Cleaner and Responsible Consumption 19 (2025) 100328

Contents lists available at ScienceDirect

Cleaner and Responsible Consumption

journal homepage: www.journals.elsevier.com/cleaner-and-responsible-consumption

Lost in the field: Understanding vegetable losses at farm level

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ARTICLE INFO

Keywords:
Food waste
Food loss
Vegetable
Horticulture
Primary production

ABSTRACT

Vast quantities of food are lost along the food value chain. Although much is known about losses at the consumer level, relatively little is known about the producer level. Using a qualitative approach, this study examines farmers' views on vegetable losses in potatoes, carrots, onions, tomatoes and lettuce. We conducted semi-structured interviews with 15 farmers in Switzerland to find out 1) during which operations losses occur, 2) what quantities are lost, 3) drivers and barriers for the reduction of losses, 4) farmers' strategies to reduce the losses and 5) how losses are disposed of. Only one farmer in our sample indicated that they recorded losses. Consequently, the quantification of losses is mostly based on estimates and subject to great uncertainty. Farmers identified various reasons for losses along the food value chain (e.g. quality deficiencies, standards of retailers or wholesalers, and market demand). Their reduction efforts were largely influenced by regulatory frameworks and market dynamics, both as drivers and barriers. Further, we found that some farmers understand vegetable food losses as intrinsic to farming, positively picturing the use of losses as feed or compost as a circular use of resources. Some farmers identified food losses as an economic issue and described strategies they use to reduce losses, again covering different stages from production to processing and market (e.g. multiple sales channels and good cultivation practices). Our study contributes to both research and practice by offering a foundation for policy development and industry initiatives aimed at reducing vegetable losses.

1. Introduction

Globally, it is estimated that one-third of all food produced is wasted along the entire food value chain (Food and Agriculture Organisation, FAO, 2011). These vast quantities not only reflect inefficiencies in food systems but also pose significant challenges to global sustainability. Reducing food waste is critical for ensuring food security, mitigating environmental degradation and staying within planetary boundaries (Gerten et al., 2020; Springmann et al., 2018; von Ow et al., 2020). Recognizing the urgency of the issue, the United Nations (UN) has integrated food waste reduction into Agenda 2030. Specifically, Sustainable Development Goal (SDG) 12 aims to halve global food waste per capita at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses, by 2030 (United Nations, 2025). In response to this goal, various countries and regions have launched initiatives, such as the European Union's Farm to Fork Strategy, which aims to accelerate Europe's transition to a sustainable food system (European Commission, 2020). These efforts reflect a growing consensus that addressing food waste is crucial for building resilient and efficient food systems.

In Switzerland, food waste similarly remains a pressing issue, with significant quantities generated annually across all stages of the food system. An estimated 2.8 million tonnes of food are lost each year, corresponding to 330 kg per person (Beretta and Hellweg, 2019). To align with global sustainability goals, the Swiss Federal Office for the Environment (FOEN) has implemented an action plan against food waste. This strategy targets all stages of the food value chain, including primary production, and involves collaboration between the federal government, cantons and municipalities. Key measures include improvements in data collection, awareness campaigns, voluntary industry agreements and regulatory adjustments, which aim to reduce inefficiencies and enhance sustainability (Der Bundesrat, 2022). Despite these efforts, significant gaps remain in understanding the specific causes and dynamics of food loss at the production stage.

Agriculture accounts for approximately 20 % of total food losses in Switzerland and is the second-largest contributor to vegetable food loss after consumers (Beretta and Hellweg, 2019). Vegetables, including potatoes, are the most wasted food category overall (Beretta et al.,

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https://doi.org/10.1016/j.clrc.2025.100328
Received 5 June 2025; Received in revised form 27 August 2025; Accepted 5 September 2025
Available online 6 September 2025

2017). This trend is not unique to Switzerland, as high vegetable losses are also observed in other European countries (Caldeira et al., 2019). Large waste volumes make vegetables highly relevant even if they have a lower per-kilogram environmental impact than other food types. Despite its significance, knowledge of food loss at primary production stage is limited compared to later stages in the supply chain, such as retail and consumer waste. While significant efforts have been made to curb household and supermarket waste (e.g., Ananda et al., 2022; Aschemann-Witzel et al., 2017), losses at the farm level remain less studied. One of the few studies addressing the issue of vegetable food loss in Switzerland, by Willersinn et al. (2015), examined the quantity and quality of losses in the Swiss potato supply chain. Other researchers estimated on-farm losses in North Carolina for a selection of crops, combining unharvested crops of marketable quality and edible but unmarketable quality, as a significant average of 42 % of the marketed yield for these crops (Johnson et al., 2018). Beyond a few studies (e.g. Hartikainen et al., 2017; Jordbruks verket, 2024), little is known about vegetable food loss at the production stage, its underlying causes and the strategies farmers employ to mitigate it.

Food loss at the primary production stage is driven by multiple interconnected factors, causing substantial quantities of vegetables to be discarded before they even reach consumers. Weather conditions and plant diseases are major contributors, as extreme temperatures, droughts and infections can compromise produce, leading to spoilage and reducing the market value (Hartikainen et al., 2018). To hedge against these risks, farmers often plant excess crops, but favourable conditions can result in unharvested surpluses (Jordbruks verket, 2014). Market conditions further impact food loss, as fluctuating prices and demand can make harvesting financially unviable. If labour and transport costs outweigh potential revenue, crops may be left in the field (Gunders and Bloom, 2017). Strict buyer standards on size, shape and appearance lead to selective harvesting, where visually imperfect yet edible produce is discarded (Beausang et al., 2017; Porter et al., 2018). For potatoes, nearly half of all losses result from failure to meet quality standards, largely due to norms set by retailers, consumer preferences and food safety concerns (Willersinn et al., 2015). Labour shortages worsen the issue, particularly for perishable crops requiring timely harvests. A lack of seasonal workers can also delay picking, increasing spoilage rates (Baker et al., 2019). Additionally, limited processing infrastructure prevents the utilisation of surplus or lower-grade crops, further exacerbating losses (Beausang et al., 2017).

Given these challenges, this study focuses on food loss in Swiss vegetable farming and on the five most common vegetable crops in terms of production volumes: potatoes, carrots, onions, tomatoes and lettuce (open field). The study aims to provide a comprehensive understanding of the underlying causes, identify where losses occur and quantify them. Further, the study investigates drivers and barriers for the reduction of losses, farmers' strategies to reduce losses and the methods used to dispose of losses. This study seeks to fill critical knowledge gaps, offering insights that can inform future policy decisions and support efforts to create a more sustainable and efficient food system in Switzerland.

2. Methods

2.1. System boundaries and definitions

This study focuses on food loss in the context of vegetable production by Swiss farmers. The system boundaries are defined as starting from when the crops are ready for harvest and ending when the produce is sent for processing, retail or direct sale. In the case of direct sale, the boundaries end when the product is sold to the consumer. Further, following previous research (Hartikainen et al., 2018), food loss in primary production is defined as follows: "*The flows of primary products that were meant to be eaten by humans but never entered the next step in the food supply chain (*e.g.*, […] retail, processing), and instead were used for other purposes (*e.g.*, feed) or sent for waste treatment.*" Even though non-edible parts of food, i.e. parts not intended for human consumption, such as onion peels or parts of tomato stem, are not defined as food loss, they are included in the quantities reported in the results section.

Food loss occurs earlier in the food value chain, while *food waste* happens closer to consumers at the end of the value chain (Parfitt et al., 2010). Therefore, in the present study, the term *food loss* is predominantly used. If *food waste* is mentioned, it refers to the broader concept encompassing losses across the entire food value chain. In addition, to specify the definitions, this study focuses specifically on *avoidable food loss* in primary production. *Avoidable food loss* refers to losses that could have been prevented through improved management or infrastructure, excluding *unavoidable losses* caused by external factors, such as weather events or infestations. However, if harvested goods are affected by weather but remain edible, they are still considered *avoidable food loss* as they could potentially be used through alternative sales channels or processing.

2.2. Participants and data collection

In Switzerland, around 54 % of plant-based foods and 50 % of vegetables are produced domestically (Bundesamt für Statistik (BFS) [Federal Statistical Office], 2025; Verband Schweizer Gemüseproduzenten (VSGP), 2025). In 2024, around 388,000 tons of vegetables were produced on a cultivation area of around 14,000 ha (Verband Schweizer Gemüseproduzenten (VSGP), 2025). On average, one out of six farms is organic (Bundesamt für Statistik (BFS) [Federal Statistical Office], 2025). The purchase of organic fruit and vegetables is disproportionally high as the market share of organic products overall was 11.2 % in 2024 (Willer et al., 2024), while the market share of organic vegetables was more than twice as high in 2020 (BioSuisse, 2020). Most of the vegetables are sold through retail outlets.

The target population for this study consisted of Swiss farmers (German-speaking) actively engaged in vegetable production. A convenience sampling and snowballing approach was used to recruit participants due to the nature of the study. Different experts in vegetable production were contacted for identification of possible participants. Participants were identified through personalised email outreach, phone calls and posts in two relevant agricultural newsletters. In total, 15 farmers participated, representing different vegetable farming types, including both organic and conventional practices. Farmers producing at least one of the following vegetables were eligible for participation: potato, carrot, onion,[1] tomato[2] and lettuce. This selection ensured a focus on the most produced vegetables in Switzerland, including potatoes (Federal Office for Agriculture [Bundesamt für Landwirtschaft (BLW)], 2024). In addition, participants received a CHF 75 voucher for an agricultural supply store as a token of appreciation for their time and input.

The interview guide consisted of introductory questions and eight main questions. After a brief informational part to explain to the respondents what the project was about and the definition used for *avoidable food loss*, the guide covered topics such as the types of vegetables produced, causes of food loss, current strategies to reduce loss and practices to manage it and drivers and barriers for food loss. The interview guide was designed based on input from experts at the Federal Office for the Environment (FOEN) and Agroscope and on the results of a literature review. It was pre-tested with a person involved in vegetable farming who was not part of the final sample to ensure the clarity and relevance of the questions.

Data were collected through semi-structured interviews that provided a balance between structured and open-ended questions, ensuring that pre-determined topics were addressed while also allowing the

[1] Spring onions not included.
[2] Cherry tomatoes included.

participants to elaborate on unexpected or unique aspects of their practices. Most interviews were conducted online via Zoom, and some were conducted in person at the respective farm, depending on the interviewee's preference. All interviews were conducted between October and November 2024. Each interview lasted approximately 1 h. For transcription purposes, each interview was audio recorded with the participant's permission.

Written consent was obtained from each participant. The participants were informed about the purpose of the study, the voluntary nature of their participation and their right to withdraw at any time. The study was reviewed and approved by the ETH Zurich Ethics Commission (project 24 ETHICS-308).

2.3. Data analysis

The collected data were analysed using qualitative content analysis, specifically thematic analysis, as it enabled the identification of recurring patterns across the interviews, ensuring a structured yet flexible interpretation of the qualitative data. Kuckartz's (2018) method was selected to code and analyse the interview transcriptions. This entails a systematic evaluation procedure that follows specific content analysis rules for examining textual material. Of the three main types of qualitative content analysis, the content-structuring analysis approach was utilised because this method is particularly effective for organising content into a structured framework and conducting analysis based on that structure. The qualitative content analysis followed a structured process. First, the transcription was reviewed to gain an overview, and key insights were noted. Next, the main categories were derived from the research questions, ensuring alignment with the interview guide. The initial coding involved systematically assigning text passages to these categories. Then, similar passages were compiled, and subcategories were developed inductively by refining the classification using data from all the interviews. The final coding applied the structured category system to the entire dataset. Lastly, the results were analysed based on the category frequency, with relevant statements highlighted and interviewer observations incorporated into the discussion. The relationship between categories was also explored (e.g. farm scale and disposal method). MAXQDA2024 software was employed to assist in this process.

3. Results and discussion

3.1. Sample

Semi-structured interviews were conducted with 15 vegetable farmers representing diverse farming practices, geographic locations and production scales across Switzerland. The participant pool included a mix of organic (40 %) and conventional (60 %) farmers, with one participant (P15) engaged in both organic and conventional methods (see Table 1). Farm sizes varied considerably, ranging from 0.2 ha for small-scale farms to over 200 ha for larger operations. Four participants operated small-scale farms, typically focusing on a more limited range of crops and relying primarily on direct marketing (DM) or direct sales for gastronomy (G). Medium-scale operations (n = 7) tended to cultivate a more diverse range of vegetables and utilised multiple sales channels. Four participants represented large-scale farms, primarily serving retail (R) and wholesale (W) markets. The 15 farms covered eight different cantons. Exact locations are not indicated to ensure anonymity of the farms.

Table 1
Participant characteristics (N = 15).

Participant ID	Farming type	Key vegetables	Farm size	Sales channel
P1	Organic	Carrot, onion, tomato, lettuce	Small	DM
P2	Conventional	Lettuce	Small	DM, G
P3	Conventional	Tomato, lettuce	Small	DM, G, R
P4	Conventional	Tomato, lettuce	Small	DM
P5	Organic	Potato, carrot, onion, tomato, lettuce	Medium	DM
P6	Organic	Potato, carrot, onion, tomato, lettuce	Medium	DM, G, R, W
P7	Organic	Potato, carrot, onion, tomato, lettuce	Medium	DM, G
P8	Conventional	Potato, carrot	Medium	DM, R, W
P9	Conventional	Potato, carrot, onion, lettuce	Medium	DM, R, W
P10	Conventional	Potato, carrot, onion	Medium	W
P11	Conventional	Potato, carrot, onion	Medium	DM, W
P12	Organic	Potato, carrot, onion	Large	R, W
P13	Organic	Potato, carrot, onion, tomato, lettuce	Large	DM, G
P14	Conventional	Tomato, lettuce	Large	R, W
P15	Organic, Conventional	Lettuce	Large	R, W

Note: The farm sizes range from small- (0.2–10 ha) and medium- (>10 ha, ≤50 ha) to large- (>50 ha) scale. Sales channels include direct marketing (DM), gastronomy (G), retail (R) and wholesale (W).

3.2. Occurrence and causes of vegetable losses

Fig. 1 illustrates the primary steps in the production chain where significant losses occur for the five crops investigated. For lettuce, losses primarily occurred early on, when the lettuce was still in the *field*.[3] Additional stages mentioned were *sorting* and *sales*. For carrots, losses were reported to occur across multiple steps in the production process. The most frequently mentioned step was *sorting*.[4] Additionally, six participants identified *harvesting*[5] as a significant stage in which losses occurred, while one participant noted losses during *storage*.[6] For potatoes, the main step associated with food loss was *sorting*. Additionally, two participants identified food loss occurring during the *harvesting* phase. For onions, food loss mostly occurred during the *storage* phase. Additionally, *sorting* and *harvesting* were each named by two participants as steps where losses occurred. Finally, losses for tomatoes occurred later, mainly during the *sales*[7] phase. Other steps included *harvesting*, *transport*[8] and *storage*.

Similarly, the causes of food loss described for the different crops vary depending on the crop (Fig. 1). For lettuce, the causes of food loss were predominantly linked to quality and market issues. The most

[3] Field: The crop is left in the field unharvested and is either mulched or ploughed under.

[4] Sorting (with or without washing): Takes place after harvesting and either before or after storage. Goods that have quality deficiencies or that do not meet standards of retail/wholesalers are sorted out either manually or mechanically.

[5] Harvesting: Not all products are harvested, remaining in the soil or in the field. Possible reasons include harvesting techniques or direct sorting in the field.

[6] Storage: Losses occur, for instance, because of contamination, rotting in storage, prolonged drying (sunburn) in the field or when the variety does not keep well in refrigeration.

[7] Sales: Losses occur during the handover to the buyer, for example, due to the sampling system or due to insufficient demand or buyer preferences.

[8] Transport: Damage occurs, for instance, when products are inadequately packaged.

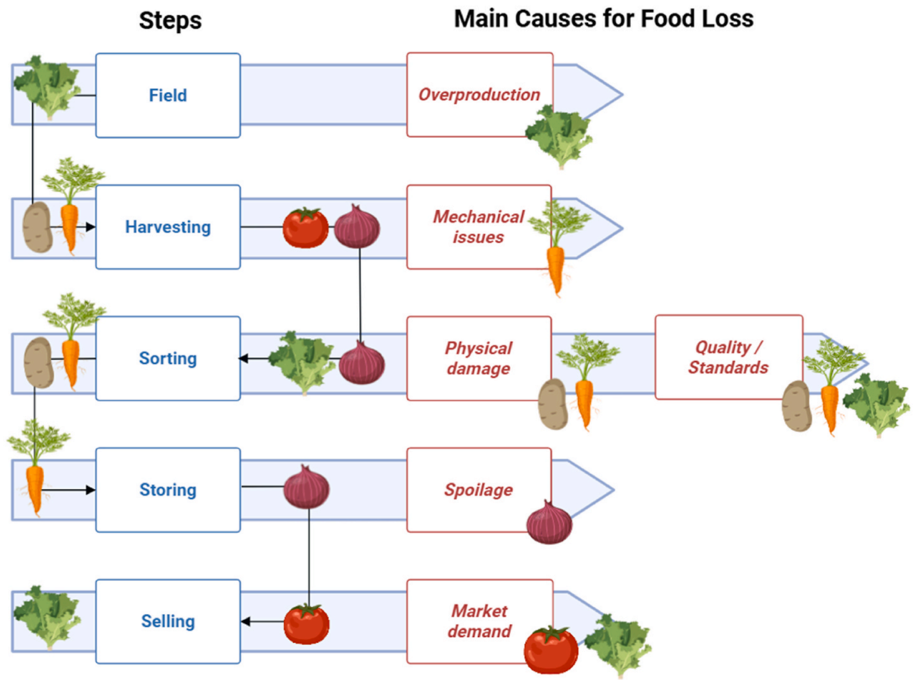

Fig. 1. Processing steps where vegetable losses occur for the five crops and the main associated causes for crop-specific the losses (Created in BioRender. Ammann, J. (2025) https://BioRender.com/dxb5ok6).

frequently cited cause was *quality deficiencies*: *"The problem is when it doesn't meet the quality standards due to infestation. For example, powdery mildew: in organic farming; it can't be fought as efficiently, and with aphids, there's zero tolerance"* (P6). Deficiencies can also be caused by weather events. This is especially relevant for lettuce, as it is a sensitive crop: *"Weather influence: When we have big raindrops, then it gets damaged but would still be edible"* (P9).

Other significant factors included *market demand*: *"We always need to have enough, so we always grow enough, and it's relatively cost-effective. What we don't sell is simply expensive green manure, meaning nutrition for the soil life"* (P7). Another participant described the challenges of DM and estimating consumer demand as follows: *"Depending on the weather or holidays, there are more or fewer people at the weekly market, which causes big fluctuations"* (P1). *Overproduction* was mentioned for lettuce specifically but was generally perceived as less problematic due to the low production costs compared to, for instance, tomatoes: *"There is sometimes overproduction to secure quantity. We don't want the overproduction, but it's part of the business; not everything can be sold, and then it stays in the field"* (P4). Strid and Eriksson (2014) found through interviews with farmers that 10–20 % of the lettuce fields were never harvested, mainly due to mismatching orders.

On the one hand, farmers often feel forced to overproduce to meet retailer demands, and overproduction has been identified as a key driver of losses in horticulture (Messner et al., 2021). On the other hand, it has also been reported that, due to good relationships between farmers and retailers, this problem has been mitigated (Beausang et al., 2017). Importantly, in our study, this was still mentioned as a key issue for food loss in lettuce production.

Less common but notable causes for lettuce loss were *not meeting standards*, *insufficient harvesting capacity* and *customer preferences*, described as follows: *"We have customers who specifically want lettuce 'hearts', so we must remove the outer leaves, which creates loss"* (P14). Additional causes included *competition from lower-grade quality* lettuce, *consumer preferences* and the *sampling system of buyers*.

For carrots, the two most frequently mentioned causes were *not meeting standards* and *quality deficiencies*. Not meeting standards can, for instance, be related to weather or climate change: *"Growth problems due to environmental factors like weather or soil preparation can happen. For example, being exposed to a long dry period, and then they become too long for the bag"* (P12). Indeed, previous research reported that around 35 % of processed carrots can be downgraded due to non-compliance with retailer standards (Pietrangeli and Cicatiello, 2024). Downgrading can be due to cosmetic standards (e.g. if the carrots are two-legged, crooked, or bent) or because they are not the requested size. As for potatoes, other causes of food loss for carrots included *physical damage* and *growing/-harvesting techniques*: *"If we sow too densely, we have too many small carrots that we have to throw away, but that could actually be avoided"* (P1).

For potatoes, the most frequently mentioned causes were *quality deficiencies* and *not meeting standards*, which one participant described as follows: *"Waxy potatoes must not be longer than* 12 cm*. However, this is no longer enforced as strictly as before. Retailers have loosened the calibre requirements, which used to be a big problem. But with misshapen potatoes, there isn't much you can do – that's just the way it is. For fries or chips, there is eventually a lower limit for the calibre; otherwise, they can potentially be used as raclette potatoes, but not always, as it depends on the raclette season"* (P10). This is in line with previous research reporting that cosmetic standards set by retailers are one of the key causes of food loss in general (Beausang et al., 2017; Göbel et al., 2015). In a similar vein, farmers have been found to use pesticides for visual purposes; that is, to increase the visual appeal of apples (Zachmann et al., 2024).

Another common cause for potato loss was *physical damage*, typically resulting from mechanical handling during harvesting or sorting: *"Sometimes there is impact damage, and then the potatoes turn black and cannot be sold"* (P10). Again, this issue is well recognised in the literature (Timmermans et al., 2014). Moreover, these losses are often seen as a trade-off. That is, when harvesting becomes more efficient due to mechanisation, yield losses due to mechanical handling are more easily accepted by the farmer (Kantor et al., 1997).

The causes of food loss for onions were distinctly different and heavily influenced by *storage*-related factors. One participant offered a possible reason: *"With a lot of rain, fungal diseases occur during cultivation, and during storage, they then rot"* (P5). Other causes included *physical damage* and challenges related to *field drying*, described by one participant as follows: *"If the timing isn't ideal, they get sunburned and then go into* *storage with quality issues, and they rot"* (P13). Less commonly mentioned causes were *storage conditions*, issues related to *varietal selection* and the *sampling system of buyers*.

The causes of food loss for tomatoes happened later in the food value chain and were predominantly related to market dynamics. The most frequently mentioned cause was *market demand*. For instance, one participant said, *"Tomatoes in summer, when there's an oversupply on the market, become overripe. There may be some that get mushy, and they won't sell in the farm shop either"* (P3). Other causes included *varietal selection* and *physical damage*. One participant described it thus: *"Some varieties are sensitive to temperature differences. In open fields, we've adapted this over the years"* (P1).

3.3. Quantities of vegetable losses

As for the causes of food loss, the estimated quantities varied considerably between the crops (Fig. 2). It is important to note that these numbers represent estimates by the farmers and sometimes even average estimates over several years. For potatoes, many participants emphasised that the year 2024 was particularly challenging in terms of production, contributing significantly to higher losses: *"This year, we are not calibrating the potatoes because we harvested so little, and the quality of what we did harvest was very poor. This year, we had 70 %–80 % less yield"* (P7). It was also recognised that there is much variability in potato losses: *"With potatoes, the fluctuation is very significant – either top results, a flop or even total failure"* (P8).

The estimated losses of carrots were quite similar to those of potatoes. Interestingly, only one carrot producer stated that losses of carrots are measured (and not estimated): *"With every washing cycle, we measure how much goes into the machine and how much we get out as first-class produce. If we have very high-quality produce, around 75 % is first-class, which is very good – so [a] 20 %–25 % loss. On a poor field, only 50 % might be good, or even less, 40 %, if we can't harvest at the perfect time and end up with many oversized carrots. Last year, we measured this precisely, and it was 60 % for first-class, meaning [a] 40 % loss"* (P6). Another participant explained why measurements are not taken: *"In general, estimating quantities is very difficult, so we don't record this. In a processing operation, you have first, second and third quality, and it all goes into the sorting system. With carrots in particular, everything is automated, so you can precisely determine how many kilos are first, second, etc. I can't say that"* (P7).

The estimated losses for onions were the second lowest (Fig. 2). Most participants estimated losses of up to 10 %. This is well-aligned with previous research, where food losses at farm level have been estimated to be around 15 % (Baker et al., 2019; Qin and Horvath, 2022). Again, some participants stated that the quantities vary significantly depending on the year. As one participant noted: *"With onions, it can range between 0 and 20 %. It very much depends on the year"* (P8). Another participant provided more detail on the variability of losses: *"With onions, it's 1 %–2 % in a good year and 10 % in a bad year. However, there have also been cases where entire fields were lost, amounting to 100 %. We lost one field before harvesting due to disease" (P9)*. Indicating the wide-ranging estimates, another participant described relatively minimal losses for onions: *"With onions, we have almost no loss, at most 5 %. It's either good or bad here, not like with other crops"* (P10).

The lowest estimates were obtained for tomatoes, which accords well with the findings of previous studies (e.g. Baker et al., 2019). One reason for this is the high costs of this crop: *"We aim for as little loss as possible with tomatoes because the crop is expensive"* (P7). Only one person estimated losses of between 11 % and 20 %; the others estimated losses of between 0 % and 10 %.

For lettuce, most participants estimated a loss of up to 30 % of overall production (Fig. 2). The influence of weather on losses of this crop was specifically highlighted by almost all participants: *"5 % or 50 %, very variable; it can also result in total loss; this year was very bad"* (P6). It was further emphasised that losses are high because lettuce is the most perishable crop: *"There is the most loss with lettuce because this crop is the most perishable"* (P5).

Overall, the quantification of food loss must be interpreted cautiously. Our data rely on farmer interviews, which is the case for most of the relatively few studies on production losses (Baker, 2006). Almost all the available data are based on self-reports. The Food and Agriculture Organisation of the United Nations (FAO) estimated around 20 % losses for fruit and vegetables in Europe (FAO, 2011; Gustavsson et al., 2013). This was for instance based on losses for carrots, onions and tomatoes estimated through farmer questionnaires (Davis et al., 2011). Similarly, the ReFED (Rethink Food Waste Through Economics and Data) report estimated from farmer interviews 20 % losses for fruit and vegetables (REfed, 2016a; 2016b). Estimates can be unreliable, as growers have difficulty estimating their loss quantities (Beausang et al., 2017).

Importantly, some farmers in our study stated that food loss was not an issue for them; their loss quantities were comparable to those who did view food loss as a problem, which can be an indication of the participants' differing opinions regarding food loss, which will ultimately impact the measures they take to reduce vegetable losses at their farms.

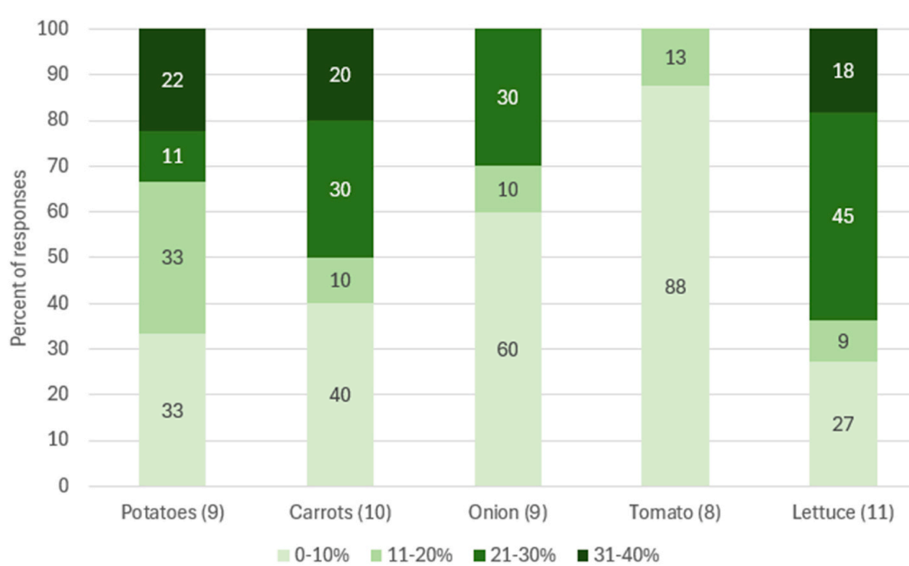

Fig. 2. Farmers' estimated vegetable losses for several years for the five investigated crops (N = 15).

Further, this discrepancy in the perception of the optimal level of food loss (i.e. what they find appropriate) not only exists between farmers but also between farmers and researchers. One possible reason could be that farmers are closer to production than researchers. On the one hand, this can give them a better sense of what is realistically achievable. On the other hand, it could also lead to a certain degree of indifference because they are confronted and struggle with the losses on a daily basis while simultaneously having to deal with other challenges on the farm.

3.4. Drivers and barriers for the reduction of vegetable loss

Understanding the factors that drive or hinder effective food loss management is essential for the development of targeted interventions. Fig. 3 provides a structured overview of the drivers and barriers mentioned by the participants for the reduction of food losses. They are categorised into six themes: *Regulatory Framework*, *Market Dynamics*, *Consumers*, *Resource Constraints, Technology and Innovation*, and *Collaboration and Communication.*

3.4.1. Regulatory framework

At the regulatory level, one participant pointed to existing efforts to address food loss, although they recognised the limitations of what can realistically be done given external constraints such as market demand and production conditions, which in turn can be seen as a barrier to the reduction of food loss: *"I am quite heavily involved with this topic. From the perspective of […], the industry organisation, efforts are already being made to counteract this. In the case of industrial potatoes, much more is possible, and tolerance regarding quality has increased. In the coming years, more potatoes that are not entirely perfect will be processed. Efforts are underway to explore what can be done in this regard. However, there are, of course, things that cannot be used for processing, and we also know that if we deliver lower-quality produce, it will still be accepted, but performance in the processing industry will significantly decline because certain items must simply be sorted out"* (P10).

Another aspect at the regulatory level is the use of plant protection products. Their use was seen as a driver, reducing losses in cultivation, but also as a barrier when products are banned and losses due to pests increase. However, the use of pesticides comes with an important trade-off: Bans on certain products have positive effects on the environment and human health (Kim et al., 2017; Rani et al., 2021), but concurrently increase losses due to quality deficiencies. Policymakers could mitigate this trade-off by introducing incentives for resilient cultivation methods, such as regenerative farming and robust crop utilisation strategies (Fieber and Bosch, 2024), and consumers should be more understanding when it comes to 'wonky vegetables'. These findings illustrate the need for systemic approaches that balance efficiency and waste reduction across the entire value chain.

3.4.2. Market dynamics

As production should be economically sustainable, market dynamics clearly play an important role in terms of drivers and barriers for food loss. For instance, strict quality and appearance standards define which products can be sold: *"The biggest hurdle is the standards. For example, products with small holes that don't affect edibility at all still cannot be sold, even though they are actually of good quality, or when we can't sell small lettuces because they weigh 200 instead of 250 g. We do find alternative buyers, but at some point, that market is also limited, and it becomes difficult to offload large quantities"* (P14).

Products that do not fit with these standards require new sales channels, which, however, come with additional effort: *"New sales channels could be sought, or campaigns could be run on social media, but the difficulty is that we don't have the capacity for such campaigns to organise everything"* (P2). Moreover, the respondents criticized supermarket campaigns to market suboptimal products because they were primarily regarded as marketing campaigns rather than effective measures to reduce food waste. This was justified, for example, by the fact that the

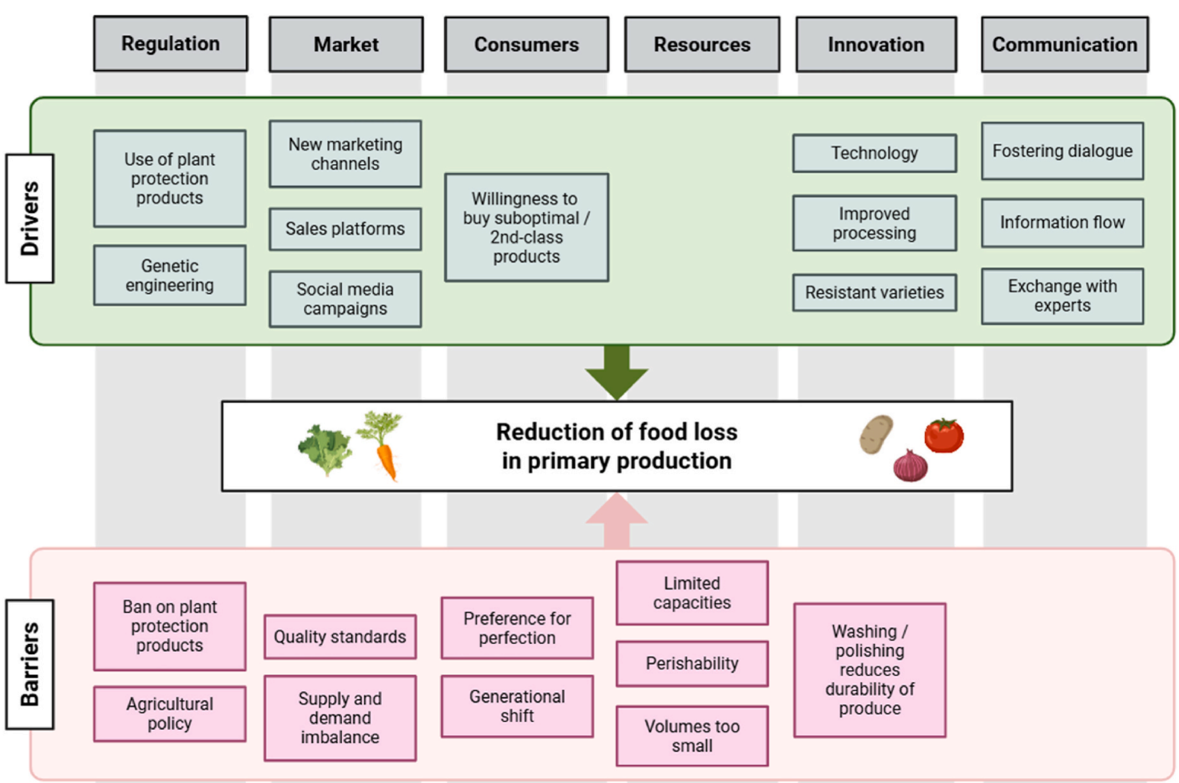

Fig. 3. Drivers and barriers mentioned for the reduction of vegetable loss in primary production for the five investigated crops (Created in BioRender. Ammann, J. (2025) https://BioRender.com/ca4j9rf).

effort for different packaging, different handling and specific delivery processes cause additional costs, which are not covered by the achieved prices.

A broader systemic challenge stems from the trade-offs inherent in retail strategies aimed at reducing food loss. As outlined in Fieber et al. (2024), loosening retail standards can effectively lower food loss at the farm level; however, this approach risks increasing food waste at the consumer level, where produce that deviates from aesthetic norms might be left on the shelf. Therefore, Beretta et al. (2013) emphasise the importance of understanding the rationales and behaviours of all value chain actors when addressing food loss and waste, as any intervention at one stage of the chain can have cascading effects on others.

3.4.3. Consumers

Another important factor to consider is consumers, as they need to buy the products. Some consumers might be willing to accept suboptimal produce yet expect reduced prices (Ammann et al., 2025; Aschemann-Witzel et al., 2018). However, farmers incur the same high production costs for these products: "*For us, the cost of producing beautiful or ugly vegetables is the same, but when the consumer is at the store, they expect a lower price for produce that looks worse*" (P15). Similarly, some participants mentioned that customers are too picky in terms of product quality: "*The question here is what is still edible? For me, many things are still edible, but for the customer, they're not. No one in Switzerland wants a product that isn't perfect*" (P14). As one participant pointed out, there may be a need for consumer education, especially with young consumers requiring education about food loss.

3.4.4. Resource constraints

Another important aspect pointed out by the interviewees was the resources needed to reduce food loss. These include aspects such as limited time, funds, infrastructure or manpower for additional measures. The perishable nature of vegetables makes it even more difficult to reduce losses. Finally, two interviewees mentioned that small quantities of surplus produce make it difficult and unprofitable to use them for sales or distribution.

3.4.5. Technology and innovation

In terms of technology and innovation for plant production, one central aspect is breeding, which can help increase resistance against climate change or pest pressure: "*Varietal breeding is relatively agile, but with potatoes, there is often a reliance on old varieties, and I see an opportunity here with more modern varieties that are better adapted to the climate or have resistance traits. Access to modern breeding methods would help*" (P8).

3.4.6. Collaboration and communication

Finally, important aspects mentioned were exchanges with experts who can help find solutions to reduce losses, an improvement in information flow with buyers, institutions and experts and fostering a dialogue with wholesalers to better address quality and supply issues. Again, these findings illustrate the need for systemic approaches that bring actors together across the entire value chain.

3.5. Farmers' strategies to reduce food loss

After identifying the drivers and barriers for the reduction of food loss, we wanted to understand specific strategies the participants used to reduce their losses. They described a wide variety of strategies that they employ to mitigate loss during the different stages of their vegetable production. These strategies were categorised based on their primary focus: *production, market, processing/storage* and *other* measures (Fig. 4).

Production-oriented strategies, such as *good cultivation practices* and *plant protection*, are commonly implemented. These can help avoid food loss early on: "*It starts with good cultivation techniques, meaning producing the best possible quality [and] choosing the right varieties. For example, last year, we had a carrot variety that tasted really good and had a high nutrient density, but it didn't produce nice-looking carrots. These are the kinds of compromises we face. Then there are high-yield varieties like Bolero carrots, which perform really well but don't have the best flavour*" (P7).

The most frequently mentioned strategies were market-oriented. These include the use of *multiple sales channels* and the *donation of surplus or 2nd-class products*. Several farmers acknowledged the benefits of DM and their networks, which allow greater flexibility compared to

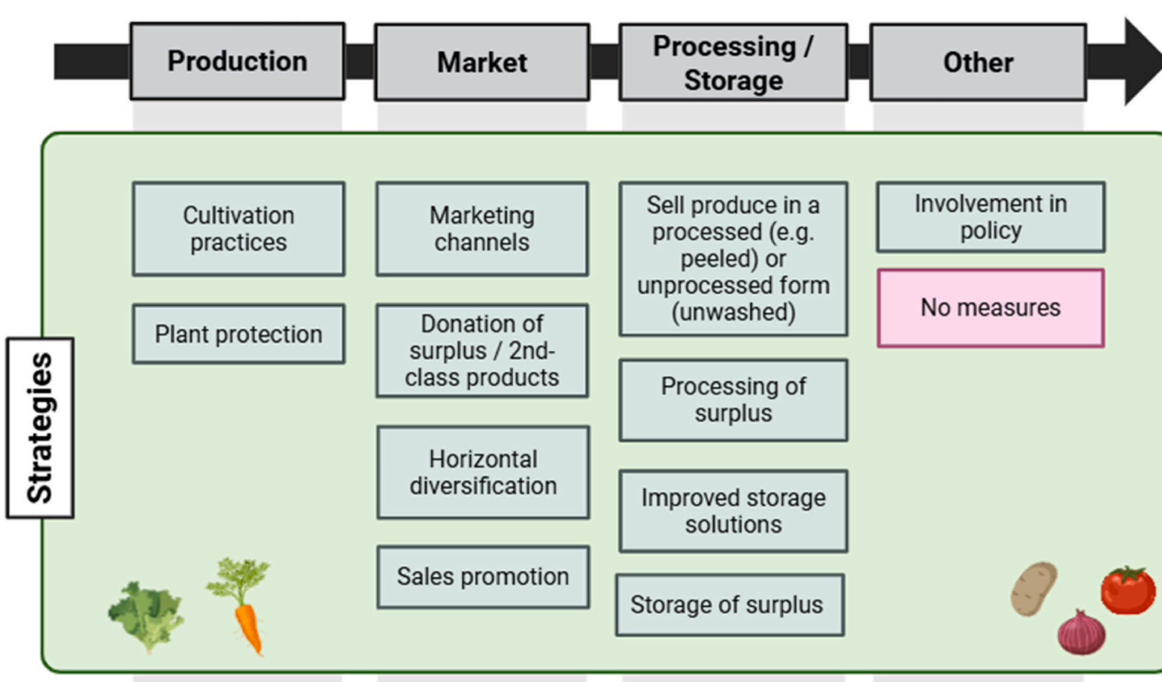

Fig. 4. Strategies used by farmers to reduce vegetable losses for the five investigated crops (Created in BioRender. Ammann, J. (2025) https://BioRender.com/e75zsxh).

dealing with wholesalers, as direct customers often accept non-standard produce. For instance, *"We have greater flexibility than large distributors. We have a wide range of customers. Some have been with us for a long time and even help out in the fields, and they think, 'My God, are you throwing this away?' Others complain about quality when they receive their delivery. So, we must ensure that we don't put every carrot in the subscription box. But we can sell a crooked carrot just fine – it's no problem for us. Especially at the market, kids are delighted when there's a small or two-legged carrot"* (P13). These contacts can also be used to deal with overproduction: *"When we have too much, we can get it to people easily because we have direct contacts and know the people in the region"* (P1).

Other approaches, such as *modifying processing steps*, were less frequently mentioned but still important for managing food loss: "*Sometimes we deliver [carrots that don't meet standards] [...] for juicing. It's not a fixed arrangement because there aren't always sufficient quantities, but it has happened a few times"* (P12). In some cases, the farmers also explored political advocacy or took no action at all, which shows how differently the importance of the food loss issue is perceived between the participants.

3.6. Disposal and utilisation of vegetable losses

When food losses have occurred, another question is how they were dealt with. Fig. 5 provides an overview of the methods used for disposal or utilisation of food losses for the five crops investigated. The most common method used was *leaving produce in the field*. Participant P3 referred to this practice as "*simply an expensive green manure*". Lettuce, due to its perishable nature and limited market demand for secondary uses, is often left in the field to decompose naturally, whereas potatoes and carrots were occasionally ploughed back into the soil. The farmers perceive this circular use of resources very positively: *"For me, everything that stays in the field is not lost and serves as fertiliser. Especially as a livestock-free operation, this is very important. We also need a lot of compost, so if something is 'lost', I have no concerns or a guilty conscience"* (P11).

Animal feed was used for potatoes and carrots, predominantly as feed for dairy cows. This finding is in line with Willersinn et al. (2015), who reported that 67 %–90 % of rejected potatoes were used as animal feed in Switzerland. The participants in our study indicated that most of this feed was provided to other farmers, with a smaller portion being used for the participants' own livestock. Again, many participants mentioned that feeding crops to animals for them was not considered food loss: *"We actually don't waste anything because everything that isn't sold is given to the cows, which then produce meat for consumption. So, in that sense, nothing is wasted"* (P7). Another participant explained, *"What is fed to animals is, for me, not a food loss. It's not the same if it's used for animal feed or sent to a biogas plant"* (P10). This is much in line with Beausang et al. (2017), who reported that farmers do not identify food waste as a primary concern, but rather accept it as an intrinsic part of farming.

Composting was a method employed across all farm sizes, indicating its broad applicability, whereas *biogas production* was exclusively used by medium- and large-scale farms, demonstrating the role of scale in adopting this method. Medium-to large-scale farms frequently send vegetable losses to biogas plants, while smaller farms tend to rely more on composting.

Overall, we identified a variety of disposal and utilisation options for vegetable food losses, reflecting the adaptive strategies employed by Swiss farmers. The widespread use of biogas production and animal feed demonstrates the farmers' resourcefulness in repurposing losses, enabling some recovery of the value embedded in lost produce by generating energy or contributing to livestock nutrition (Garrone et al., 2014; Redlingshöfer et al., 2017). And even though it is not considered food loss, for the sake of completeness it should be mentioned that a part of the non-marketed produce is consumed by the farmers' families and workers. However, while such solutions optimise the use of food losses, they often fail to fully recapture the economic, nutritional and environmental value of the original produce. Preventing food loss remains the most sustainable and impactful strategy, as it avoids not only the loss of the product but also the resources used in its production, such as water, energy and labour (Beretta and Hellweg, 2019; FAO, 2019; Hamilton et al., 2015). Thus, although the ingenuity of Swiss farmers in managing vegetable losses through repurposing channels is commendable, a stronger emphasis on awareness and preventive measures is crucial for addressing the root causes of food loss.

3.7. Limitations and outlook

Some limitations of our study must be acknowledged. Food loss is an emotional topic, and self-reported quantities of food loss might be

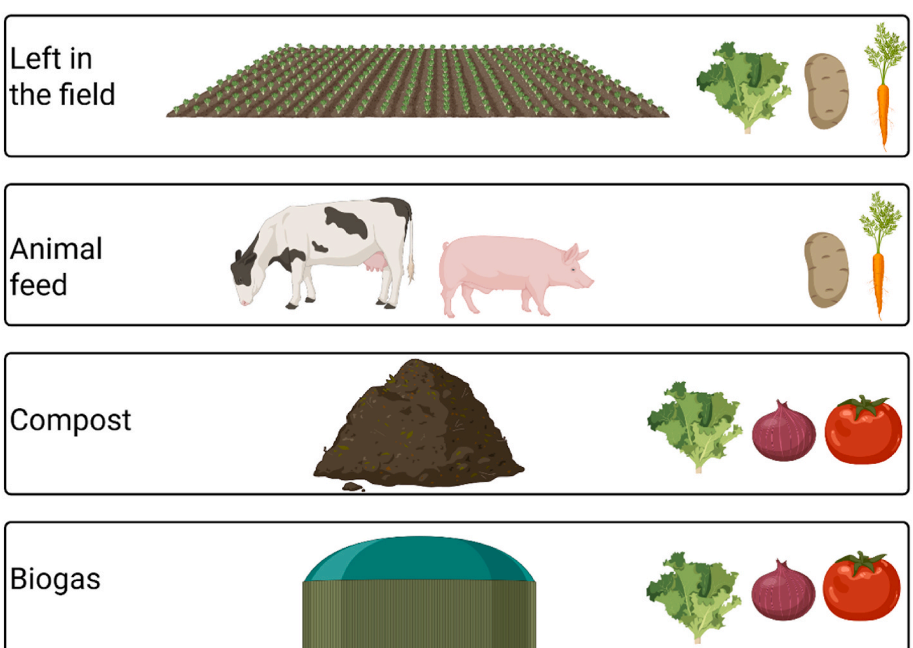

Fig. 5. Methods of disposal or utilisation of vegetable losses for the five investigated crops.

subject to optimistic bias. Additionally, while this study focuses on five of the most produced vegetable types in Switzerland, this narrow scope may limit the generalisability of the findings to other crops. Expanding future research to include a broader range of crops and production systems (e.g. fruit) would provide a more comprehensive understanding of food loss across the sector.

Another limitation of this study is the absence of systematic data collection by the participants regarding the quantities of food lost. The farmers' reliance on estimates rather than measured data introduced uncertainty into the findings, particularly in quantifying loss rates and evaluating their economic significance. This finding aligns with broader research gaps in measuring food loss in primary production (Beausang et al., 2017; Redlingshöfer et al., 2017). Still, the results are comparable to previous research partly conducted in other countries (Hartikainen et al., 2018; Porter et al., 2018; Willersinn et al., 2015).

Switzerland is a small country with a limited number of crop farmers. To ensure anonymity of participants, we did not report age, gender or exact geographic location of the farms. These are aspects that, however, might impact food losses or participants' perception thereof. Therefore, future studies should look into these aspects more closely. Additionally, we here worked with a convenience sample. Using a representative sample would allow to investigate differences in motivations and efforts to reduce food loss related to farm size and between organic and conventional farms.

Future studies should explore innovative and resilient cultivation methods, such as regenerative farming, to counteract losses exacerbated by stringent pesticide policies. Evaluating the effectiveness of multi-stakeholder platforms that enhance communication and collaboration along the entire food supply chain will also yield valuable insights into systemic solutions. Moreover, insights on methods applied and applicable by farmers to quantify food loss as well as best practices will be helpful to develop a robust knowledge of quantities of lost food. Overall, addressing these limitations in future research could enhance the reliability, representativeness and applicability of the findings, contributing to more effective strategies for reducing food loss in Switzerland and beyond.

3.8. Implications

From a practical perspective and based on our findings, there are some implications for the reduction of food loss. First, the available data should be improved. Out of 15 interviews, only one interviewee reported actually measuring food losses. This means that the figures reported are subject to considerable uncertainty, as they are primarily based on individual estimates. To identify areas for action and develop targeted measures, it is important to be able to do so on the basis of a good data set, which is currently not available. To address this challenge, we recommend using carrots as a pilot for the development of standardised measurement frameworks. As described by interviewee P6, carrots are characterised by relatively high loss rates and significant economic importance, making them a strategic and promising starting point.

Second, retailers should be encouraged to adopt more flexible standards that allow for minor cosmetic imperfections without compromising safety. However, for this to be successful, sector-wide agreements are needed. Moreover, establishing alternative marketing channels, including farmer networks and digital platforms, could reduce reliance on conventional retail outlets. It is also critical that farmers receive greater support to implement new strategies. At the same time, a stronger, more integrated support system among all value chain actors – policymakers, trade organisations, agricultural producers, consumers and researchers – should be developed.

Third, respondents were rather critical of supermarket campaigns to market suboptimal products. Such strategies were primarily seen as marketing campaigns rather than effective measures to reduce food waste. This was justified, for example, by the fact that the effort required to produce second-class products – such as additional packaging, different handling and specific delivery processes – was often not reflected in the prices offered, which were too low to justify the additional work involved. Instead, it would be better to focus on consumer behaviour and ensure that the acceptance of suboptimal products is increased. This could be achieved through mixed bags (e.g. potatoes or carrots) or information campaigns.

4. Conclusion

This study provides a comprehensive analysis of vegetable food loss in the early stages of the Swiss food value chain by comparing the five most produced vegetable types: potatoes, carrots, onions, tomatoes and lettuce. The findings reveal a complex interplay of causes, including quality deficiencies, non-compliance with standards and market demand, and underscore the dual roles that regulatory frameworks and market dynamics play as both drivers and barriers for food loss reduction. Additionally, the study highlights the diverse strategies farmers employ to mitigate losses, such as diversifying marketing channels, improving cultivation practices and repurposing surplus produce through green manure, composting, animal feed and biogas production. However, it must be noted that these repurposing strategies do not fully recapture the economic, nutritional and environmental value of the original produce, indicating that prevention remains the most sustainable approach.

In sum, by addressing critical knowledge gaps and providing actionable insights, this study contributes to both research and practice by offering a foundation for future policy development and industry initiatives aimed at reducing vegetable loss. The findings may also serve as a model for similar efforts beyond Switzerland, reinforcing the global relevance of effective food loss mitigation strategies.

CRediT authorship contribution statement

Jeanine Ammann: Writing – original draft, Supervision, Project administration, Methodology, Conceptualization. **Sara Visco:** Writing – review & editing, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Manika Rödiger:** Writing – review & editing, Conceptualization.

Declaration of competing interest

Declarations of interest: none.

5 Acknowledgements

This study received financial support from the Federal Office for the Environment (FOEN). The authors thank the FOEN, Martin Schlatter and Prof. Dr. Michael Siegrist, who provided valuable feedback on the interview guideline and FOEN and Dr. Sergei Schaub for his critical comments on the manuscript.

Appendix A. Supplementary material

Supplementary material to this article can be found online at https://doi.org/10.1016/j.clrc.2025.100328.

Data availability

Data will be made available on request.

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