hard work of picking... It introduces young people to potential summer jobs." Similarly, Farmer 6 notes the economic disbalancing point at which paid labour becomes unprofitable: "Once we have collected top-quality strawberries, paid picking becomes unprofitable, leading us to either offer self-picking or to stop picking entirely."

Such strategies blur the boundaries among agrotourism, labour substitution, and food loss mitigation, suggesting an emergent form of multifunctional agriculture sensitive to both economic and ecological thresholds. Farmer 1 adds:

Families with children, during summer vacations, visit self-picking farms to enjoy eating berries more than collecting them... and make us happy to clear out berries that are too costly to harvest professionally.

Finally, waste plants, which provide solutions such as organic waste valorisation, face practical and biophysical indifference due to the zero value of the strawberry food loss.

The biomass from berries consists mainly of water. Farmers are more likely to sell their products

at lower prices, produce side-products, or use the biomass on-site rather than bring it to us. (Respondent 5)

Even the entrepreneurial efforts of creating new products, such as berry-based mineral supplements, have proven to have zero market interest.

...the entrepreneur claimed that 35 kilos of berries were reduced to 2 cubic centimetres of mineral substance... the project was discontinued since our farm couldn't afford the comparatively greater food loss. (Farmer 5)

Therefore, food loss mitigation strategies vary based on materiality, market orientation, labour cost structures, and the capacities of downstream value chains, rather than relying on a universal technological solution.

In summary, resilience in Finnish strawberry value chains is built through a combination of market practices, on-farm processing techniques, composting of food loss into resources, social labour mobilisation, and high-demand preservation technologies. Not only technical or economic optimisations, but also spatially and socially embedded negotiations become visible through the lens of relational economic geography. The food loss mitigation lens, focusing on system-level designs, internalises complexity and uncertainty.

Governing the complexity of strawberry food loss through the five lenses

Analysing through the policy and institutional lens reveals that food loss in North Karelian strawberry production arises from uncertainty about rules and their implementation. Varied interpretations of 'loss', discretionary grading, and tight harvest windows shape outcomes. The lack of clear guidance leads stakeholders to adapt to challenges, passing risks to less prepared actors in the value chain. This highlights the demand to manage uncertainty and effective governance, as misaligned institutions may increase systemic vulnerability.

A comprehensive lens on technology and innovation reveals that integrating socio-technical advantages into systemic tools significantly enhances effectiveness. The success of protective tunnels, cold storage, and other technologies relies on aligning with work patterns and coordinating processes from the field to intake. When sorting practices and transportation schedules are primarily harmonised, technologies can effectively reduce spoilage time and manage loss dynamics. While these infrastructural and technological solutions offer promising reductions in food loss, they also pose certain challenges. For instance, they require additional material and energy inputs, including the need to regularly replace plastic coverings and an increase in energy consumption on farms. Consequently, these adjustments may shift environmental burdens, potentially impacting the sustainability of production, even while achieving a measurable reduction in food loss. Conversely, a lack of synchronisation limits labour and technological benefits, underscoring the need for avoiding a one-size-fits-all approach.

The labour and migration lens makes it clear that the unpredictability of seasonal work and the development of collective skills among workers further complicate matters. Recruitment uncertainties and changing migration conditions, combined with short harvest periods, exacerbate informalized training and communication. Farms with a structured multilingual orientation, standardised protocols, and incentivising frameworks are better prepared for external disruptions, especially when grading feedback is timely. This perspective highlights the crucial role of labour during daily uncertainties, thereby linking the resilience of regional food systems to governance and infrastructure.

The sustainability lens emphasises that reducing food loss is closely tied to environmental constraints, certification standards, and market expectations. Factors such as limited growing seasons, climate unpredictability, and the delicate nature of strawberries necessitate interventions that align with biophysical constraints. Additionally, factors such as organic integrity and regional identity influence viable, economically sound approaches. This demonstrates that the pursuit of sustainability often involves balancing ecological, regulatory, and market dynamics, which are shaped by local compromises rather than a single standard.

The food-loss mitigation lens highlights that effective strategies emerge when actors acknowledge complexity and uncertainty. Key practices, including a combination of transparent and tailored protocols for quality levels, fair valuation of peripheral farms, and logistics services, treat mitigation as a systemic property rather than an isolated solution. Hence, instead of overleaping uncertainty, stakeholders may focus on redistributing information and responsibility to buffer shocks collectively. This emphasises the central claim that advances economic geography in this field: to understand who and how can act under uncertainty, the institutional and spatial frameworks involved, and the supporting infrastructure, rather than simply assuming stable conditions for farmers, which, in practice, they do not have

Discussing the complexities

Food loss in Finnish strawberry production is not a discrete or accidental occurrence, attributed solely to the inefficiencies of individual farmers, but rather a complex, adaptive system, in which weather and labour uncertainties interact with temporal-spatial disparities (Martin & Sunley 2007; Guthman 2017; Springmann *et al.* 2018). It materialises where formal rules, spatial networks, and workforce asymmetries intersect, confirming the claim that agri-food vulnerabilities are institutionally and relationally co-produced rather than isolated from farm-level accidents (Yeung 2005; Wilson 2009; Fuenfschilling & Truffer 2014).

By examining the impacts of gaps in the cold chain, intake procedures, organic certification processes, wage structures, and opportunities for valorisation, the study emphasises how micro-level elements influence decisions about what is harvested, categorised, discarded, or left in the fields (McPherson & Sauder 2013). It reveals that the notion of 'zero-loss agriculture' serves as a selective initiative that primarily benefits well-equipped, financially stable farms. This places peripheral and resource-limited producers at heightened risk of food loss.

Through the empirical analysis, this research illustrates the intricate ways in which interrelated economic, institutional, and stakeholder dynamics shape both the capacity to mitigate loss and the emergence of new vulnerabilities (Currie & Spyridonidis 2016). It reframes the challenge of strawberry food loss as a geographically uneven governance issue, deeply rooted in broader socio-technical and market frameworks, rather than a mere technical or ethical concern encountered solely at the farm level.

The concept of zero-loss represents a strategic path towards minimising avoidable losses within the unique structural, climatic, and organisational contexts that vary across farms, regions, and segments of the value chain (Sydd 2025). It serves as a compelling governance tool that fosters investment, control, and collaboration to support technologically and financially stable, well-connected farms over marginalised, resource-limited ones. Therefore, 'zero-loss agriculture' should not be viewed as a goal to eliminate food loss completely.

Research indicates that the complexities inherent in value-chain processes, including quality standards, climate fluctuations, labour limitations, organic certification processes, infrastructure shortcomings, and side-flow processing, inevitably contribute to some degree of physical food loss and its reclassification (Hartikainen *et al.* 2018). Examining food loss in strawberries through this perspective highlights that significant progress relies less on pressuring individual farmers to attain perfection. Instead, it depends entirely on transforming the institutional, infrastructural, and market systems that unevenly distribute both the opportunities for reducing food loss and the acceptance of inevitable losses.

The lens of relational economic reveals that food loss in the strawberry sector is not solely an agricultural concern but a multifaceted challenge geography (Yeung 2005; Coenen *et al.* 2012). This is viewed as an informal fix consistent with Clark and Munroe's (2013) findings on neighbourly reciprocity. However, as warned by Marjamaa and colleagues (2021), when volumes surge, these informal relations burden and even lead to a neighbourhood quarrel between the uneven leaders. The unequal access to advanced technologies, such as plastic tunnels, high-tunnel or post-harvest packaging, even compounds these gaps (Wikström *et al.* 2019; Benyam *et al.* 2021).

Institutional theory emphasises policy frameworks, regulatory requirements and the operational routines, underscoring the interrelated aspects of labour, technological innovation, and sustainability (Fuenfschilling & Truffer 2014). For instance, organic certification rules impose a higher level of bureaucratic burden, forcing farmers to prioritise regulatory compliance over technological and labour interventions. Interviews highlight that informal networks for practical exchanges and the understanding of FAO (2014) food loss definitions are noteworthy (Clark & Munroe 2013). For example, policymakers, farmers, juice producers, and pickers pay attention to discarded food only because of its quality degradation and view food loss as a predictor of financial losses, thereby impacting the profitability and sustainability of the value chain. This explains how these actions lead to economic impacts and subsequent rounds of action that may follow (Bathelt & Glückler 2014).

The stakeholder-centric approach makes these structural patterns more tangible, creating a better understanding of the cultural turn, methodology, and rationality (Jones 2014). Within the Finnish strawberry value chains, these interactions emerge clearly under institutional and relational conditions through labour relations. Interviews with farmers, who introduced bonus-based salaries and peer mentoring, reported measurable declines in food loss. This reinforces findings of Sutherland and Marchand (2021) that respectful labour regimes boost quality along the supply chain. At the same time, farmers deliberately report that high labour costs still drive selective harvesting of only premium berries, leaving less attractive non-marketable items unpicked. Such a contradiction frames the double-task of valuing labour while managing costs (Ababio *et al.* 2025).

Likewise, combining strategic measures stabilises the food loss even under climatic stress. For instance, high-tunnel raising supplemented with reduced bruising packaging and consequent juice and jam production demonstrates argument of Paasi (1986) that infrastructural layering that becomes an established entity can neutralise spatial disadvantage in individual and institutional practices. Conversely, minor, detached interruptions, such as delays in harvesting or transportation disruptions, rapidly transform into systemic events, leading to broader infrastructure fragmentation and spatial disparities.

Occasional labour shortages are addressed by shifting the responsibility onto consumers through self-picking agrotourism, as noted by Mahaliyanaarachchi and colleagues (2019), who suggest that such multifunctionality can help fill workforce gaps. Still, farmers note that tourist turnout depends only on weather and school calendars, underscoring the warning of Fastenrath and Braun (2018) on the contradictions of socio-spatial context that facilitate volatility. In addition, socio-economic disparities, as highlighted by Joensuu and colleagues (2021) and Muiilu (2010), create significant contradictions and disrupt the balance between immediate and long-term solutions. These illustrate Hansen and Coenen's (2015) warning that circular initiatives without market incentives are likely to remain limited to pilot stages.

Above these layers, the interviews reveal significant systemic gaps, including complexities in intricate regulations (Geels 2011). The lack of temporal and spatial resources that extend beyond financial investments and the certification stringency diverts farmers' attention from productivity to compliance (Wei 2015; Sydd 2025). Repeatedly described the harvest-versus-paperwork collision, farmers report it as a form of governance misalignment, leading to broad infrastructural and spatial disparities, where paperwork cycles compress field decision-making time and intensify food loss risks during short harvesting windows (Paasi 1986).

The classification of what constitutes food loss remains ambiguous at various levels, interlinked by institutional and practical contexts. For example, some farmers dispute energy costs and carbon inputs for maintaining cold storage, which align with Soode-Schimonsky, Richter and Weber-Blaschke (2017), who caution that these costs offset environmental impact gains. Advanced processing solutions express comparable doubts: while freezing saves surplus volumes, as farmers confirm, it degrades taste on thawing, echoing the views of Simkova and colleagues (2024).

Unpicked, harvest-ready strawberries are not always considered food loss and can still be harvested later (FAO 2014). Or, potentially viewed as a form of biomass, thus reducing the environmental impact, depending on whether they are spoiled during ripening, spoiled during picking, consumed by wildlife, redirected for animal feed, or composted. While the definitions of policy, measurement and farmers'

interpretations remain imbalanced, food loss becomes evident, taking concrete forms and volumes, thus complicating rational decisions on food loss mitigation processes (Wilson 2009).

More evident from the interviews is that Finnish strawberry stakeholders not only understand the quantities of food loss but are also skilled at quantifying these levels. Farmers use these measurements to assess stability and predict economic viability in both the short and long term. Farmers utilise the zero-loss benchmark as a diagnostic tool and report a heightened awareness of temporal bottlenecks. Farmers assess the concept of zero-loss level through a range of metrics, including financial, natural, harvesting, logistical, biological, processing, and unavoidable loss indicators. Such an approach, acknowledging the complexities, is associated with tackling the most ambiguous goals (Buschke & Brownlie 2020).

To effectively implement mitigation efforts, it is essential to harmonise certification processes with harvest calendars, enhance cold-chain infrastructure in remote regions, promote scalable labour-saving technologies, and encourage the development of the strawberry value chain. Meanwhile, the lack of standardised guidelines and clear tools presents challenges for benchmarking zero levels of food loss (Sydd 2025). This situation complicates the efforts of policymakers, farmers, processors, and pickers to enhance agricultural practices and advance sustainability initiatives.

The integration of relational economic geography with institutional and stakeholder perspectives formalises three mechanisms: temporal-spatial coupling, performative grading rules, and capability complementarities. This generates a transitional construction that can be conceptualised as a 'loss corridor', a segment of the supply chain where structural conditions systematically concentrate losses, converting abstract complexity into comparative metrics. This multi-level construction explains food loss under uncertainty, where advancing economic geography toward a comparative agenda coordinates across places, spaces, power, and agency, proposing a revised social capital research rather than illustrating simplicity and parsimony (Naughton 2014).

Embedding farm-level loss metrics into the Finnish circular economy frameworks, under the Circular Economy Act and the National Waste Plan, could turn strawberry field data into actionable regional signals. Interviews demonstrate that farmers, who already experience picking, harvesting and post-harvest losses, aggregate these micro-records into a real-time food loss database. Turning these data into valuable datasets fulfils the highly demanded National Waste Plan 2027 and complies with the EU GD policy indicators (Ympäristöministeriö 2022).

By coordinating these interconnected strategies, Finnish strawberry producers may achieve higher levels of systematic loss prevention while also preserving the workforce and the landscapes that sustain the industry.

Conclusions

The findings suggest that 'zero-loss agriculture' in Finnish strawberry production is best understood as a nuanced initiative driven by governance and infrastructure considerations, rather than a universal performance standard for farms. While it is challenging to completely eliminate food losses due to various factors, including weather-related risks, stringent quality standards, labour shortages, the location of processing facilities, and disparities in access to technologies, the study highlights the potential for targeted improvements.

By adjusting contracts, intake practices, certification processes, and labour arrangements, it is possible to reduce avoidable losses and soften the challenges faced by peripheral and smaller producers. Therefore, progressing towards a zero-loss model involves harmonising regulatory frameworks, investments, and coordination efforts with the specific relational and institutional dynamics of the strawberry sector, rather than assuming only the most advantaged participants can meet such expectations.

Deeply intertwined with economic geography, the complexities of food loss emphasise the relational interdependencies between stakeholders, infrastructure, and environmental factors. Labour shortages, exacerbated by geopolitical factors and the reliance on seasonal migrant workers, remain a central challenge. Effective labour strategies, including improved wages and working conditions, as well as the adoption of performance-based incentives, improve harvesting efficiency.

The perishable nature of strawberries further compounds this vulnerability, making timely harvesting and quality control crucial to minimising food loss.

Clarifying organic farming policies can improve its expansion, while a standardised framework for defining and measuring food loss is vital for consistent practices. Technological advances, such as automation and cold storage infrastructure, hold significant potential for mitigating food loss by reducing reliance on manual labour and ensuring product quality even during short transportation and storage periods. Integrating sustainable practices, such as climate-resilient farming, and producing value-added products, such as jams and juices, enhances long-term sustainability and environmental resilience. Practical accessibility for small-scale farmers, who face financial, technical, and knowledge barriers, is crucial for successful sustainability transitions.

Ultimately, the combination of improved infrastructure, national policy adjustments, labour policies, and technological adoption, supported by regional planning, offers the potential for Finland's strawberry sector to reduce food loss while fostering long-term sustainability. These efforts make the industry more resilient and support the broader objectives of national food security and rural development, aligning with EU sustainability goals. Balancing policy enhancements, improving infrastructure, adopting innovative technologies, and fostering stakeholder collaboration are imperative to minimise food loss in the Finnish strawberry supply chain.

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