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Lost vegetables, lost value: Assessment of carrot downgrading and losses at a large producer organisation

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ABSTRACT

Retailers usually impose strict private quality standards on fresh fruit and vegetable products, mainly focused on cosmetic features. At the supplier level, this generates a stream of suboptimal products that cannot be sold on the fresh market. This article studies the impact of these standards on suppliers by means of a direct quantification conducted in 2023 in the carrot supply chain of an Italian Producer Organisation. 34.64% of the carrots processed in terms of mass is downgraded because of non-compliance with the standards imposed by retailers, while 12.57% is lost at the primary stage due to food safety reasons. Downgrading occurs as a result of cosmetic imperfection (33.28% of mass) or because carrots are out-of-size (66.72%). The downgraded carrots are reprocessed for industry, generating an additional loss of 15.27% of mass along the way. The economic loss linked to downgrading would account for 22.05% of potential turnover if no cosmetic quality standards were applied. By modelling a series of hypothetical scenarios, this article discusses the impact on the producer if the private quality standards imposed by retailers were more flexible.

1. Introduction

The incidence of food loss in the fruit and vegetable sector is estimated as 20–25% of production in terms of mass (Porat et al., 2018; FAO, 2019). When considering the early stages of the supply chain, from farms up to - but no including - retail, 13.8% of the economic value of food produced globally is lost (FAO, 2019). However, at these stages, the availability of data gathered through direct quantification is limited (Caldeira et al., 2019; Corrado et al., 2018; Schneider et al., 2019) and many studies rely on data obtained from literature reviews or indirect measurement, significantly limiting its accuracy (Corrado et al., 2019). The main factors contributing to food loss in the fruit and vegetables value chain are agronomic practices, disease, deterioration, incorrect storage, human error, and product defects (Ishangulyyev et al., 2019; Gustavsson et al., 2011). While many of these factors can hardly be managed or prevented through human action, several are due to the actions of operators in the value chain. This is the case of private quality standards, which are increasingly considered relevant to discussion about food loss in the fruit and vegetable sector (de Hooge et al., 2018; Pietrangeli et al., 2023; Porter et al., 2018; Porat et al., 2018).

Private quality standards are requirements that buyers (especially retailers) impose on suppliers with the aim of standardising the appearance and features of fruits and vegetables (de Hooge et al., 2017, 2018; Hartmann et al., 2021). These standards are stricter than the requirements established by public and semi-public institutions (such as the EU or UNECE) to ensure food safety. The application of such standards prevents the sale of products with imperfections, for example black spots, non-straight shapes or other cosmetic issues, resulting in the rejection of a substantial volume of produce, referred to as suboptimal (Commons, 2017; Hezarkhani et al., 2023). These products have the same intrinsic quality and safety as products that meet the standards, but their visual appearance, shape or colour deviate from the norm; for this reason, they may be deemed undesirable by consumers and retailers may not accept them to be sold on the fresh market (Aschemann-Witzel et al., 2015).

For some products, the application of private quality standards starts in the field, with selective harvesting (Gunders, 2012; Suresh Kumar et al., 2023). More often, private quality standards are applied during post-harvest operations, when suboptimal products are selected and downgraded, thus leaving the stream of products destined for the fresh market. If they are not quickly reallocated to alternative, less remunerative, marketing channels (such as the food industry, Pietrangeli

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et al., 2023), they can become a food loss, due to their perishability (de Hooge et al., 2018).

FAO (2021) estimates that between 25% and 30% of carrots do not reach grocery stores due to physical or cosmetic defects. In the UK, on-farm and grade-out losses due to cosmetic issues are between 23% and 44%, and the products with the highest losses are potatoes, carrots, onions, and brassicas (Porter et al., 2018). In England, 3%–13% of potatoes, 9%–20% of onions, and 5%–25% of apples are discarded for aesthetic reasons (Commons, 2017). In a study conducted in Australia, tomato losses during post-harvest operations are 40.3% of the total harvestable product; of this, between 68.6% and 86.7% are rejected due to out-grades (McKenzie et al., 2017). In the fresh longan fruit supply chain in Thailand, from harvesting, sorting, grading and packaging to transportation, qualitative loss amounts to 11.02% of total production (Tansuchat et al., 2023). In Finland, 13%–31% of carrots produced are diverted to a side stream, the main reason being flaws in quality, size or appearance (Hartikainen et al., 2017).

In Switzerland, Willersinn et al. (2015) found that total potato losses are approximately 41%–46% of the initial processing mass, and half of these losses are due to quality standards. Fernandez-Zamudio et al. (2020) quantified losses of persimmon in Spain at the harvest and post-harvest stages as equal to 38.5% of the mass ultimately commercialised, or 29.5% of the entire volume produced; persimmons presenting purely aesthetic damage, and thus not meeting quality standards, are 4.57% of the harvested fruit on average. De Falco et al. (2022) studied the artichoke chain in Italy, where food loss was between 58.5% and 69% in the post-harvest phase.

The application of private quality standards has a huge impact on operators in the upstream stages of the supply chain: harvesting, processing, and distribution (Porter et al., 2018). In the fruit and vegetable supply chain, Producer Organisations (POs) play a crucial role in harvest and post-harvest operations. These are farmers' associations which oversee the harvesting and marketing of produce, achieving greater bargaining power than individual farmers (Herzberg et al., 2022). POs perceive private quality standards as a challenge, due to the strict requirements set by retailers (Pietrangeli et al., 2023).

This paper aims to contribute to this stream of research by providing a direct quantification of the carrots lost and downgraded due to private quality standards, in terms of mass and value, on the basis of field data retrieved at one large PO in Italy. The research questions behind this study can be defined as follows: (i) what proportion of carrots are downgraded due to private cosmetic quality standards, and how many are lost, out of the total mass processed at a PO? (ii) what are the economic implications of downgrading and loss of carrots, in terms of turnover for the PO and, in turn, for producers? (iii) what are the possible actions to reduce downgrading and sell more carrots on the fresh market?

2. Material and methods

2.1. Case study

This paper focuses on the postharvest phases of the carrot supply chain. Carrots fall within the EU common market organisation for fruit and vegetables, and producers are frequently associated in POs, which take care of post-harvest operations and market commercialisation, through retailers or industry. The field study was conducted at the warehouse of a PO located in central Italy. The total production of fruit and vegetables by this PO is 78 million kilos per year from 183 farms, and its annual gross turnover from all services provided by the PO is around 40 million euros. The main products of the PO are fennel, carrots, potatoes and salad vegetables, with a total cultivated area of over 32,000 ha. Italy is the 5th largest producer of carrots in the EU and the 15th in the world (Brandi et al., 2021), with a total production of 4,991, 515 quintals per year (Istat, 2023). The case study PO is located in Abruzzo, the top Italian region in terms of quantity of carrots produced (1,501,000 q per year).

2.2. Definitions

This study focuses on post-harvest operations in the carrot value chain. In this case study, carrots are sorted into three categories, based on their quality attributes (Johnson et al., 2018), and in line with the European definition of food waste (Directive EU – 2018/851) (Fig. 1).

- *Marketable as fresh*: carrots that are suitable for human consumption, with no visual or cosmetic defects, diameter between 20 and 40 mm (imposed by buyers as part of private quality standards). These carrots are sold to retailers to be marketed as fresh.
- *Downgraded – Edible but not marketable as fresh (DØtot)*: carrots that are safe and nutritious, not under- or over-ripe but not saleable on the fresh market because they do not meet the private quality standards relating to size, shape and colour; these carrots are reprocessed and sold for industry.
  - o *DminØ*: carrots with a smaller diameter than the minimum accepted by buyers (<20 mm);
  - o *DmaxØ:* carrots with a larger diameter than the maximum accepted by buyers (>40 mm);
  - o *DØ:* carrots with a diameter between 20 and 40 mm, discarded due to cosmetic issues.
- *Unfit*: carrots discarded after harvest because they are unfit for human consumption; these are further sorted into two categories:
  - o *Primary loss:* carrots that are damaged, diseased, decayed, under- or over-ripe and are discarded upon arrival at the PO warehouse.
  - o *Secondary loss*: inedible parts of carrots that are cut and discarded during the re-processing of downgraded carrots destined for industry.

These parameters are specific to the PO in this case study, as they are the result of negotiation between buyers and suppliers.

This study also attempts to evaluate the economic implications of carrot downgrading and loss. The definitions used for this purpose are.

- *Potential turnover (€/kg)*: turnover that could be gained if no private cosmetic quality standards were applied and all edible carrots were sold on the fresh market. Here, it is assumed that the additional carrots are sold at the same sales price.
- *Current turnover (€/kg)*: turnover currently gained with the application of private cosmetic quality standards.

2.3. Methodology of assessment

For the purposes of this study, a field assessment was conducted at the warehouse of the PO, to measure the streams of carrots, in terms of mass and economic value, at every stage of post-harvest operations, from the moment the harvested carrots enter the warehouse until they are sold to the fresh market or industry.

The unit of measurement used for direct quantification is the kilogram, while the unit of reference to assess the stream of carrots during processing in the PO warehouse is the plastic bulk bin that is used to process carrots. Each bin is measured, and on average their capacity is 350–400 kg. Therefore, each bin processed corresponds to one observation in the final dataset.

The method of data collection is based on several points of assessment, where streams of carrots are measured, as shown in Fig. 2. For each stream, the quantity of carrots in terms of mass (kg) and, if possible, value (sales price in €) is assessed.

During harvesting, the carrots are collected in bins (still with soil and stones). No selective harvesting occurs on the field. The carrot bins are taken into the PO warehouse and placed in cold storage. Upon receipt of an order from a retailer, the carrot processing process starts. Each bin to be processed is weighed (still dirty) and unloaded onto a platform which

Fig. 1. Classification of carrots in the three different categories: marketable as fresh (I), downgraded – edible but not marketable (II) and unfit (III).

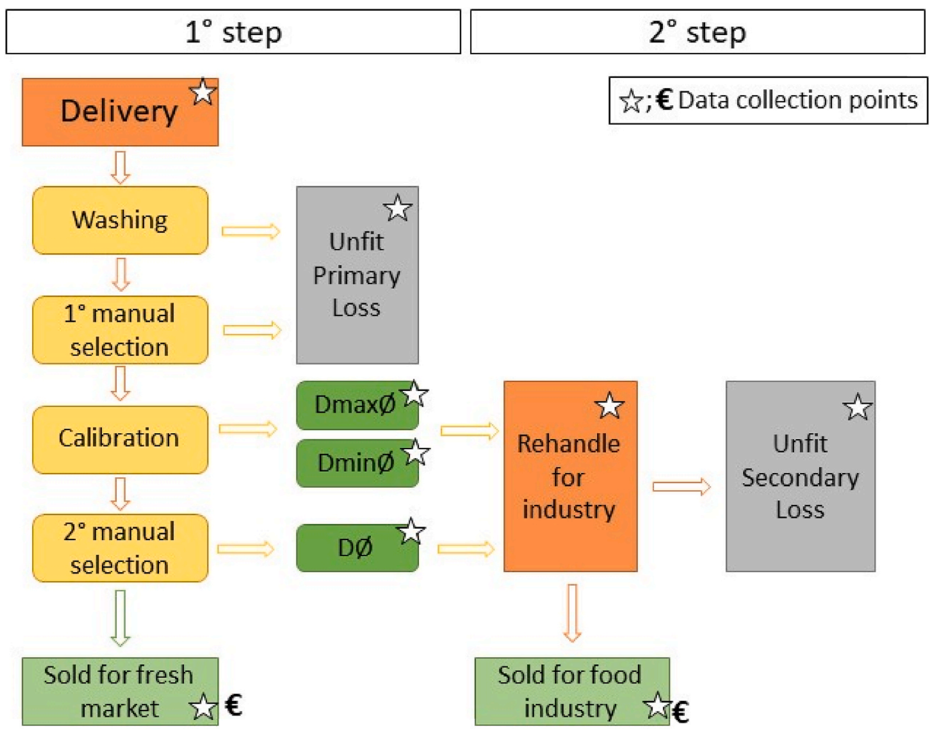

Fig. 2. Carrot processing operations in the PO warehouse. Each arrow represents the flow of the process to the next step. Each star represents a data collection point, at which the quantity (kg) is assessed for each bin processed. For quantities sold for the fresh market and the food industry, the economic value is also recorded (€).

transfers the carrots to the washing machine. Here, an initial stream leaves the process, consisting of unfit carrots (diseased or rotten), soil and stones. Unfit carrots (primary loss) and soil and stones are weighed separately. After this, the carrots go through a process of manual selection, to detect any unfit ones. The carrots then pass through the calibration machine, where they are sorted by size: carrots with a diameter between 20 and 40 mm continue in the process, while out-of-size carrots are downgraded because they are too small (DminØ in Fig. 2) or too large (DmaxØ in Fig. 2). The in-size carrots are manually re-sorted to remove any carrots with cosmetic imperfections that do not meet the private cosmetic standards imposed by buyers (mainly large retail companies); these carrots with cosmetic flaws are downgraded, meaning that they are not considered suitable to be sold as fresh products (DØ in Fig. 2). Carrots that are in-size and free from cosmetic imperfections are sold for the fresh market. They can be sold in bulk bags (average weight approximately 1100 kg), trays (1 kg, 500 g, 600 g or 750 g) or boxes (10 kg); they are packed and loaded onto trucks at the PO warehouse, to be delivered to retailers.

Downgraded carrots are re-processed, either on the same day or in the following days, to be sold to the food industry; this requires a process during which imperfections, black spots and splits are removed. Also in this case, the carrots are loaded onto trucks at the PO warehouse and delivered to the food industry. Meanwhile, unfit carrots are disposed of as organic waste or used for animal feed.

As a result of the data collection, for each bin assessed the quantities measured are: weight on delivery, unfit carrots (primary loss), downgraded carrots divided into DminØ, DmaxØ, and DØ, carrots sold for the fresh market, carrots re-processed for industry, carrots discarded during re-processing because unfit for human consumption (secondary loss), and carrots sold to the food industry. These secondary losses are also disposed of or used for animal feed.

The field data collection covers 18 days during the months of July, August and September 2023. The total mass of carrots sampled is 279,757 kg, which represents around 1% of the PO's total production in one season.

To weigh the bins, scales with a sensitivity of 1 kg are used; weight is measured with the help of forklifts. Meanwhile, manual scales with a sensitivity of 1 g are used for boxes; for trays, a built-in scale in the packaging machine is used. All weights recorded during the study are net of tare.

For each bin sampled at the beginning of the process, all the data at the data collection points are detected and recorded in a database built on Excel. The accuracy of the data collection is checked on a daily basis by cleaning and monitoring the dataset, also using historical data from the production years 2020, 2021 and 2022 as a benchmark.

Due to the different timing of post-harvest carrot operations at the PO warehouse, the data collection process is divided into two stages, reflected in Fig. 1.

1. Collection of data on carrots processed, from their arrival at the PO warehouse to their sale on the fresh market or downgrading;
2. Collection of data on carrots re-processed for industry, from the re-processing of downgraded carrots to their sale to industry.

The sales prices of the product are also recorded in order to support economic evaluation. Data on sales are acquired from PO records from 1st of January to 31st of August 2023. The names of the buyers are anonymised by means of a code, to prevent any sharing of market-sensitive information. However, sales to different buyers are recorded separately because the PO negotiates the price of products individually with each, and significant differences in price are possible even within the same day for a given product. In the dataset, every individual sale that occurred within the period is recorded, along with the quantity and sales price. Sales are categorised by type of buyer, to distinguish between retailers (fresh market) and industry (re-processed carrots); they are also divided by the type of carrots sold (conventional or organic) and type of packaging.

2.4. Elaborations

In total, 182 bins of carrots were sampled during the study period, corresponding to a total mass of 279,757 kg of carrots, approximately 1% of the PO's overall yearly production. Two different datasets are elaborated, reflecting the two separate stages of the carrot process in the PO. Dataset 1 focuses on the first step of data collection, from harvest to the sale of carrots for the fresh market, including the side stream of downgraded carrots; Dataset 2 focuses on the second stage of the process, from downgrading to the re-processing of carrots, until they are sold to the food industry. A Dataset 3 is also elaborated, with the sales records acquired from the PO, including the product code, name, quantity, price, value, and the anonymised customer identification number.

The datasets are composed of 136, 36 and 724 observations respectively. Table 1 describes the variables used for the elaborations.

As an initial part of the elaborations, a Sankey diagram is created to represent the streams of carrots during post-harvest operations at the PO warehouse, referring to step 1 of the data collection.

Secondly, a descriptive analysis of Dataset 1, Dataset 2 and Dataset 3 is performed. In Dataset 3, price variation during the season is analysed.

The third section concerns the analysis of the economic implications of downgrading. To this end, Dataset 1, Dataset 2 and Dataset 3 are analysed collectively.

Lastly, scenarios are modelled with various levels of acceptance of private cosmetic quality standards, with the aim of analysing the potential effect of greater acceptance of defects in carrots, in terms of the mass of carrots delivered to the fresh market or lost, and the consequent economic implications. Four different scenarios are modelled.

- Scenario 1 (S1): the mass of carrots downgraded due to excess size (DmaxØ) is decreased by 10%, reflecting a greater acceptance of carrots that are currently considered too large to be sold on the fresh market
- Scenario 2 (S2): the mass of carrots downgraded due to small size (DminØ) is decreased by 10%, reflecting a greater acceptance of carrots currently considered too small to be sold on the fresh market
- Scenario 3 (S3): the mass of in-size carrots downgraded due to cosmetic defects (DØ) is decreased by 10%, reflecting a greater acceptance of cosmetic defects in carrots to be sold on the fresh market

Table 1
Variables used in the elaborations of the article. FM = fresh market.

Numerical variables						
Variable	Description	Unit	Min	Max	Mean	Std. Dev.
Tot_kg_processed	Total quantity of carrots harvested	Kg	250.00	13470.00	1939.38	2839.96
Tot_kg_FM	Total quantity of carrots sold to FM	Kg	89.00	6475.00	1023.70	1166.94
DØtot	Total carrots downgraded	Kg	50.00	5594.00	671.88	1118.33
DØ	Carrots downgraded for cosmetic reasons	Kg	0.00	928.00	223.63	147.98
DminØ	Carrots downgraded due to small diameter	Kg	3.00	3651.00	171.13	490.33
DmaxØ	Carrots downgraded due to large diameter	Kg	0.00	3521.00	277.13	696.74
Unfit_primary loss	Carrots unfit for human consumption	Kg	10.00	3955.00	243.80	620.75
Loss	Primary loss carrots discarded	Kg	10.00	3014.00	230.50	568.75
Animal	Primary loss carrots used for animal feed	Kg	0.00	941.00	13.29	90.34
Industry_kg	Total carrots re-processed for industry	Kg	80.00	4087.00	1074.27	1073.69
Industry_worked_kg	Total carrots sold to industry after re-processing	Kg	52.00	3328.00	910.20	902.59
Industry_secondary_loss	Secondary loss from industry re-processing	Kg	10.00	863.00	164.07	191.37
Tot_kg_FM (%)	Total quantity of carrots sold to FM	%	22.53%	91.11%	59.87%	13.47%
DØtot (%)	Total carrots downgraded	%	7.85%	62.58%	32.31%	11.43%
DØ (%)	Carrots downgraded for cosmetic reasons	%	0.00%	48.14%	19.09%	11.35%
DminØ (%)	Carrots downgraded due to small diameter	%	0.43%	29.99%	4.54%	4.68%
DmaxØ (%)	Carrots downgraded due to large diameter	%	0.00%	29.49%	8.68%	6.09%
unfit_primary loss (%)	Carrots unfit for human consumption	%	1.05%	32.07%	7.82%	4.55%
Loss (%)	Primary loss carrots discarded	%	0.87%	24.44%	7.54%	4.32%
Animal (%)	Primary loss carrots used for animal feed	%	0.00%	7.63%	0.28%	0.95%
industry_worked_kg (%)	Total carrots sold to industry after re-processing	%	0.09%	0.97%	0.83%	0.09%
loss_industry (%)	Secondary loss from industry re-processing	%	0.52%	0.48%	0.17%	0.09%
€_conventional_carrots	Sale price of conventional carrots sold to FM	€/kg	0.25€/kg	1.20€/kg	0.72 €/kg	0.18€/kg
€_organic_carrots	Sale price of organic carrots sold to FM	€/kg	0.33€/kg	1.50€/kg	0.85 €/kg	0.20€/kg
€_industry	Sale price of carrots sold to industry	€/kg	0.27€/kg	0.85€/kg	0.49 €/kg	0.11€/kg

Category and dummy variables						
Variable	Description	Type	Category	Category description	Observations	%
Organic_c	Conventional carrots	Dummy	0	No	30	16.50%
	Organic carrots		1	Yes	152	83.50%

- Scenario 4 (S4): the mass of carrots downgraded is decreased by 5% for each of the three defects considered (DmaxØ; DminØ; DØ), reflecting a greater acceptance of suboptimal carrots on the fresh market.

The economic value of the resulting mass of carrots accepted for the fresh market is calculated by using the specific median price, considering variations across the season, for conventional and organic carrots sold to the fresh market, and for carrots re-processed for the food industry separately. The results are compared with the status quo.

3. Results

3.1. Descriptive analyses of the quantity of carrots processed

A total of 279,757 kg of carrots is sampled. Subtracting tare (soil and stones), the mass of carrots starting the process in the PO warehouse is 263,755 kg. Of these, in the first stage, 52.78 % are sold for the fresh market (139,223 kg), 34.64% (91,376 kg) are downgraded (DØtot), and 12.57% are primary loss (33,156 kg). Analysing the reasons for downgrading, out-of-size carrots account for 66.72% (60,963 kg of the total downgraded), of which 25.47% (corresponding to 8.82% of total carrots processed) are smaller than the minimum required diameter (DminØ) and 41.25% (14.29% of total carrots processed) are larger than the required diameter (DmaxØ). 33.28% (30,413 kg) of downgraded carrots (corresponding to 11.53% of total carrots processed) fail to meet the private cosmetic quality standards required for sale on the fresh market, even if they are the correct size, and are therefore downgraded (Fig. 3).

Fig. 4 analyses the distribution of downgrading across the observations of Dataset 1. The variables present a normal distribution. Average downgrading amounts to 32.31% and is composed of values that are generally higher than the average. Analysing the three variables that lead to downgrading (DmaxØ, DminØ and DØ): DØ has an average of 19.09%, higher than the out-of-size carrots, with a normal distribution; DmaxØ, with an average of 8.68%, has many values lower than the average; DminØ, with an average of 4.54%, presents the opposite situation. The proportion of unfit carrots (primary loss) has an average of 7.82%, and the distribution shows a shift towards lower values than the average.

The second stage focuses on the re-processing of downgraded carrots, which are sold to industry. For this elaboration, Dataset 2 is used. The quantity re-processed does not correspond to the quantity downgraded recorded in Dataset 1 because the re-processing may occur on different days. The sample to which Dataset 2 refers has a total mass of 75,199 kg of downgraded carrots. Of these, 84.73% (63,714 kg) is sold to industry, while the remainder, 15.27% (11,485 kg), is discarded as a secondary loss.

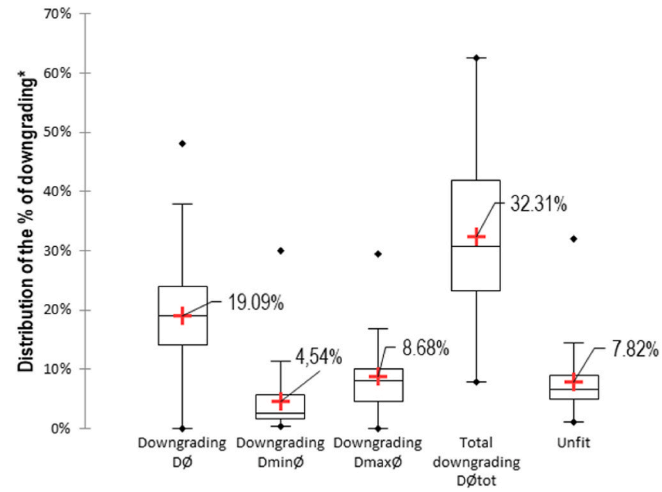

Fig. 4. Boxplot showing the distribution of downgraded and unfit carrots in the first stage of the PO process, calculated on the basis of the quantity processed in the same observation in the row. Values are expressed as percentages (%). On the Y axis, the distribution of the percentage of downgrading (calculated as mass of downgraded carrots as a proportion of the total mass of carrots processed) across observations (N = 136); on the X axis, the variable analysed: DmaxØ, DminØ, DØ, *DØtot* and unfit carrots, representing primary loss.

3.2. Descriptive analysis of the sales price of carrots

Carrot sales prices are analysed for carrots sold both to the fresh market and to the food industry (Fig. 5). The sales price of carrots sold to the fresh market varies with the week and the various buyers, depending on ongoing negotiations between the PO and retailers. Different

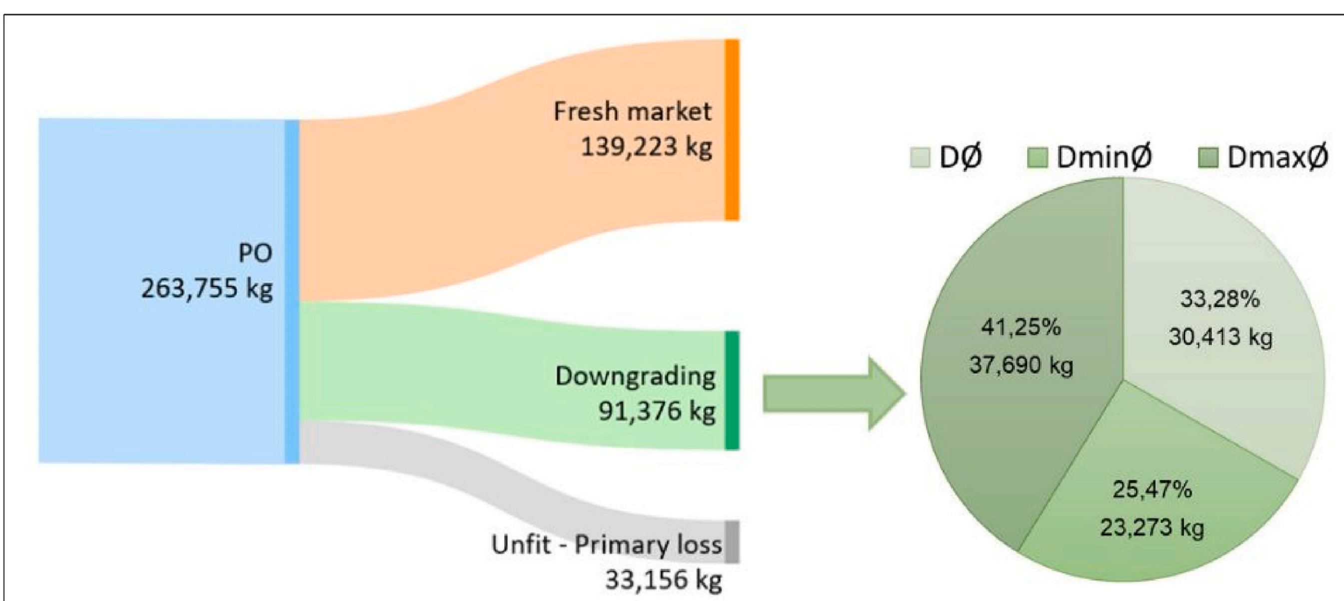

Fig. 3. Sankey diagram showing the first stage of the carrot processing in the PO, from harvesting to the selection of carrots in the warehouse for sale on the fresh market, downgraded and unfit as primary loss.

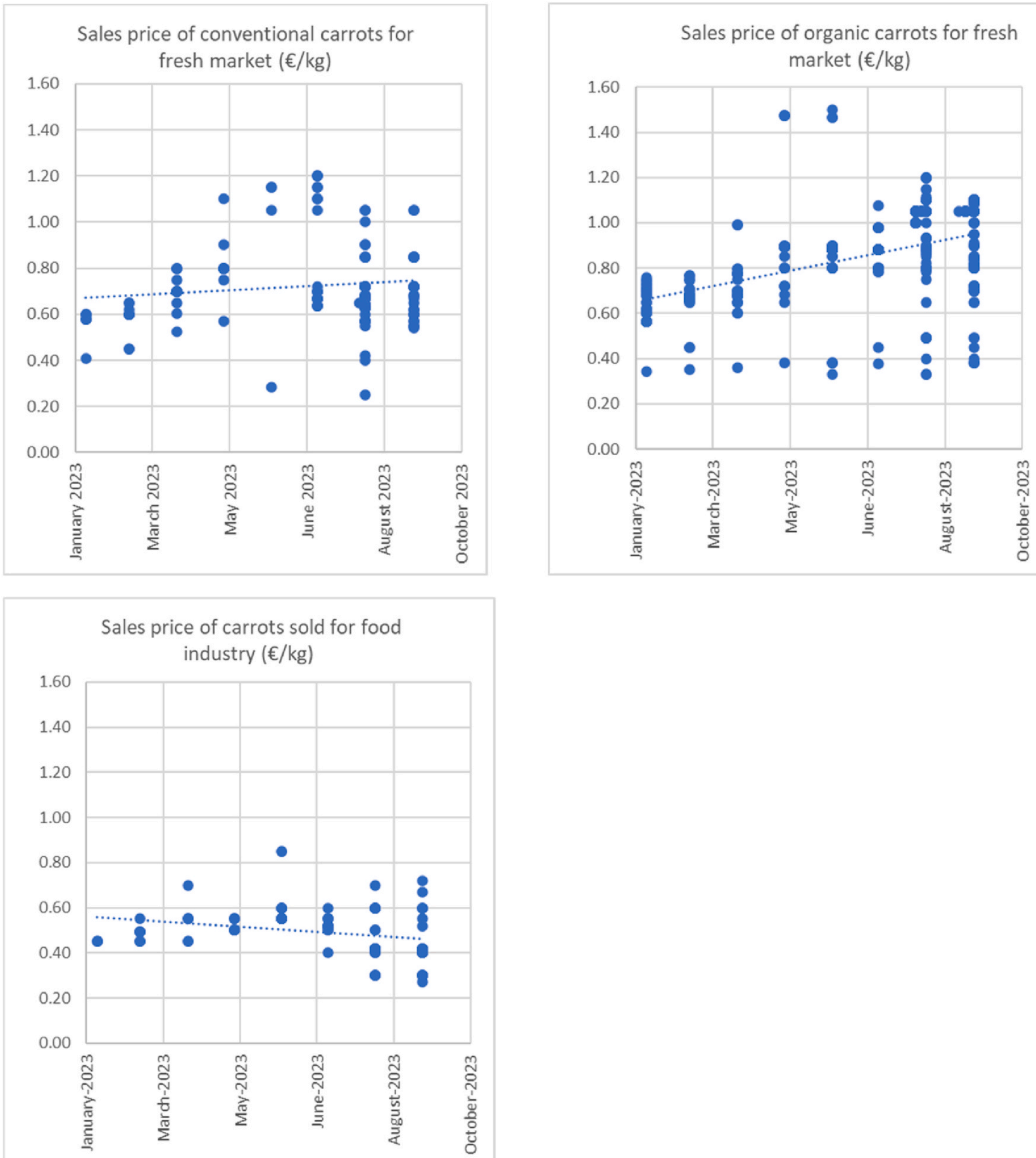

Fig. 5. Scatter plot of sales prices divided by market channel destinations (fresh market or industry). For the fresh market, the sales price is divided into conventional and organic carrots. The X axis shows the months of 2023; the Y axis shows sales prices (expressed in €/kg).

negotiations, and therefore different prices, are reported for conventional and organic carrots, with an average sales price from January 2023 to August 2023 of 0.72 €/kg and 0.85 €/kg respectively, and a median price of 0.68 €/kg and 0.86 €/kg.

Regarding the sales price for industry, this is systematically lower than the fresh market price; it also shows less fluctuation, remaining more stable throughout the season. Here, conventional and organic carrots are sold at the same price, but the sales price may vary between buyers (various food industry companies). The average sales price from January to August 2023 is 0.49 €/kg, while the median price is 0.50 €/kg.

Table 2 focuses on the variation in sales price during the months of the field data collection. In particular, between June and August 2023 the sales price for conventional carrots averages 0.72 €/kg, with a lower standard deviation (0.18 €/kg) and a median of 0.68 €/kg. The price of organic carrots is higher; the average sales price is 0.85 €/kg, with a standard deviation of 0.20 €/kg and a median of 1.00 €/kg, showing a higher fluctuation at the higher end.

The industry sales price is more stable over the season, with small fluctuations compared to the price on the fresh market: the average is 0.49 €/kg, with a standard deviation of 0.11 €/kg and a median of 0.42 €/kg during the months of the data collection.

3.3. *Economic implications*

The economic implications of the application of private cosmetic quality standards by retailers are analysed on the basis of Dataset 1, as shown in Fig. 6, comparing the current turnover (turnover currently gained with the application of such quality standards) with the potential turnover. Potential turnover is calculated by considering the mass of carrots that could potentially be sold on the fresh market if no private cosmetic quality standards were applied, and represents the turnover

Table 2
Sales price of carrots during the months of the data collection, divided by destination (fresh market or industry) and type of carrots (conventional or organic). All prices are in €/kg. FM = fresh market.

	Mean	Median	Stan dev	Min	Max
	€/kg	€/kg	€/kg.	€/kg	€/kg
Sales price for conventional carrots sold to FM	**0.72**	**0.68**	**0.18**	**0.25**	**1.20**
June 2023	0.87	0.70	0.24	0.64	1.20
July 2023	0.68	0.67	0.15	0.25	1.05
August 2023	0.72	0.72	0.14	0.54	1.05
Sales price for organic carrots sold to FM	**0.85**	**1.00**	**0.20**	**0.33**	**1.50**
June 2023	0.86	0.88	0.13	0.38	1.08
July 2023	0.94	1.00	0.18	0.33	1.20
August 2023	0.91	1.00	0.18	0.38	1.10
Sales price for carrots sold to food industry	**0.49**	**0.42**	**0.11**	**0.27**	**0.85**
June 2023	0.52	0.52	0.04	0.40	0.60
July 2023	0.45	0.42	0.10	0.30	0.70
August 2023	0.44	0.42	0.12	0.27	0.72

that could be achieved if no such standards were applied. Starting with the total carrots processed (263,755 kg), the primary loss (12.57%) is discarded as unfit for human consumption. Potential turnover is calculated as the gross revenue from carrots sold to the fresh market, plus the gross revenue that could come from downgraded carrots, if they were also sold to the fresh market. The median sales price recorded during the season is used for this purpose. The potential turnover, corresponding to 87.43% of carrots processed (currently sold to the fresh market, plus downgrading), amounts to 193,873.08 €. However, due to private cosmetic quality standards, only 52.78% of total carrots processed is sold to the fresh market, corresponding to a turnover of 118,599.32 €, 61.17% of potential turnover. The remaining carrots are downgraded and re-processed for the food industry. In this process, a secondary loss equivalent to 15.27% of the re-processed mass occurs, therefore 84.73% of the total mass of re-processed carrots is sold to the food industry. Considering the median price at which carrots are sold for industry, this process generates an additional turnover of 32,517.43 €. In the current situation, total turnover is 151.116,75 € for 263,755 kg of carrots processed.

The economic loss linked to the application of private cosmetic quality standards amounts to 42,756.33 € (22.05% of potential turnover), and is due to (i) the secondary loss that occurs during the re-processing of carrots, and (ii) the difference between the sales prices for the fresh market and industry. This economic loss is directly dependant on the private cosmetic quality standards imposed by buyers, and does not take into account the additional cost that the PO must bear to re-process downgraded carrots and prepare them for sale to industry.

In this calculation, we assume that the sales price remains the same for all carrots sold on the fresh market.

For a more in-depth study of the impact of private cosmetic quality standards, the mass of carrots sold to the fresh market and the associated economic loss are calculated for the four scenarios outlined in the methodology, and compared with the status quo scenario described above. All calculations are made on the basis of a total mass of carrots of 263,755 kg.

3.3.1. Scenario 1 (S1)

Scenario 1 (S1) reflects a greater acceptance of carrots that are currently considered too large to be sold on the fresh market, with a decrease of 10% of DmaxØ. In this situation, the turnover increases to 152, 657, 80 €, 1.02% higher than current turnover. At the same time, economic losses decrease by 3.60%. In terms of the mass of carrots, secondary losses (in kg) decrease by 4.12%.

3.3.2. Scenario 2 (S2)

Scenario 2 (S2) reflects a greater acceptance of carrots that are currently considered too small to be sold on the fresh market, with a

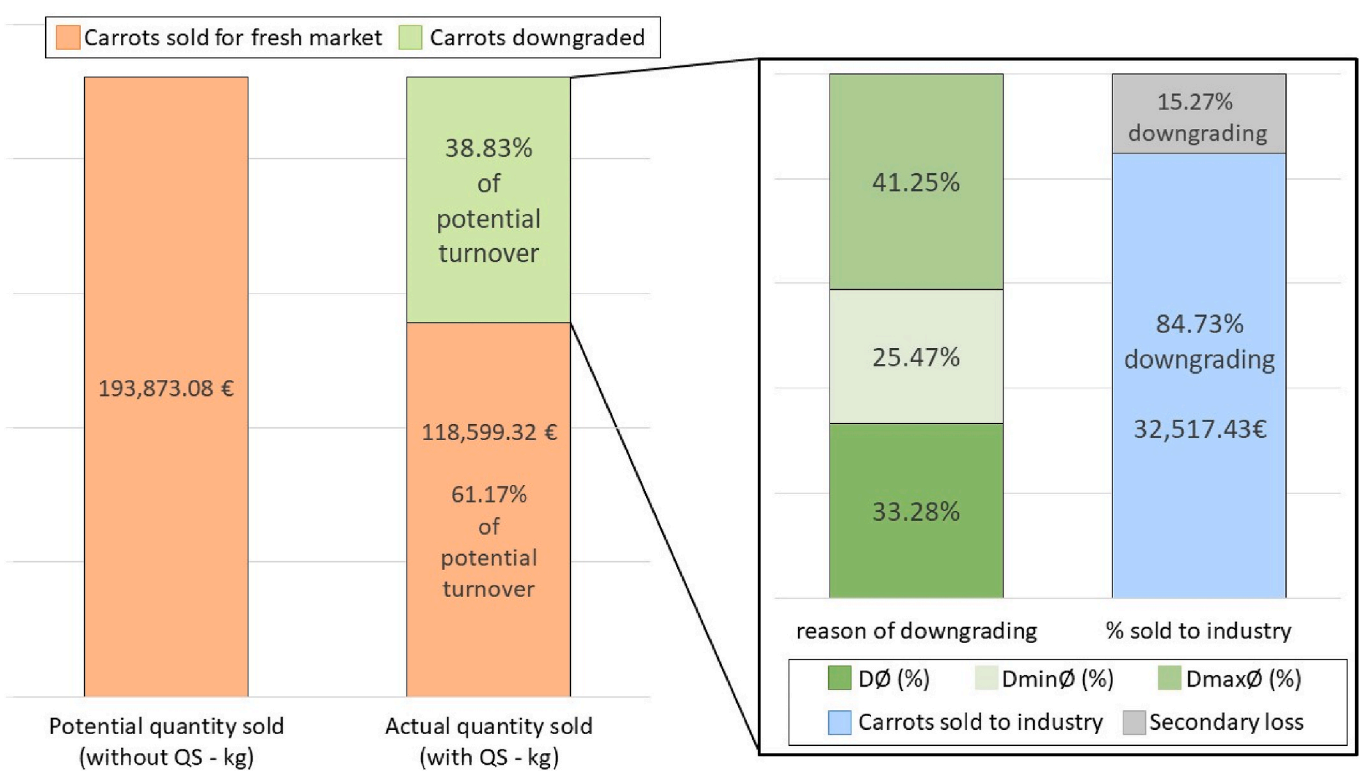

Fig. 6. Economic implications of private cosmetic quality standards on turnover. Potential turnover is compared to the current figure, where private cosmetic quality standards are applied.

decrease of 10% of DminØ. Also in this scenario, the quantity of carrots sold for the fresh market increases (+1.67%), and economic losses decrease (−2.04%); however, even if the quantity sold is higher, the turnover does not grow as much as in S1 (+0.58%) since smaller carrots weigh less and carrots are sold by the kilo. Secondary losses decrease by 2.55%.

3.3.3. Scenario 3 (S3)

Scenario 3 (S3) hypothesises a greater acceptance of carrots that are currently downgraded due to cosmetic defects (DØ), with a decrease of 10% of DØ. As a result, total turnover increases by 1.23% compared to the current situation, and the turnover from the fresh market increases by 2.48%. Secondary losses decrease by 3.33% in terms of mass, while economic losses decrease by 4.35%.

3.3.4. Scenario 4 (S4)

In Scenario 4 (S4), a 5% decrease in downgrading is modelled for all three reasons (DminØ; DmaxØ; DØ). In this scenario, turnover increases by 1.41%, while economic losses and secondary losses (kg) decrease by 5%.

Table 3 compares the four scenarios with the current situation. In the table, S1 corresponds to a 10% decrease in DmaxØ-downgraded carrots, increasing the quantity sold for the fresh market; S2 to a 10% decrease in DminØ-downgraded carrots and an increased quantity to be sold for the fresh market; S3 to a 10% decrease in DØ -downgraded carrots and increased quantity to be sold for the fresh market; and S4 is a 5% decrease in downgrading and the corresponding increase in the quantity sold for the fresh market. In each scenario, the first column shows data calculated, while the second column shows the difference compared to the current situation, expressed as a percentage (%). The highest overall turnover is shown in S4, with an increase of 1.41% compared with current turnover. It also shows the lowest losses in terms of mass following the hypothesised greater acceptance of all types of defects on the fresh market.

However, when a greater acceptance is hypothesised for only one defect (S1, S2 and S3), Scenario S2 shows the least change in terms of mass and value. In S3, the turnover is higher by 1.23% compared to the status quo, while in S1 (DmaxØ) turnover increases by 1.02%.

4. - Discussion

This study provides a direct assessment of the impact of private cosmetic quality standards imposed by retailers in the fruit and vegetable value chain. It measures the quantity of downgrading and loss in the carrot value chain at the post-harvest phase. There is an ongoing discussion on whether cosmetic quality standards affect the extent of food losses in the fruit and vegetable sector, as suggested by initial evidence provided for other products (Fernandez-Zamudio et al., 2020; Opara et al., 2021; Commons, 2017; McKenzie et al., 2017; Tansuchat et al., 2023; Willersinn et al., 2015; Hartikainen et al., 2017). In this case, we measured and weighed the streams of carrots at a PO warehouse, where the carrots are processed after harvesting, prepared, and sold to buyers.

One key fact is that 12.6% of carrots processed at the PO are discarded because they are deemed unsuitable for human consumption. This result is in line with the losses of up to 9% recorded by Schneider et al. (2019) for potatoes, although in that case the primary losses were measured in the field, while in this study the selection of carrots only occurs at the PO warehouse. Fig. 4 suggests that the data is relatively stable across the 136 observations collected, even though the 2023 season was fairly challenging in the study area due to weather conditions. Such primary losses can hardly be prevented, but they can be used as inputs for other processes (Papargyropoulou et al., 2014), for example the production of animal feed and biogas (de Oliveira et al., 2021).

Focusing on the role of private cosmetic quality standards, 34.64% of the carrots processed are not considered suitable for the fresh market because they fail to meet the standards, and are therefore downgraded. This figure is in line with available data in the literature for carrots (FAO, 2021), potatoes, onions, and apples (Porter et al., 2018); while it seems lower when compared with tomatoes (McKenzie et al., 2017). More specifically, our results fall within the range of carrot loss estimated by FAO (2021), which suggested that between 25% and 30% of carrots are lost before retailing due to physical or cosmetic defects. However, FAO data are obtained through indirect measurement (Stuart, 2009).

The main reasons for downgrading are size (25.47% too small and 41.25% too large, in terms of mass) and cosmetic issues (33.28% of mass). In all these cases, carrots are perfectly edible from a food safety perspective; they merely lack the “right appearance” to be accepted at retail. The downgraded carrots are not lost, but re-processed within the PO, prepared for further industrial processing and sold to industry at a lower price. The food industry is an important marketing channel for POs operating in the fruit and vegetable sector; it is considered more stable than the fresh market in terms of price and demand, albeit less remunerative (Pietrangeli et al., 2023). However, during the re-processing of carrots, a secondary loss occurs, larger than expected in terms of quantity. Following the food hierarchy procedure (Papargyropoulou et al., 2014), this secondary loss is mostly used for animal feed or disposed of as waste. Another possible destination is biogas production, although this was not the case in our study because

Table 3
Comparison of the four scenarios compared with the current situation; FM = fresh market.

Total carrots processed and ready to be sold - without primary loss (kg)									263,755
Potential quantity sold for FM (kg)									230,599
Potential turnover (€)									193,873.08 €
	Current situation	S1		S2		S3		S4	
Total turnover (€)	**151,116.75 €**	**152,657.80 €**	**1.02%**	**151,989.99 €**	**0.58%**	**152,978.10 €**	**1.23%**	**153,254.57 €**	**1.41%**
Qty sold to FM (kg)	139,223	142,992	2.71%	141,550	1.67%	142,264	2.18%	143,792	3.28%
Turnover from FM(€)	**118,599.32 €**	**121,481.61 €**	**2.43%**	**120,300.76 €**	**1.43%**	**121,542.96 €**	**2.48%**	**122,363.01 €**	**3.17%**
Qty carrots downgraded (kg)	91,376	87,607	−4.12%	89,048	−2.55%	88,334	−3.33%	86,807	−5.00%
Qty carrots re-processed and sold to industry (kg)	77,422	74,229	−4.12%	75,451	−2.55%	74,846	−3.33%	73,551	−5.00%
Turnover from industry (€)	**32,517.43 €**	**31,176.19 €**	**−4.12%**	**31,435.14 €**	**−2.55%**	**31,435.14 €**	**−3.33%**	**30,891.56 €**	**−5.00%**
Turnover loss compared with potential turnover (€)	**42,756.33 €**	**41,215.28 €**	**−3.60%**	**41,883.09 €**	**−2.04%**	**40,894.98 €**	**−4.35%**	**40,618.51 €**	**−5.00%**
Quantity of secondary loss (kg)	13,953	13,378	−4.12%	13,598	−2.55%	13,489	−3.33%	13,255	−5.00%

no facilities are available in the area.

The economic result of this situation is that the PO systematically loses part of its turnover because a significant portion of its production is diverted from the fresh market and reallocated to industry. The loss of turnover calculated in this study, for the sampled mass of carrots (around 1% of the PO's total yearly production), is 42,756.33 €, equal to 22.05% of the corresponding potential turnover. This value is higher than expected, which can probably be explained considering that 15.27% of the downgraded carrots are lost during re-processing (5.29% of the initial mass); this means not only that the downgraded carrots are sold to industry at a lower price, but also that the quantity available to be marketed for industry is lower due to losses during re-processing. As a consequence, the actual economic loss may even be higher, since products must be processed twice, with a corresponding increase in cost and effort.

However, commercial criteria vary from crop to crop and between individual buyers: everything is at the discretion of the buyer, and this results in significant variation. Depending on the buyer's preferences, it might reject a product that another buyer would accept. These criteria increase the difficulty for POs, as well as affecting logistics and production costs. This issue should be addressed through political bodies or trade regulations, such as those of the World Trade Organization.

Some studies argue that alternative marketing channels can be found for downgraded products and, more generally, products with minor defects. Some authors suggest that "ugly" carrots can be mixed with "beautiful carrots" in bunches to be sold on the fresh market (Qi et al., 2022), but many other alternative marketing channels are being developed. Online channels aiming to sell suboptimal products are growing (de Hooge et al., 2018), for example "*Belli dentro*" (https://www.belladentro.org/) in Italy. Another example is the reprocessing of 'misshapen' carrots into 'baby' carrots (Porter et al., 2018; Peterson et al., 2008). It was not the case in this particular study, but sometimes misshapen or out-of-size products are left in the field and not harvested; when this happens, creative marketing/processing/distribution of such produce could reduce avoidable on-farm loss, potentially increasing income and food availability (Delgado et al., 2021; Fernandez-Zamudio et al., 2020; Baker et al., 2019), for example through gleaning (Johnson et al., 2019; Kowalczyk et al., 2020).

But is it true that consumers would not accept misshapen and wrong-sized products if they were sold as fresh at retailers? Today's literature provides evidence that consumers might be willing to accept suboptimal products, especially if they are sold at a reduced price (de Hooge et al., 2017, 2018; Aschemann-Witzel et al., 2017; Hartmann et al., 2021; Tait et al., 2024; Tsalis et al., 2024).

Our results suggest that greater flexibility in private cosmetic quality standards could significantly reduce the loss of product and revenue at the PO/farm level. In this regard, the priority suggested by our analysis of scenarios is to increase the acceptability of wrong-sized carrots. Accepting 10% more oversized carrots could result in an increase of 1.02% in total turnover for producers, while accepting 10% more small carrots could result in an improvement of 0.58% in total turnover. Obviously, these are only theoretical scenarios, but they provide concrete evidence of the impact that a higher rate of acceptance of such products can make. Besides size, another important aspect to consider is the acceptance of carrots with small cosmetic defects. Accepting 10% more carrots that are in size, but are downgraded for cosmetic reasons, could result in an increase of 1.23% in total turnover. When greater acceptance is hypothesised on all the defects considered (S4), turnover increases by 1.41%. All these scenarios seem reasonable in the light of numerous studies suggesting that consumers are willing to buy products with minor defects, possibly sold at a lower price (Aschemann-Witzel et al., 2017; de Hooge et al., 2017).

In this study, we assume that the selling price at which buyers purchase carrots from the PO does not change when an additional volume of "lower quality" carrots is marketed. This can be considered realistic for our specific case study, whose focus is on one PO which may be able to negotiate a good price for the additional carrots sold on the fresh market, despite their small defects in size, shape and appearance. However, if we extend our scenarios to other producers, it is possible that that price of carrots on the fresh market may decrease in response to the additional quantity delivered. Of course, in this situation the gains of POs due to reduced private quality standards could also decrease. However, we can also hypothesise that if the selling price of carrots decreases, the demand for carrots increases. For example, Henneberry et al. (1999) estimates an own-price demand elasticity of −1.653 for carrots with respect to their price, suggesting that a 10% decrease in the price of carrots would lead to a 16.53% increase in demand. Substitution effects between carrots and other vegetables may also occur (Henneberry et al., 1999), with potential impact on their markets. Another aspect that merits discussion is that, if private quality standards were made more flexible for all producers, the overall quality of carrots on the market would decrease, possibly affecting the willingness of consumers to pay for purchasing this product. Previous studies on this topic suggest that such a decline in the willingness to pay may not be linear. Qi et al. (2022) report that consumers' willingness to pay for carrots decreases even if only one carrot in a bunch is suboptimal; however, up to 40% of suboptimal carrots in a bunch, this willingness to pay does not decline further. In this situation, adding a promotional message linking the purchase of suboptimal produce with the reduction of food waste can partially offset the decreased willingness to buy these products, especially if combined with messages pointing out the authenticity and naturalness of "ugly" carrots (Qi et al., 2022).

Consumer acceptance of minor cosmetic defects could be further increased by raising the level of food literacy (Palumbo et al., 2019) obtained through exposure to food and its uses over time, which has been lost in developed countries, where consumers are increasingly far away from the supply chain and its operation (Porter et al., 2018).

In this study, 83.54% of the sampled carrots are organic. This product is mostly preferred by customers with a greater awareness of sustainability; these consumers are expected to be more environmentally responsible and more flexible regarding products with less stringent aesthetic requirements.

In any case, the extent to which increased consumer willingness to buy suboptimal products can push retailers to be more flexible in their acceptance of products that fall below current private cosmetic quality standards is not clear. In a study investigating retailers' cosmetic specifications, Herzberg et al. (2022) found that these companies do not perceive themselves as responsible for the food losses that arise earlier in the supply chain due to the quality standards they demand. However, such requirements are likely to become stricter when the product is abundant, while more flexibility is common in years of short supply (Herzberg et al., 2022).

Some retailers may also be hesitant to accept suboptimal products because they are afraid of the effects on the image of other products sold in the same store or with other competitors (Aschemann-Witzel et al., 2020). It appears clear that these actors have greater bargaining power and a more powerful position on the market than POs (Herzberg et al., 2022; Pietrangeli et al., 2023); therefore the focus of research and policy should remain the producer-retailer interface and the push for greater acceptance of products with minor defects on the fresh market. The results of this study suggest that even a small change can make a significant impact on the economic results of farmers and POs.

The sales price for the fresh market is negotiated differently for conventional and organic carrots, and agreed on a weekly basis. In this study we could only partially break down the results into conventional and organic carrots, but the downgrading of organic carrots can be considered to have an even higher impact than that of conventional ones: their production cost is higher, and their organic attributes are not considered when selling to industry. The economic loss of downgrading organic carrots is therefore likely to be higher. Future research may investigate further on this; in organic production, the restricted use of fertilisers and pesticides may increase the frequency of cosmetic defects (Oosterkamp et al., 2019) possibly leading to a higher rate of downgrading for these products.

Lastly, increasing the acceptance of additional carrots sold on the fresh market could increase turnover for both POs and farmers, and at the same time reduce costs during the post-harvest phase.

This study has several limitations. The data collection was conducted during a single productive season; studying more seasons would certainly provide a more accurate assessment, especially with greater seasonal variation linked to climate change. However, field data collection is extremely demanding in terms of time and resources, so the value of the data collected remains high. Furthermore, the assessment refers to carrots, and it does not follow that other vegetables or fruit will show the same results.

5. Conclusions

Evidence on the quantity and composition of food loss at the producer-retailer interface is rather scarce in comparison with the bulk of literature available on food waste in the subsequent stages of the supply chain. In this study, we argue that private quality standards imposed by buyers generate a significant stream of suboptimal products, which producers must reallocate in other markets, with considerable economic loss and the additional burden of their further processing. By analysing a range of scenarios, we suggest that a small effort to increase acceptance of products with defects can result in a substantial increase of turnover for the PO.

For these changes to be feasible, one key point is to persuade consumers to buy imperfect products, perhaps at lower prices, which seems reasonable considering previous studies in the literature surrounding these issues. Another key point is to encourage buyers – especially retailers – to accept imperfect products as a "normal" part of the bulk of vegetables sourced from farmers. Currently, farmers and POs are the only actors bearing the cost of product imperfection, although the definition of such imperfection comes from other actors in the supply chain. Closer collaboration between producers and retailers to find appropriate and remunerative channels for imperfect products should be envisaged, especially targeting consumers who are willing to buy these products. Such collaboration would rebalance bargaining power in the supply chain and, at the same time, contribute to making supply chains more sustainable and fairer.

CRediT authorship contribution statement

R. Pietrangeli: Writing – original draft, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **C. Cicatiello:** Writing – review & editing, Validation, Supervision, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of Competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The data that has been used is confidential.

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