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Loss of beef during primary production at Swedish farms 2002–2021

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Loss of animals is a considerable waste of resources in the meat supply chain, where quantitative data are scarce but critical for guiding improvements. In this study, we used material flow analysis to track the amount of beef diverted away from the food supply chain at the farm level. The beef losses (absolute and as the proportion of yearly initial production) were estimated from data on assisted and unassisted deaths of cattle on Swedish farms obtained from the central register of bovine animals for 2002–2021 combined with official statistics on slaughter weight. The fallen animals were grouped according to age, sex and breed, to enable estimations of the lost amount of carcass weight, both in total and per animal group. The yearly loss during primary production 2017–2021 was on average 13,000 ton carcass weight, or 8.5% of the initial production. No decreasing trend for the loss rate could be determined after 2015, when the Agenda 2030 target 12.3 (Halved food waste and reduced early losses) was introduced. Female dairy breeds showed greater beef losses than dairy males or beef breeds and crossbreeds of both sexes, and their beef losses mostly occurred at 4–5years of age, thus constituting the hot spot group for lost beef. The results can serve as a base for directed reduction efforts.

KEYWORDS
food loss, food waste, meat production, dairy production, sustainable farm management, material flow analysis

1. Introduction

United Nations Agenda 2030 Sustainable Development Goal (SDG) 12.3 sets a target to "… *reduce food losses along production and supply chains, including post-harvest losses*," while the European Union (EU) Farm to Fork Strategy aims to investigate food losses during production and explore ways of preventing these (European Commission, 2020). It has previously been estimated that one-third of all food produced globally is lost or wasted along the food chain (Gustavsson et al., 2011). A more recent study estimates that the number is more likely 40% of food produced for human consumption, after adding 1.2 billion tons of lost food in initial stages of the global food supply chain (Parfitt et al., 2021a,b). The magnitude of the food loss problem has thus increased, or at least the awareness of the same. Reducing food loss and waste is one of three major strategies for keeping the food system within the planetary boundaries (Springmann et al., 2018) and tackling the challenges of food loss and sustainable food waste management is key to fulfilling obligations in the Paris Agreement (You et al., 2022). Consumption in EU countries occupies a large share of the safe operating space globally available, with food being a major contributor (Sala et al., 2020). Reducing losses of beef, which is an environmentally high-impact European food, could bring substantial improvements.

When seeking to reduce losses, it is important to know the baseline and possible causes of losses. Food loss data are currently scarce, but critical to understanding production systems

(Corrado et al., 2017; Xue et al., 2017; Hartikainen et al., 2018; Karwowska et al., 2021). In particular, there is a great need for studies on food waste in primary production, for which only limited transparent and detailed data exist (Hartikainen et al., 2018). In a review on food losses and wastage in the meat sector, one conclusion is that data are limited, despite the unfavorable environmental impact of meat and meat products (Karwowska et al., 2021).

A review by Corrado and Sala (2018) of food waste accounting along global and European food supply chains found that available data provide an overall picture on food waste generation at global and European scale but are not sufficient to support specific food waste-related interventions and monitoring of their progress over time. Those authors call for more specific data from individual stages of the supply chain and for food products or commodity groups, to allow more precise estimation and support identification of hotspots, i.e., potential targets for food waste reduction strategies.

Sweden has specific targets for reducing food losses, based on the EU requirement that member states must reduce food waste at every stage of the food chain (European Commission, 2018) and the Swedish government's environmental milestone target on reducing food losses (Government Offices of Sweden, 2020). The Swedish Board of Agriculture (SBA) is responsible for monitoring these food losses (Lindow et al., 2021), and is thus in need of quantitative data.

When performing life cycle assessment of beef and dairy products, losses during primary production should ideally be included. In a study by Moberg et al. (2019) losses were included, but partly based on a mortality rate where a loss rate had been needed, possibly due to lack of published loss rates for dairy and beef production.

Against this background, there is clearly a need for relevant, updated, transparent, and high-quality data on food loss rates, not least for the environmentally heavily impacting beef production sector, to reduce confusion and account for the losses at their right magnitude.

The aims of the present study were to determine the loss rate of beef in Swedish primary production, estimate the yearly amount of lost beef, analyze changes in these indicators over time, and gain insights into how losses differ between groups of cattle differing in age, sex, and breed, in order to guide efforts to reduce on-farm losses. For this, a material flow analysis was performed, based on official data on numbers and type of lost cattle and estimated slaughter weights of these animals.

2. Materials and methods

2.1. Methodological framework, main data source, and system boundaries

We used material flow analysis (MFA) as the methodological framework for studying flows of loss as share of total outflows of our system. MFA is widely applied in different disciplines and has, e.g., been used for tracking flows of beef in the Italian and German meat supply chains (Xue et al., 2019; Amicarelli et al., 2021) as well as used in two previous studies on losses of Swedish beef during primary production (Strid et al., 2014; Lindow and Andersson, 2022). In the present study, the outflows of beef from Swedish farms were traced to the destinations of abattoir slaughter, home slaughter or loss.

The method takes advantage of the fact that, in accordance with EU regulations on food safety monitoring (European Union, 2016), all Swedish cattle are individually registered (identified by unique numbers on yellow ear tags) in the central register of bovine animals (CDB). Swedish cattle farmers are required under regulation EC 1760/2000 (European Commission, 2000) to report all cattle movements to CDB. The CDB database, managed by the Swedish Board of Agriculture, includes information on births, fallen animals, slaughtered animals, rearing establishment, animal movements, etc. It is, however, voluntarily to report stillborn calves. The number of fallen animals is key information for calculating loss of beef during primary production. CDB was used as the main data source of the study, providing data on lost, slaughtered and home slaughtered animals.

The system boundaries were set to include beef losses occurring on Swedish farms, during transport and during live inspection before slaughter (*ante mortem* inspection), i.e., all loss flows registered in the CDB database. Stillborn calves were included to the extent they were voluntarily reported in the database. Condemned carcasses at slaughter and the fate of exported animals were outside the system boundaries. Beef loss flows were related to initial production, which was set to the sum of slaughtered (abattoir-slaughtered and home-slaughtered) animals and lost animals.

The methodological workflow is illustrated in Figure 1, whereas a more detailed description of the method is described in sections 2.2–2.6.

2.2. Categorization of animals into groups

The animals were first structured into groups, as broadly presented in Table 1 and described in more detail in the Electronic Supplementary material (gray tab). All age categories are presented in Table A1 (Appendix).

2.3. Data on number of lost and slaughtered animals

Data on the numbers of fallen animals (unassisted death or euthanization), voluntarily reported stillborn calves, home-slaughtered animals, and abattoir-slaughtered animals between the years 1998 and 2021 were retrieved from the CDB database (SBA, 2022b) and organized separately in Microsoft Excel 2016. For details on numbers of lost and slaughtered heads, please refer to the Electronic Supplementary material (orange tabs). As an example, an overview of the dairy breed losses during the last 5 years of the study period is also presented in Table A1.

2.4. Modeling of lost and home-slaughtered individual carcass weights

For animals slaughtered at abattoir, actual carcass weight (skinned, gutted, and beheaded weight, i.e., meat with bones) is recorded in the official slaughter database *Regina*, but for lost animals carcass weights

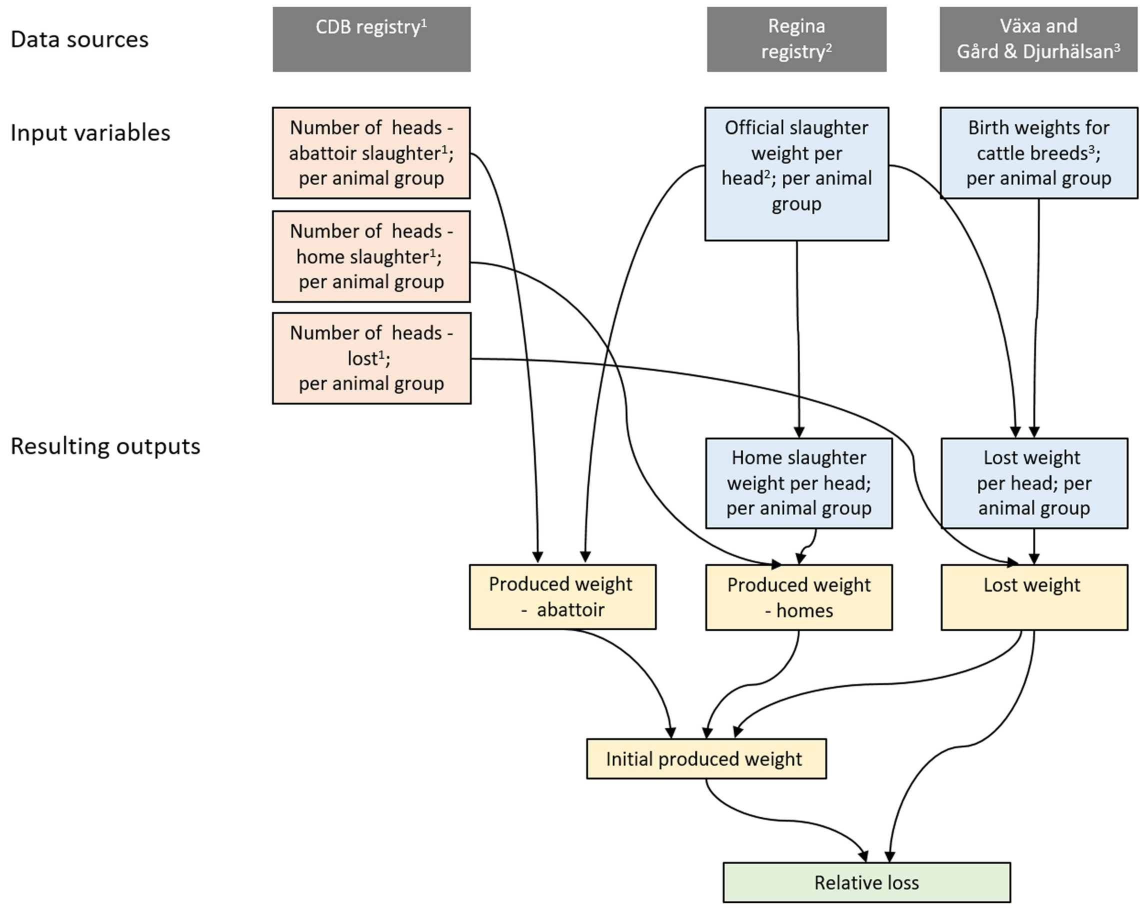

FIGURE 1
Illustration of the methodological workflow. Input variables were retrieved from CDB[1], Regina[2], Växa[3], Gård & Djurhälsan[3] and organized into defined animal groups categorized by age, sex and breed. Calculations were done for each animal group separately as well as in total.

TABLE 1 Overview of cattle groups in study.

	Dairy breeds [Breeds* 1–6, 37, 38, 40, 41]	Beef breeds [Breeds 8–36, 39, 42–55]	Crossbreeds [Breed 99]
Females	22 age groups [stillborn, 0–1, 1–2 … >120 months]	Same age groups as for dairy breeds	Same age groups as for dairy breeds
Males	22 age groups [stillborn, 0–1, 1–2 … >120 months]	Same age groups as for dairy breeds	Same age groups as for dairy breeds

*Breed numbers are listed in the Electronic Supplementary material.

had to be modeled from known facts. We used data from CDB on age group, breed group, and sex of lost animals to model lost individual carcass weights, based on the key assumption that lost animals weigh the same as their slaughtered counterparts (see Eq. 1).

$$\text{CW of lost animal}_{absy} = \text{CW of abattoir slaughtered animal}_{absy} \quad (1)$$

where CW = carcass weight, a = age, b = breed group, s = sex and y = year interval of data.

The average registered carcass weights for abattoir slaughtered animals for the respective age, sex, and breed groups in the years 2000, 2005, 2010, 2015, 2020, and 2021 were retrieved from the *Regina* database, thereby updating values at least at the start of each five-year period. The data were quality controlled and where values were obviously disproportionate or based on only a few animals, the value was replaced with a data gap. For animal groups lacking data (such as slaughtered calves aged 0–1 months) or assigned a gap from the data quality control, carcass weights were calculated separately. For calves, linear interpolation between breed-specific birth weights from statistics (Växa Sverige, 2020; Gård och Djurhälsan, 2022) with an estimated slaughter yield of 40%, and the first reasonable slaughter weight from *Regina* was used. For older cattle, mean values of slaughter weight were created from data of all years instead of a single year. Average birthweights, slaughter weights and interpolated values are specified in the Electronic Supplementary material (blue tabs).

Carcass weights of home-slaughtered animals were calculated with the same procedure, i.e., assuming they had the same carcass weight as their abattoir-slaughtered peers in the corresponding age/sex/breed group. Slaughter weight and carcass weight are used as synonyms throughout the study.

2.5. Calculation of absolute and relative beef losses

To calculate annual beef losses per animal group, estimated individual carcass weight per group was multiplied by the number of lost heads in that group. The grand total amount of lost beef (with bones) per year in absolute terms was then obtained by summarizing the values for all animal groups. In all calculations, stillborns were included as 50/50% males and females, except when scrutinizing the distribution of lost heads on different animal groups, where stillborns were excluded.

Relative beef losses (loss rates) were calculated with a "share of total outflow" perspective, also referred to as "share of initial production." The total outflow or initial production was defined as the sum of all animals' weights, i.e., the weight of abattoir-slaughtered, home-slaughtered and lost animals.

The relative losses were thus expressed as lost amount of carcass weight compared to initial production of carcass weight (Eq. 2):

$$\text{Relative loss of beef} = \text{Lost beef} / \text{Initial production of beef} \quad (2)$$

For details of the calculations on absolute and relative losses, see Electronic Supplementary material (yellow and green tabs).

Many results were presented as the average over the five-year period 2017–2021, as we wanted to highlight the conditions in general during recent years, thus avoiding effects of single years and too old data.

2.6. Statistical methods and trends over time

The aim of the statistical analysis was to support the study with additional insights, especially with trends over time and with identification of possible significant effects of breed and sex on the losses. Possible trends over time in relative beef losses were investigated using the Mann-Kendall test, which is often employed in environmental statistics, as implemented in the R package 'trend' (Pohlert, 2020). In the study of relative losses, comparing breeds and sex, respectively, linear models were applied (with Tukey's method for multiple comparisons). When investigating possible relationships between the time series, cross-correlation functions were used.

3. Results and discussion

3.1. Absolute and relative Swedish beef losses

Produced and lost beef in absolute terms as well as lost beef as a share of initial production (loss rate) for the years 1998–2021 are presented in Table 2. The results for the first 4 years appeared to be unreliable and were therefore excluded from further analysis. Absolute beef losses ranged from 11.8 kt (1000 metric tonnes) in 2003 to 14.4 kt in 2008 and 2009, while relative losses ranged from 7.6% in 2002 to 9.9% in 2008.

Mean yearly loss for the last 5-year period was 13.0 (SD = 0.5) kt, corresponding to 8.5 (SD = 0.4) % of initial production. A graphical abstract illustrating this result can be found in the Supplementary material. When instead calculated as proportion of official beef production (abattoir-slaughter), 9.5 (SD = 0.4) % of carcass weight was lost. Mean yearly number of lost animals between 2017 and 2021 was 84,000 (SD = 4,900), of which 21,000 (SD = 1,200) were stillborn or died before the mandatory registration at day 20 after birth. The vast majority of animals died on-farm, but some died during transport to slaughter or were rejected during live inspection at the abattoir (Lindow and Andersson, 2022). The numbers of stillborns are voluntary to report, which indicates that there could be a number of stillborns never reported, thus making the figure of lost heads possibly underestimated. Since stillborns have a low carcass weight, the possible underestimation would only have a minor impact on the lost amounts of beef.

3.2. Losses for different breed groups and changes over time

The results for different breed groups, which can be taken as indicators for the respective production system, showed that beef loss rates for dairy breeds were about twice as high as for the other two groups (see Figure 2). The dairy breeds had a 5-year average loss rate (2017–2021) of 11.7 (SD = 0.4) %, while those for beef breeds and crossbreeds were 5.6 (SD = 0.7) and 5.2 (SD = 0.5) %, respectively. The dairy loss rate was found to be significantly higher ($p < 0.001$) than either of the other two loss rates, whereas the loss rate for beef breeds was not significantly higher than that for crossbreeds ($p = 0.44$). Beef breeds and crossbreeds showed very similar loss patterns in terms of loss rates and how these varied over time and could thus from a loss perspective be seen as representing the same production system.

Absolute losses of beef from dairy breeds were 9,000 (SD = 0.3) ton/year, whereas beef breeds and crossbreeds together lost 4,000 (SD = 0.5) ton/year (5-year average for 2017–2021).

For the whole study period between 2002 and 2021, there was an increasing trend in relative losses among dairy cattle ($p = 0.017$), but not for the other breeds or when viewing all cattle together (Figure 2). Despite the United Nations' SDG 12.3 being adopted in 2015, the increasing trend ($p = 0.024$) in beef losses among dairy breeds persisted (2015–2021) and there was no decreasing trend for all cattle. There is thus unfortunately no sign that the Swedish dairy and beef primary production sector is on track to reach SDG 12.3 (halved food waste and reduced food losses along production chains). More efforts are needed, particularly to gain insights into root causes of lost animals and the effectiveness of potential prevention strategies.

The beef loss rate of the total cattle population did not increase in the study period, despite the increasing loss rate of the dairy breeds, owing to demographic changes over time. The proportion of breeds with lower loss rates (beef and crossbreeds) in the cattle population increased from 30% in 2002 to 40% in 2021 (SBA, 2022c), thereby counteracting the increased beef loss rate from the dairy breeds. From a national perspective, increasing the share of beef breeds at the expense of dairy breeds can thus be a mitigation strategy for reduced meat losses.

All breed groups showed similar relative beef loss patterns, indicating that they may be influenced by a common external factor. We examined cross-correlations between the time series and found the maximum correlation at a time lag of zero, so statistically speaking there was no delay in time between the quantities. Thus, their overall

TABLE 2 Recorded amount (1,000 ton, kt) of abattoir-slaughter in Sweden in the years 1998 to 2021, estimated amount of abattoir-slaughter (based on no. of heads and weight categories in study), home-slaughter, and lost beef per year, and losses as a proportion (%) of initial production.

	Official statistics	Calculated in present study			
Year	Abattoir slaughter (kt)	Abattoir slaughter (kt)	Home slaughter (kt)	Lost carcass-weight (kt)	Beef losses. % of initial production
1998*	143	0	0.1	0.2	62.5
1999*	144	125	0.2	0.2	0.2
2000*	150	144	0.4	0.5	0.4
2001*	143	137	3.0	4.8	3.3
2002	146	141	5.2	12.0	7.6
2003	140	137	4.8	11.8	7.7
2004	142	139	4.7	12.1	7.7
2005	136	135	5.0	13.6	8.8
2006	137	135	5.1	14.2	9.2
2007	134	131	4.6	13.4	9.0
2008	129	126	4.9	14.4	9.9
2009	140	135	5.2	14.4	9.3
2010	138	137	4.8	14.3	9.1
2011	138	139	4.7	13.5	8.6
2012	125	126	4.5	12.8	8.9
2013	126	126	4.8	13.1	9.1
2014	132	131	4.5	13.0	8.8
2015	133	132	4.6	12.7	8.5
2016	131	128	4.7	13.0	9.0
2017	132	127	4.5	12.8	8.9
2018	137	133	4.9	13.7	9.0
2019	140	136	4.7	13.1	8.5
2020	141	140	4.8	12.5	7.9
2021	136	135	4.5	12.7	8.4

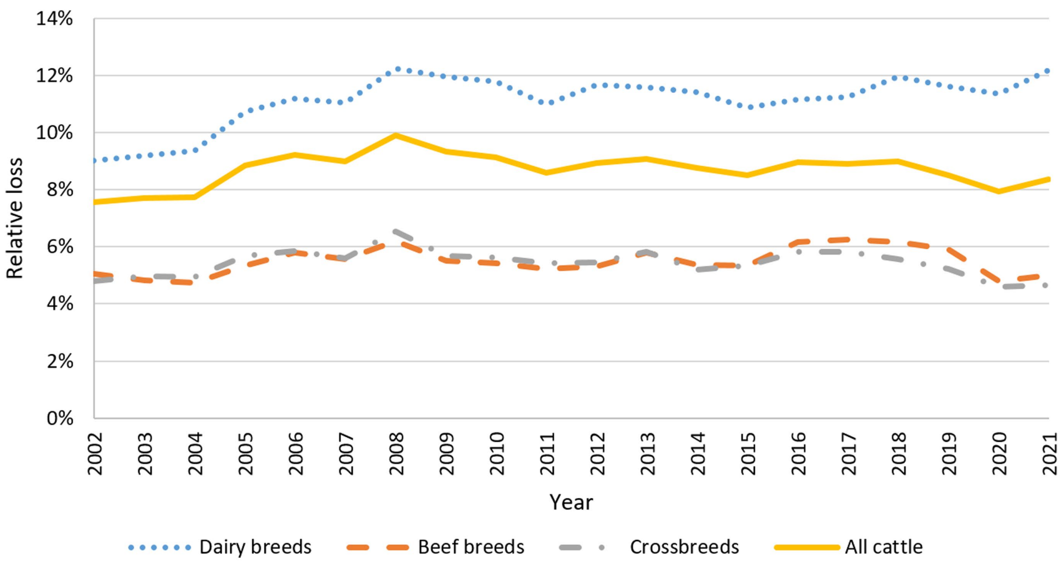

FIGURE 2
Lost carcass weight between 2002 and 2021 in relation to initially produced carcass weight for dairy, beef, and cross- breeds, and for all cattle in Swedish primary production.

changes (variation in loss rate from year to year) may be the result of some external driver. Identifying this driver, which possibly influences the magnitude of beef losses, is crucial for understanding the root causes of losses and designing mitigation strategies.

3.3. Losses for different sexes

Relative beef losses for the different breed groups were further divided by sex. For all breed groups and considering annual differences during the period 2002–2021, females had statistically significantly higher loss rates than males ($p < 0.001$, using paired samples). Figure 3 visualizes differences in loss rates (averages of the last five-year period 2017–2021) for the two sexes, for the three breed groups, respectively.

Figure 4A visualizes how the lost beef is distributed among the different breed groups and their sexes, where females together contributed to 76% of beef losses. Figure 4B visualizes how the loss of liveborn animals is distributed, where females together reach 62%. The lost females were not only more numerous, but also generally heavier as many of them got lost during adulthood, leading to their dominance of lost meat. Males were mainly lost at younger ages before reaching their full weight.

The reasons behind the higher loss rates for female cattle than males (Figure 3) could be their longer planned life span, as the median age group for slaughter was 36–48 months, compared to 18–21 months for males. Higher age would increase the possibility of age-related illness and the incidence of events that can lead to losses. There may also be sex-related risk factors, with female events

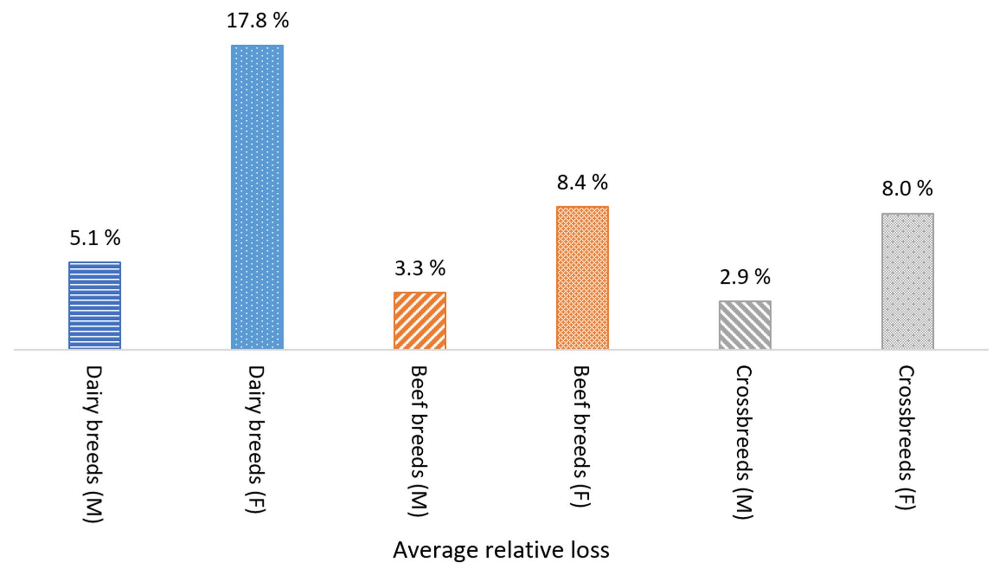

FIGURE 3
Relative beef losses (% of initial production; average for 2017–2021) for dairy breeds, beef breeds and crossbreeds, for males (M) and females (F) respectively.

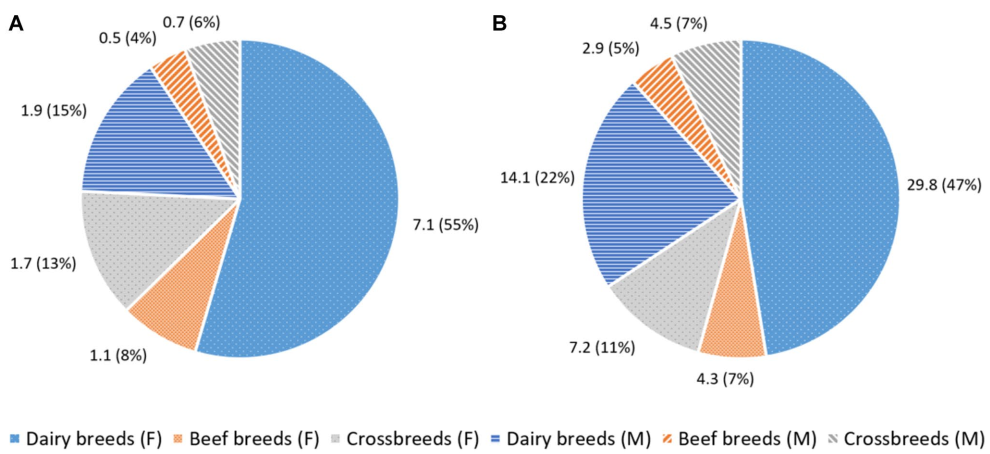

FIGURE 4
(A) Distribution of lost carcass weight, in 1000 tons (and %), and **(B)** distribution of lost liveborn heads, in 1000 heads (and %), for the studied breed groups for males (M) and females (F), respectively. Average for 2017–2021.

such as parturition or lactation-related infections possibly leading to greater beef losses than typical male events. Several risk factors for culling of individual cows have been identified, such as high parity (many births), Holstein breed, longer calving intervals, calving difficulties or twin births and health disorders (Rajala-Schultz and Gröhn, 1999; Weller and Ezra, 2015; Bieber et al., 2019; Gussmann et al., 2019; Rilanto et al., 2020), potentially contributing to the higher loss prevalence among females (Figure 4B). Acknowledgement of these risk factors would be beneficial in mitigation strategies for reduced beef losses, as many regard specifically females, which is the subgroup with highest losses.

3.4. Losses for different age groups

For a better overview when studying losses in relation to age, the many age groups in the raw data and early calculations were aggregated into yearly cohorts. The two youngest groups (0–1 and 1–2 years) contributed most to lost amounts of beef (Figure 5). Within these two age groups, male dairy calves contributed most and could thus be a target group for loss reduction measures. The voluntarily reported stillborns did not constitute a large loss. The high losses of male dairy calves might be due to euthanization of unwanted males or to illness and accidents (Graunke et al., 2011; Hessle and Jamieson, 2020; Webb et al., 2023). Losses in absolute tons were successively lower for each additional life year up to the aggregated '10 years and older' group, except for the small stillborn group and the cohort 4–5 year, which had higher losses than the 3-4-year cohort (Figure 5).

Above 2 years of age, the pattern changed drastically, and losses derived mainly from female dairy breeds, while losses from all types of males were much lower. A possible explanation for low losses of males aged above 2 years is that they are largely eradicated from the population, either through slaughter or loss at young age. Female dairy breeds dominated beef losses up to the '10 years and older' group, where female beef breeds and crossbreeds took over, possibly reflecting a strategy of more actively replacing dairy breeds at high age, thereby saving the meat, whereas female beef breeds might be kept on for longer.

3.5. Hotspots for losses and suggested solutions

On assessing meat losses for the six animal groups based on breed group and sex, female dairy breeds emerged as a hotspot for losses followed by male dairy breeds, whereas male beef breeds contributed least to lost amount of meat (Figure 4A). This was most likely a result of demographics in the Swedish cattle population, with 51% dairy breeds, 31% crossbreeds, and 18% beef breeds (SBA, 2022a; as approximated by the share of slaughtered animals), in combination with different production targets for males (meat), suckler females (offspring), and dairy females (milk). Beef losses for females of dairy breeds peaked during their fifth life year, where this cohort alone contributed to 9.3% of total Swedish beef losses, whereas beef losses for male dairy breeds mainly occurred during their two first life years (Figure 5). To avoid losses, better care of dairy cows and dairy male calves seem necessary. In addition to solutions that seek to avoid losses, valorization of losses could also be of interest. Rescuing carcasses that could be brought into the food system is an opportunity that should not be overlooked. This may need strategies for how, e.g., emergency slaughter can become a natural part of the beef supply chain.

In dairy systems, milk production is the primary focus and is usually promoted over meat production (Bergeå et al., 2016; Webb et al., 2023). Increasing cow longevity can bring both environmental and economic benefits, as the rearing costs can be paid back with additional lactations (Grandl et al., 2019). However, this carries a risk

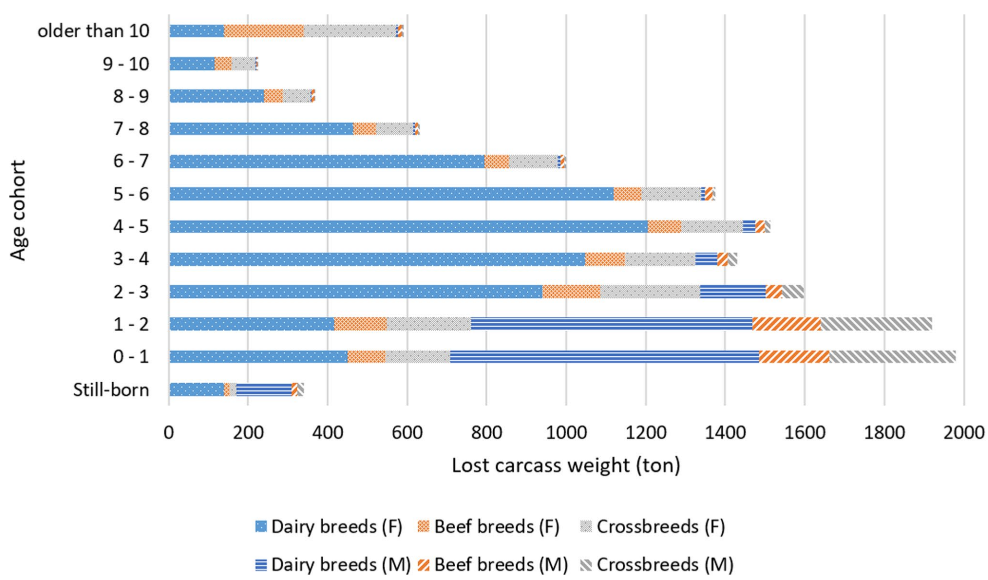

FIGURE 5
Calculated lost carcass weight (ton) per breed group, sex, and age cohort in Swedish primary production. Average for 2017–2021.

of losing the meat of that individual cow, since the risk of most production diseases increases with parity (Alvåsen et al., 2012; Lean et al., 2022), while other causes of death also can arise. When deciding on sending a cow to slaughter, it is thus important to consider both expected milk production and the risk of losing the carcass to waste. Better support tools that give reliable estimates of the risk of an individual animal becoming unfit for slaughter could facilitate this type of decision.

3.6. Comparison with retail food waste

Compared with losses of Swedish beef in retail stores, which are around 2% of total sold and wasted volumes (Eriksson, 2015), the on-farm losses of 8.5% are remarkable. However, the challenges facing farmers to reduce the losses are most likely more complicated than the challenges facing retailers, who need to, e.g., forecast sales volumes and keep packaging material undamaged.

3.7. Comparison with other climate mitigation options

If the carbon footprint of losses were evaluated as the farm gate footprint of beef with data from, e.g., Hietala et al. (2021) of 19.5 kg CO_2e/kg carcass weight for dairy breeds and 33.6 kg CO_2e/kg carcass weight for beef breeds multiplied by the amount of lost beef for these two breed groups (9,000 tons and 4,000 tons, respectively; see section 3.2), overall beef losses would have caused approximately 310,000 tons of CO_2e per year. However, according to life cycle assessment methodology, any waste occurring in a product's life cycle should be allocated to the product, in this case the produced meat and milk, hence not causing any carbon footprint of its own (ISO, 2006). Assigning beef losses a carbon footprint value equal to that of produced beef at farm gate, could be useful when evaluating the environmental mitigation potential in reducing beef losses. A so assigned carbon footprint of Swedish beef losses would correspond to 12% of the annual carbon savings resulting from the 4,800 activities included in the 1.1 billon EUR Swedish climate investment program (Swedish Environmental Protection Agency, 2022). This implies that beef losses are not a minor problem compared with issues already addressed, and that investments in beef loss reduction should be considered in future screenings for cost-efficient climate solutions.

Food loss and waste reduction is, however, not the silver bullet for a sustainable food system, since environmental savings level off at 8–10% when all stages of the food supply chain reduce their losses by 50% (Read et al., 2020). A shift in food choices has been proposed as a more powerful tool than a reduction in food loss and waste for the reduction of greenhouse gases from the food system (Springmann et al., 2018). But, since the two strategies are additional both can be employed simultaneously.

3.8. Comparisons with other studies

Our value of 8.5% beef losses, which refers to Swedish primary beef production and covers all registered cattle between 2017 and 2021, aligns well with values in previous studies by Strid et al. (2014), Hartikainen et al. (2018), and Lindow and Andersson (2022), where beef loss rates, covering the same system, but over fewer years, were 8.5, 8.3, and 8.3% of initial production, respectively. Good agreement was expected, since all those studies are related. Our value was also in the same range as the 10% beef losses reported for primary production in China (Xue et al., 2021), but higher than the 4% reported by Beretta et al. (2013) for Swiss farms. A French study that aimed at analyzing the extent of food loss and waste (including beef) in upstream stages of food supply chains in industrialized countries, unfortunately omitted losses prior to slaughter transport (Redlingshöfer et al., 2017), so this source could not contribute relevant data.

When searching for other studies we found a striking lack of original sources. A review by Xue et al. (2017) concluded that only around 20% of existing publications on food loss and waste quantification were based on first-hand data. Global Food Losses and Food Waste is one of these few works and also one of the most cited works in the field (Gustavsson et al., 2011). In their methodological background report (Gustavsson et al., 2013) the authors present a figure of 2.3% beef losses for Europe, North America & Oceania, and Industrialized Asia, which is only about a quarter of the value we found. However, that 2.3% loss rate is based on mortality rates for dairy and beef herds, explaining the much lower figure. Mortality rates represent the incidence of deaths occurring in herds of living animals, and not the percentage loss of annual production (Alvåsen et al., 2012). Despite this, the authors applied the mortality rate on the yearly beef production and presented the result as yearly loss of beef. Unfortunately, this leads to an error in FAO's estimate of beef losses that propagates into their total meat loss estimates. If our Swedish results are representative for high- and medium-income regions, there is an obvious risk that meat losses have been underestimated on numerous occasions during the past decade. Similarly, Parfitt et al. (2021b) re-evaluated the scale of global food waste during primary production and suggested that total losses are more extensive than estimated in the 2011 FAO report. There is, however, a possibility that Sweden have larger losses than other countries, if its authorities are more rigorous regarding animal welfare, thereby hindering farmers from sending unfit animals for slaughter. In a survey of Swedish dairy farmers by Alvåsen et al. (2014), some farmers reported that veterinary inspections at abattoirs had become stricter in recent years, and that this had affected their behavior so that some cows that would have been sent to slaughter a few years earlier would now probably be euthanized on-farm instead. This cautious perception seems to persist, based on informal interviews with farmers at the latest annual meeting of the Swedish Beef Producer's Association (M Jacobsen, personal communication, 10–11 November 2022).

In the FAO methodological report for the Global Food Loss Index (SDG 12.3.1), pre-slaughter losses are excluded (FAO, 2018), partly because this "avoids double counting of pre-harvest (and pre-slaughter) losses due to environmental disasters, which are captured by another SDG indicator (SDG 1.5)." The findings in our study do not support the FAO decision to omit pre-slaughter losses on the basis that they only occur in relation to extreme events. The summer of 2018 was unusually hot and dry in most parts of Sweden and media reported a tough situation for grazing livestock. Lack of feed led to long queues at abattoirs, which had difficulty accepting all the animals that needed to go to slaughter prematurely (Swedish Television, 2018). This event could be seen as a (mild) environmental disaster, but beef losses in 2018 were only marginally higher than in the year before and after (Figure 2). It would probably take a much more extreme event to give markedly higher losses, so the level of beef losses determined in the present study most likely represents the normal situation on Swedish cattle farms.

3.9. Limitations of the study

A limitation of the study could be the assumption that lost animals have the same weight as the slaughtered ones at their corresponding age, sex and breed group, since some of the lost animals might have a reduction in body weight due to problems such as disease or injury. The assumption of same weight can be justified, since seriously injured animals in pain, where there is no economically viable way to alleviate the pain, must be euthanized immediately (Council regulation EC No 1009/2009) and can thus be assumed to have the same weight as they had before the injury. There might also be a number of animals that get euthanized on farms as a result of the farmers' fear of authority remarks on animal welfare (Alvåsen et al., 2014), who might have a similar weight as animals sent to slaughter. However, some animals suffering from diseases can be expected to have a reduced body weight before they are euthanized or die unassistedly, as weight loss is sometimes a consequence of disease due to, e.g., reduced feed intake (Alawneh et al., 2012; Hägglund et al., 2022). A recent study by Vlemminx et al. (2023), found an association between health disorders observed at slaughter and a reduction in carcass weight. It is thus reasonable to assume that animals considered to be fit for transport and slaughter are in a better condition than the unhealthy animals dying on farm after suffering from disease (some of them being recumbent), which would most likely result in a weight loss for those animals. Since the purpose of the present study was to estimate the amount of wasted beef, this would not pose a major problem as the *ante mortem* weight loss would also be a loss. If the purpose instead had been to estimate the food potential of the lost animals, the weight loss would have been an issue as the food potential could have been slightly overestimated. However, diseased animals and animals under treatment are unfit for food consumption and would have been diverted from the food supply chain in later stages, why a possible overestimation is less relevant in reality. Another limitation of the study is the voluntary registration of stillborn calves, which can lead to an underestimation of lost calves.

4. Conclusion

Loss rate of beef during Swedish primary production 2017–2021 was on average 8.5% of initially produced carcass weight. If this value is more representative for high- and medium-income regions than the 2.3% used in the widely cited 2011 FAO report, global meat losses could be heavily underestimated. The beef loss rate for the overall Swedish cattle population did not change over the study period 2002–2021, and for the subgroup dairy breeds it even increased. This is especially unfortunate in the light of the ambitious food loss reduction targets set at global, European, and national levels. To combat beef losses on Swedish farms, there is a need for better care of dairy cows and male dairy calves alongside better access to forecasting tools for timely slaughter decisions on dairy cows and for better solutions to valorize potential food grade carcasses from animals that die on-farm, which thus should be three research priorities. Future research should furthermore aim for similar studies in other countries to obtain a larger number of national beef loss rates, both to compare with for identifying best available technology and successful management practices and to gain knowledge on European and global losses for policy development.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

IS, KA, and JR contributed to conception and funding acquisition. IS developed the design and methodology of the study, with contributions from MJ, KA, and JR. MJ organized the database, curated the data, performed data collection, and created visualizations, with contributions from IS. JR performed the statistical analysis. IS, MJ, and KA did literature searches. IS and MJ wrote the first draft of the manuscript, and IS finalized the introduction and discussion sections. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2023.1171865/full#supplementary-material

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Appendix

TABLE A1 Number of lost* dairy breed animals 2017–2021, and beef loss rate per age group.

Category	Breed group	Sex	2017	2018	2019	2020	2021	Beef loss rate (%; mean 2017–2021)
[Code 7 + 8] – deceased/euthanized								
0–1 month	Dairy	Male	3,714	3,923	3,539	3,243	3,311	98
1–2 months	Dairy	Male	1,800	1,910	1,700	1,506	1,455	96
2–4 months	Dairy	Male	2,249	2,678	2,387	1,992	1,901	94
4–6 months	Dairy	Male	1,444	1,695	1,354	1,158	1,163	88
6–8 months	Dairy	Male	906	1,006	770	763	754	39
8–10 months	Dairy	Male	659	675	649	577	558	10
10–12 months	Dairy	Male	632	627	639	524	540	20
12–15 months	Dairy	Male	882	872	920	730	829	17
15–18 months	Dairy	Male	749	764	792	759	715	3
18–21 months	Dairy	Male	525	520	525	439	453	2
21–24 months	Dairy	Male	294	372	315	296	230	2
24–30 months	Dairy	Male	405	351	355	299	213	2
30–36 months	Dairy	Male	217	128	220	120	170	3
36–48 months	Dairy	Male	195	113	175	136	162	6
48–60 months	Dairy	Male	165	48	67	71	58	18
60–72 months	Dairy	Male	33	22	25	36	9	19
72–84 months	Dairy	Male	8	7	18	34	14	29
84–96 months	Dairy	Male	8	17	16	13	5	36
96–108 months	Dairy	Male	2	10	11	5	2	32
108–120 months	Dairy	Male	3	8	5	7	3	47
> 120 months	Dairy	Male	10	8	4	8	8	41
Sum deceased males	Dairy	Male	14,900	15,754	14,486	12,716	12,553	5.1
0–1 month	Dairy	Female	3,347	3,500	3,149	3,004	3,118	99
1–2 months	Dairy	Female	1,356	1,492	1,274	1,297	1,370	97
2–4 months	Dairy	Female	1,322	1,545	1,362	1,223	1,285	94
4–6 months	Dairy	Female	775	801	708	740	727	91
6–8 months	Dairy	Female	519	553	471	454	558	74
8–10 months	Dairy	Female	445	466	366	349	448	44
10–12 months	Dairy	Female	375	392	318	319	364	33
12–15 months	Dairy	Female	524	512	488	422	482	62
15–18 months	Dairy	Female	457	470	451	391	473	46
18–21 months	Dairy	Female	431	423	414	363	422	24
21–24 months	Dairy	Female	462	494	486	458	500	15
24–30 months	Dairy	Female	1,881	1,851	1,705	1,649	1,660	14
30–36 months	Dairy	Female	1,690	1,707	1,560	1,466	1,575	14
36–48 months	Dairy	Female	3,663	3,747	3,715	3,418	3,491	16
48–60 months	Dairy	Female	3,827	4,148	3,881	3,913	3,810	16
60–72 months	Dairy	Female	3,440	3,804	3,472	3,481	3,577	17
72–84 months	Dairy	Female	2,428	2,764	2,444	2,445	2,526	18
84–96 months	Dairy	Female	1,433	1,595	1,474	1,451	1,507	17
96–108 months	Dairy	Female	773	828	733	736	813	17
108–120 months	Dairy	Female	349	420	373	321	408	17
> 120 months	Dairy	Female	494	511	470	422	427	22
Sum deceased females	Dairy	Female	29,991	32,023	29,314	28,322	29,541	17.8

Source: Central registry of bovine animals (CDB), 2022-01-30. Data for all breeds, years, and categories can be found in the Electronic Supplementary material. *Lost animals were defined as animals recorded with code 7 and 8, deceased/euthanized with or without destruction.