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Carrot losses in primary production – a study case in Federal District, Brazil

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Milza Moreira Lana

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Sumário

Carrot losses in primary production – a study case in Federal District, Brazil

Milza Moreira Lana[1]

Abstract – Carrot loss at primary production comprises the loss that occurs during the harvesting and during the preparation of the produce for the market in the packing house. In this research it was estimated in 4 farms in Federal District, Brazil. From those, 2 are organic farms producing carrots in small areas, and 2 are large farms using conventional system. The surveys were initiated in 2019, interrupted during the Covid-19 pandemic and resumed in 2022. The total loss of carrot roots varied from 6.2% ± 1.0% to 34.8% ± 2.4% of the total production what corresponded to a mass of 1.000 kg/ha ± 425 kg/ha to 22.947 kg/ha ± 3.637 kg/ha. Except for one farm, loss at harvest was higher than loss in the packing house because the farmer wants to avoid the costs of transporting and washing roots that will not be sold. Misshaped root was the main cause of discard at harvest in 5 of the 7 surveys, where it represented 2.0% ± 1.3% to 22.5% ± 6.2% of the total root production. Small root was the main cause of discard at harvest in 2 surveys, both in organic farms. Broken and damaged by pest were the main causes of root discard in the packing house in 4 (1.2% ± 0.6% to 5.2% ± 1.4% of the total root production) and 3 (0.3% ± 0.3% to 15.3% ± 6.1% of the total root production) of the 7 surveys, respectively. Misshaped root was the second main cause in 5 out of 7 surveys. In the 2 small farms, the actual volume of discarded roots per day was very small because a typical daily harvest varied between 10 and 50 crates of 25 kg each. Furthermore, the largest part of the waste was not edible consisting of rotten roots or badly damaged or very small underdeveloped roots. On the 2 large farms, the situation was quite different. Even a small percentage of carrot loss represents a substantial mass of roots since tons of carrots are harvested

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daily. Part of this discard is edible and could be redirected for gleaning, food donation, processing (fresh-cutting or drying) or alternative markets.

Index terms: *Daucus carota* L.; post-harvest losses; harvest loss; food loss.

Perdas de cenoura na produção primária – um estudo de caso no Distrito Federal, Brasil

Resumo – A perda de cenoura na produção primária compreende a perda que ocorre durante a colheita e durante a preparação do produto para o mercado na casa de embalagem. Nesta pesquisa a perda de cenoura foi estimada em 4 estabelecimentos agropecuários no Distrito Federal, Brasil. Destes, 2 são estabelecimentos orgânicos que produzem cenoura em pequenas áreas e 2 são grandes áreas que utilizam o sistema convencional de plantio. Os levantamentos foram iniciados em 2019, interrompidos durante a pandemia de Covid-19 e retomados em 2022. A perda total de raízes de cenoura variou de 6,2%$\pm$ 1,0% a 34,8% $\pm$ 2,4% da produção total, o que correspondeu a uma massa de 1.000 kg /ha $\pm$ 425 kg/ha a 22.947 kg/ha $\pm$ 3.637 kg/ha. Com exceção de um estabelecimento, a perda na colheita foi maior que a perda na casa de embalagem, porque o agricultor evita transportar e lavar as raízes que não serão vendidas. Raiz deformada foi a principal causa de descarte na colheita em 5 dos 7 levantamentos, onde representou 2,0% $\pm$ 1,3% a 22,5% $\pm$ 6,2% da produção total de raízes. Raiz pequena foi a principal causa de descarte na colheita nos 2 pequenos estabelecimentos agropecuários. Raízes quebradas e danificadas por pragas foram as principais causas de descarte de raízes na casa de embalagem em 4 (1,2% $\pm$ 0,6% a 5,2% $\pm$ 1,4% da produção total de raízes) e 3 (0,3% $\pm$ 0,3% a 15,3% $\pm$ 6,1% da produção total de raízes) dos 7 levantamentos, respectivamente. Raiz deformada foi a segunda causa principal em 5 levantamentos. Nos 2 pequenos estabelecimentos, o volume de raízes descartadas por dia era muito pequeno porque uma colheita diária típica variava entre 10 e 50 caixas de 25 kg cada. Além disso, a maior parte dos resíduos não era comestível, consistindo em raízes podres ou muito danificadas ou raízes subdesenvolvidas. Nas 2 grandes áreas, a situação era bem diferente. Mesmo uma pequena porcentagem de perda de cenoura representa uma massa substancial de raízes, já que toneladas de cenoura são colhidas diariamente. Parte desse descarte é comestível e pode ser redirecionado para colheita por e/ou doação para instituições de assistência social, processamento (processamento mínimo ou secagem) ou para mercados alternativos.

Termos para indexação: *Daucus carota* L.; perdas pós-colheita; perdas na colheita; perda de alimentos.

Introduction

Food loss in primary production of vegetables comprises the loss that occurs during the harvesting and during the preparation of the produce for the market (washing, grading, packing). It happens when the vegetable presents some change in appearance that reduces its commercial value; when the harvest is not carried out because the costs of harvesting, processing and marketing are higher than the selling price of the produce; when there is no market for the produce.

Estimates of losses in primary production can be obtained through different methods. The most used are the analysis of secondary data (Redlingshofer et al., 2017; Porter et al., 2018; WRAP, 2019); interviews (Roels, 2015; Beausang et al., 2017; Gillman et al., 2019; Ludwig-Ohm et al., 2019), on-farm data collection (McKenzie et al., 2017; Johnson et al., 2018a; 2018b; Baker et al., 2019) and the combination of two or more methods (Franke et al., 2016). The method of choice will depend on the aim of the research and the human and financial resources available.

There is no consensus on whether the proportion of the crop which is not fit for human consumption at the time of harvest, due to biological or climatic reason, should be considered food loss. FAO (2018) defines it as pre-harvest loss and excludes it from the Global Food Loss Index. Strid and Eriksson (2014) considered that damaged vegetables left on the field are part of yield loss and only unharvested high-quality vegetables should be considered food loss. On the other hand, WRAP (2017) considered loss due to pest and disease damage to be yield loss, when it arises before the crop maturation, and food loss, when it arises after crop maturation.

In the study reported here, the vegetable loss at primary production was studied from the point of view of food security and the farmer’s profitability. Its main research question is what proportion of the total production is discarded and what are the causes for it. By identifying the volume and causes of losses, it is possible to identify which actions are most appropriate to reduce these losses. Necessary actions may include changes in cultural and postharvest practices (e.g. plant density, harvest maturity, washing equipment) farm management (e.g. harvest crew size and training), market and consumer preference (e.g. standard specifications, creation of alternative market), among others.

Carrot was chosen as the crop to be studied due to its economic importance for the Federal District and because it is a good model to study differences between small and large farms in what concerns food loss. Discussion with several actors from the carrot supply chain indicated that in farms that produce carrots on a large scale and serve large retail chains, the requirements for aesthetic standards lead to a significant discard of roots suitable for consumption in harvesting and processing. On the other hand, farms that produce on a smaller scale have established alternative markets for the worst-looking product, thus reducing disposal on the farm.

To obtain these estimates, on-farm data collection was the chosen method. Carrot roots discarded or left unharvested in the field and roots discarded in the packing house were considered part of vegetable loss at primary production, no matter the reason for the discard.

This approach differs from that used by authors such as Roels et al., (2014) and Colbert and Stuart (2015) where the main interest lies in studying how factors external to the farm result in perfectly edible food being wasted in the farm. These factors include short-term changes in customer demand, different quality standards among the different customers, not meeting the cosmetic quality standards required among others.

In this research, it is considered that factors internal to the farm are equally important to reduce losses at primary production. The discard of edible food in the farm indicates the need for adjustments in consumer behavior and market demands while the disposal of inedible food indicates the need for adjustments in the production system and practices in the farm. Both are important to increase the amount of food available to the population and the profitability of the farmer.

Material and Methods

Carrot loss at primary production was estimated in 4 farms in Federal District, Brazil. Farms differed in relation to size and production system. Farms 1 and 4 are organic farms that produce carrots in small areas, while Farms 2 and 3 produce carrots in a large-scale conventional system. The surveys were initiated in 2019, interrupted during the Covid-19 pandemic and resumed in 2022.

Definition of losses in primary production

Losses in carrot primary production comprised losses during harvesting and in the packing house, during preparation for the market. Harvest losses included the fraction harvested and discarded immediately after root uprooting and the fraction left in the soil. Packing house losses included roots retained and damaged in the washer and those discarded during sorting, grading and packaging.

Loss ratios

Losses were expressed in kg/ha and in mass proportion (%) of total production (kg/ha). For this, it was necessary to measure the area in the field where the samples were collected, as detailed below.

Sample size

The size of each sample or replicate was defined according to the capacity of the root washing system used in the farm. When the washer was fed in batches, like as in a cylindrical washer, the quantity of roots harvested per replicate was equal to the batch size. In the case of a washer with continuous feeding, such as on a packing line, the amount of roots harvested per replicate was equal to the minimum quantity necessary for the washer to operate at the capacity of the line.

Farms 1 and 4 used a cylindrical washer and size sample was equal to 3 harvest crates. Farms 2 and 4 used a packing line. On farm 2, size sample was equal to 20 harvest crates. On farm 4, size sample was equal to the amount of harvest crates collected in a bed length of 50 meters (around 25 crates).

Collection of samples in the field

In each crop, 5 samples or replicates were collected. The distribution of these samples was made in such a way as to include, in a representative manner, the edges and middle of the crop, the tractor tire tracks and the positioning of the irrigation systems. Each sample consisted of ***n*** boxes of commercial carrots and ***p*** boxes of discarded carrots (Figure 1). The value of ***n*** is the same for all plots and defined in each farm surveyed, as described in ***Sample size***. The value of ***p*** is variable and indirectly dependent on the value of ***n***. The collection of each sample was performed by the farm staff. After harvest, the length of the harvested bed was measured.

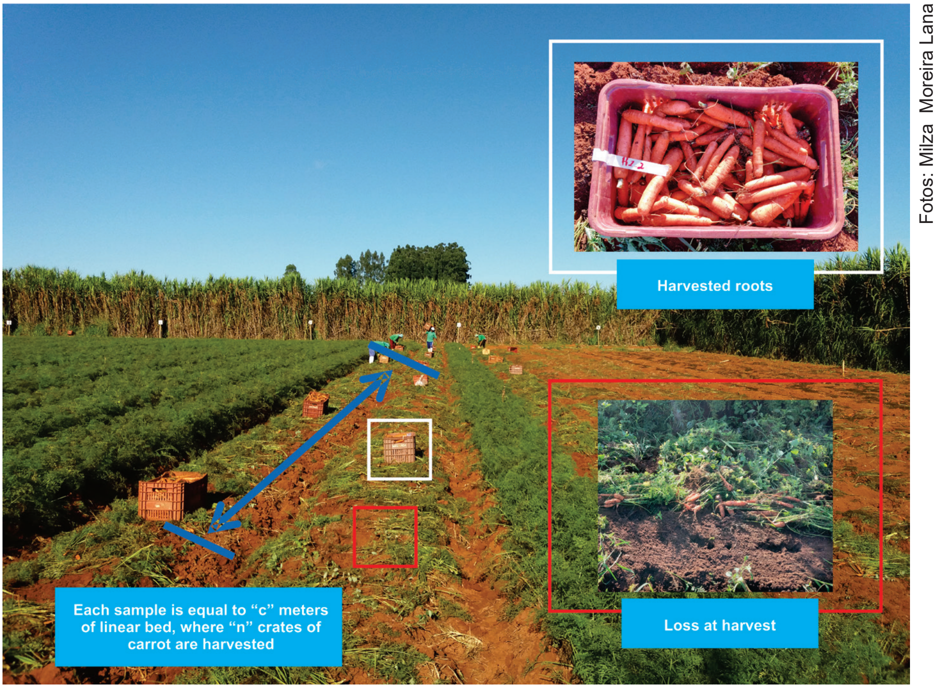

Figure 1. Sample collection to quantify carrot losses at primary production.

Harvest loss Assessment

Roots from the harvest loss fraction were hand washed to prevent root breakage. They were then classified by the researchers, in order of priority, into only one of the following classes (Figure 2a and 2b):

i. Pest: whole roots with symptoms of attack by fungi, bacteria, nematodes or insects, alone or with another associated defect, except broken.

ii. Pest and broken: pieces of root with symptoms of attack by fungi, bacteria, nematodes or insects, alone or with another associated defect.

iii. Shape defect: whole roots with growth crack, tortuosity, bifurcation, alone or with another associated defect, except broken and with pest.

iv. Shape and broken defect: pieces of root with growth crack, tortuosity, bifurcation, alone or with another associated defect, except broken and with pest.

v. Broken: pieces of root without any other associated defect or whole roots with mechanical damage (cracks, cuts, scratches) without any other associated defect.

vi. Small root: root with a length inferior to the smallest length accepted in the commercial whole carrot fraction.

vii. Large root: root with length and/or diameter greater than the longest length accepted in the commercial whole carrot fraction.

viii. Root without defect: whole root, with size and format accepted in the commercial fraction.

ix. Each fraction was weighed separately.

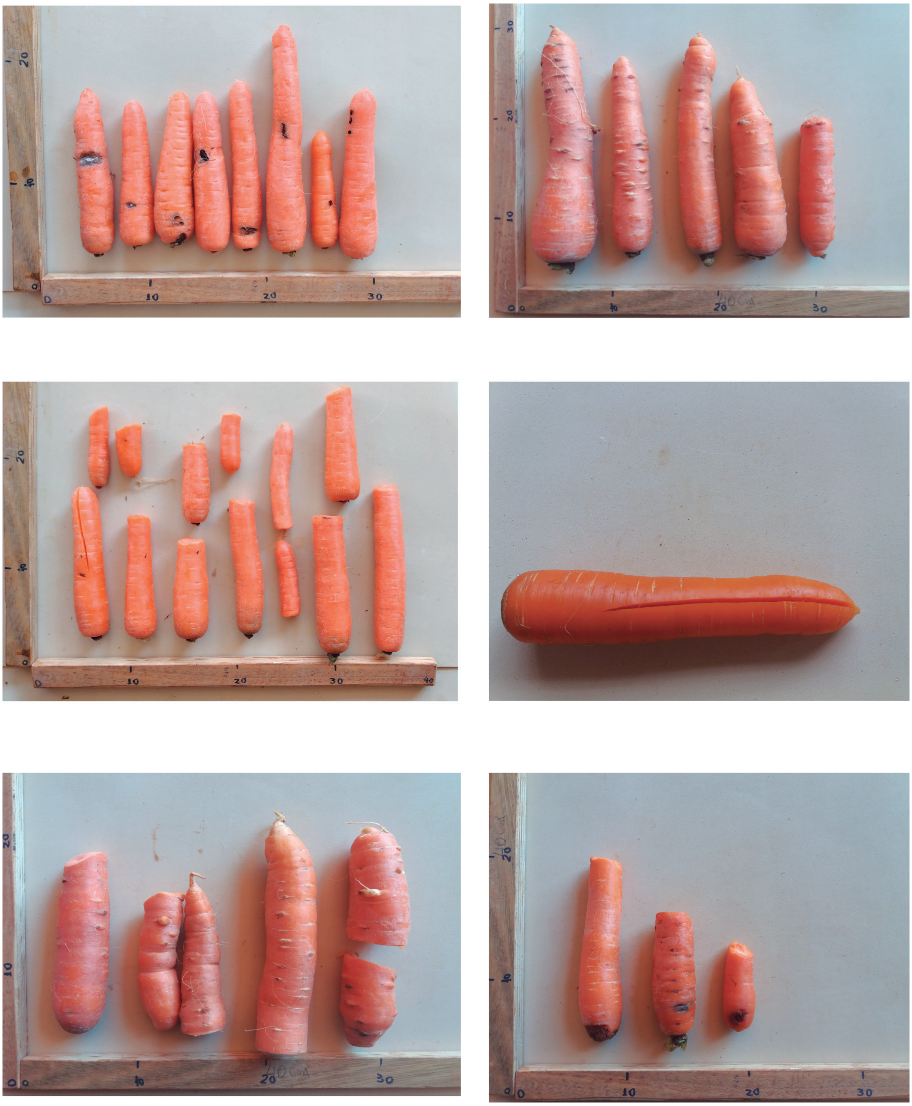

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Figure 2a – Causes of carrot discard at harvest and in the packing house: damaged by pest (A,B) broken (C,D), damaged by pest and broken (E,F).

Fotos: Milza Moreira Lana

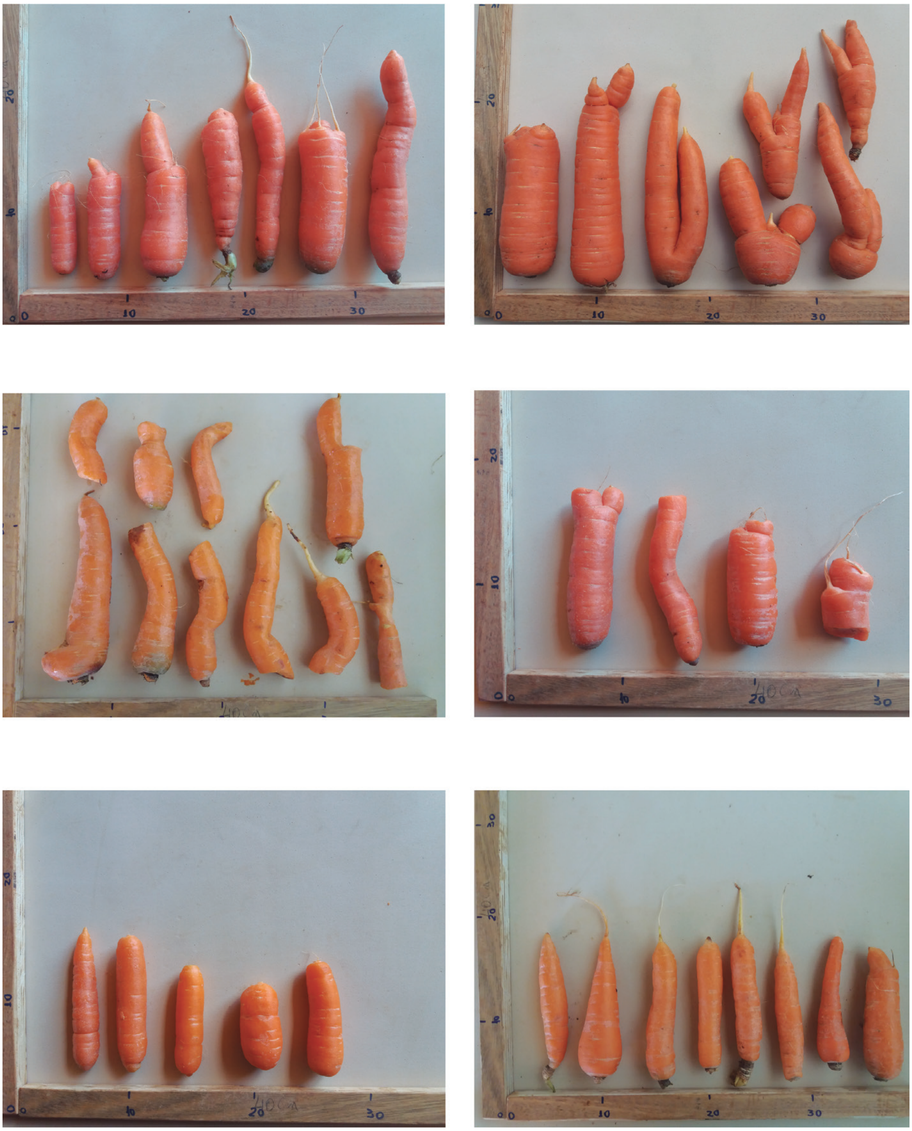

Figure 2b – Causes of carrot discard at harvest and in the packing house: shape (F,G), shape and broken (H,I) and small (J,L).

Selection of commercial carrot

The harvested carrot fraction was washed and classified by the farm staff according to the routine procedure. after the washing of each of the five samples was finished, the roots that were retained and those that fell from the washer and the carrots discarded by the staff were collected. these two fractions added together constitute the loss in the packing house.

Commercial production, consisting of harvested carrots minus loss in the packing house, was classified according to routine procedures, by the establishment's employees, and each class was weighed separately (data not shown).

Assessment of loss in the packing house

The roots of the packing house loss fraction were classified by the researchers, in order of priority, in the same classes described for the harvest loss fraction (Figures 2a and 2b) plus one extra class with the roots, retained in the washer or thrown out of the washer.

Conversion of data in kg/plot to kg/hectare

The mass of each fraction, expressed in kg of carrots per sample (each plot corresponded to "***x***" linear meters of bed), was converted into kg per hectare, considering that each hectare has ***y*** linear meters of bed.

$$carrot\ mass\ \left(\frac{kg}{ha}\right) = carrot\ mass/sample * \frac{lenght\ bed\ per\ hectare}{lenght\ bed\ per\ sample}$$

To express the loss as a proportion of total production, it was considered that

$$Total\ production = comercial\ carrot + harvest\ loss + packing\ house\ loss$$

Result and Discussion

The total and commercial production of carrot roots, and the loss at harvest and in the packing house, varied greatly among farms and among crops within the same farm. The main causes of loss were the same in all farms, that is, roots outside the size and/or shape accepted by customers and roots with symptoms of pest attacks. However, the limits that define each of these categories were different in each of them, as will be detailed below.

Amount of loss and variability in loss indexes

The total production of carrot roots varied from 15.870 kg/ha ± 2.313 kg/ha to 106.877 kg/ha ± 3.682 kg/ha when individual surveys were considered (Table 1). The total loss varied from 1.000 kg/ha ± 425 kg/ha to 22.947 kg/ha ± 3.637 kg/ha (Table 1). Comparisons between farms should be made with care because the surveys were not simultaneous and the reported differences were greatly influenced by the time of the year. These indexes were converted to a same basis (kg/ha) but the reader should keep in mind that the areas harvest in Farms 2 and 3 were in the range of tens of hectares while in Farms 1 and 4 they were in the range of tens of square meters.

For the objectives of this research, it is more relevant to consider the proportion of the total production that was lost as much as at what stage it happened (Table 2). This is a better index to represent the efficiency of the crop system in terms of food loss than the absolute numbers (Table 1), which in turn, are more important to know the amount of food available and the amount of organic waste generated in the farm. Again, comparisons between farms should be taken with care for the reasons already reported.

The total loss of carrot roots varied from 6.2% ± 1.0% to 34.8% ± 2.4% of the total production (Table 2). Except for Farm 4, loss at harvest was higher than loss in the packing house because the farmer wants to avoid the costs of transporting and washing roots that will not be sold. For the second crop of Farm 2, the proportions of loss at harvest and in the packing house were similar. This happened during the rainy season when many roots with small lesions of soft rot were discarded after washing. These roots were not discarded in the field because the small lesions were not visible when the roots were covered by soil, but only after being washed.

Table 1. Production and loss of carrot (kg/ha) in primary production in the Federal District, Brazil.

Farm-crop	Total production (kg/ ha)	Commercial production (kg/ha)	Harvest Loss (kg/ha)	Packing house loss (kg/ha)	Total loss (kg/ha)
1-crop 1	15.870 ± 2.313	14.871 ± 2.341	714 ± 328	286 ± 158	1.000 ± 425
2-crop 1	106.877 ± 3.682	84.430 ± 5.472	15.218 ± 3.587	7.229 ± 669	22.447 ± 2.956
2-crop 2	64.861 ± 4.386	42.313 ± 3.491	12.516 ± 2.608	10.032 ± 1.719	22.548 ± 2.017
2-crop 3	68.147 ± 4.898	45.200 ± 4.504	21.374 ± 3.506	1.573 ± 413	22.947 ± 3.637
3-crop 1	43.862 ± 2.538	41.180 ± 2.830	2.334 ± 244	348 ± 197	2.683 ± 334
4-crop 1	33.523 ± 5.580	23.860 ± 2.704	3.452 ± 298	6.211 ± 2.853	9.663 ± 2.937
4-crop 2	51.805 ± 6.732	46.928 ± 6.143	1.348 ± 651	3.529 ± 1.263	4.877 ± 729

Table 2. Production and loss of carrot (percentage of the total production) in primary production in the Federal District, Brazil.

Farm-crop	Commercial production (% of total production)	Harvest Loss (% of total production)	Packing house loss (% of total production)	Total loss (% of total production)
1-crop 1	93.6 ± 2.9	4.6 ± 2.4	1.7 ± 0.9	6.4 ± 2.9
2-crop 1	79.0 ± 3.1	14.3 ± 3.5	6.8 ± 0.6	21.0 ± 3.1
2-crop 2	65.2 ± 2.4	19.2 ± 3.2	15.6 ± 3.2	34.8 ± 2.4
2-crop 3	66.3 ± 4.7	31.4 ± 4.8	2.3 ± 0.4	33.7 ± 4.7
3-crop 1	93.8 ± 1.0	5.4 ± 0.9	0.8 ± 0.4	6.2 ± 1.0
4-crop 1	71.7 ± 4.3	10.5 ± 1.8	17.8 ± 5.6	28.3 ± 4.3
4-crop 2	90.6 ± 0.8	2.7 ± 1.3	6.7 ± 1.8	9.4 ± 0.8

The lowest proportion of loss was observed in Farms 1 and 3, the 2 farms where it was not possible to perform more than one survey. Farm 1 is an organic farm where a large range of carrot products are produced. Big roots are sold in bulk or used for processing fresh-cut produce, medium roots are sold packaged and very small or deformed roots are used for processing fresh-cut produce. Because of this, the low loss of carrot, measured in this research, is expected throughout the year. Still, during the rainy season, when the incidence of soft rot is high, losses can increase substantially.

On Farm 4, on the other hand, the low volume of loss was due to an exceptional condition of low offer and very high carrot price in the market. Under this condition, deformed, cracked and broken roots, which are usually discarded, were sold (Figure 3). This means that the low amount of carrot loss, as measured in this study, is not expected to be representative of what happens in this farm along the year.

The author is unaware of other surveys on carrot loss in Brazil. The available data are from countries with climatic conditions, production systems and market quite different from Brazil and were obtained mostly by interviews. Frankie et al. (2016) reported harvest losses of carrot in Norway and Finland of 4.2% $\pm$ 2.5% and 6.2% $\pm$ 2.0%, respectively. In Scotland, the estimated total loss varied from 30% to 50% of the carrot production (Beausang et al., 2017). One point in common though, is the large variation in these indexes. Scottish farmers reported that it was difficult for them to provide an estimate when it varied so much year-to-year, and it was not something they recorded. Representatives of the carrot supply chain in Germany estimated food losses at farm level to be, for washed carrot, on average 25% to 40% but this range encompassed an even larger variation with loss in good years, reaching 10% to 15% and in bad years, more than 50% (Ludwig-Ohm et al., 2019).

Fotos: Milza Moreira Lana

Figure 3 – Misshapen and broken carrot roots either sold in the market or discarded on the farm, depending on the time of the year and the price and availability of the carrot in the market.

The large variation in the amount of carrot loss along the year within a single farm, besides the large variation observed among farms, represents one of the main challenges when looking for solutions to reduce food loss at primary production or to give the best possible destination to the waste produced. In addition, the reasons for discarding also change during the year, meaning that the solution proposed for the rainy season does not necessarily apply to the dry season, for example.

Causes of loss at harvest or causes of crop failure

The causes of carrot root discard at harvest and the quantity of discarded roots in each category are presented in Table 3.

Misshaped root was the main cause of discard at harvest in 5 of the 7 surveys, where it represented 2.0% ± 1.3% to 22.5% ± 6.2% of the total root production. This category includes cracked roots that are too fibrous to be used as food and edible roots (Figure 4), both discarded due to the demand for straight roots. Small roots were the main cause of crop discard in 2 surveys, both on organic farms (Table 3). It is important to consider that in both cases the roots were much smaller than those in the same category in the conventional Farms 2 and 3. For conventional farms, roots 10 to 12 cm in length, or a bit smaller, are considered too small and are discarded. Roots of the same size are considered marketable on organic farms and, for that reason, are not discarded.

The large quantity of roots with no defect in the survey Farm 2-Crop 1 may have been overestimated due to an error during the evaluation of roots with incipient soft rot and nematode infections (Figure 5). This possible error was corrected in subsequent evaluations after discussing the causes for discard with the farm staff and finding that these defects possibly went overlooked by the researcher in the first survey. Employees are trained to recognize these defects, because these infections, barely visible when the roots are washed and packaged, progress rapidly during transport and marketing. Nematode knots break down and are easily infected by fungi and bacteria, and small soft rot spots rapidly spread, especially under conditions of high temperature and humidity.

Table 3. Mass of carrot loss at harvest (kg/ha) and proportion in relation to the total production (%) according to the cause of loss.

Farm-crop	Pest	Broken	Pest & broken	Shape	Shape & broken	Small	No defect	Big
	Amount of roots (kg/hectare)							
1-Crop 1	50.5 ± 80.9	51.8 ± 28.8	0.0 ± 0.0	27.4 ± 23.9	0.0 ± 0.0	397.7 ± 190.8	186.3 ± 98.2	0.0 ± 0.0
2-Crop 1	194.91 ± 244.4	773.4 + 641.1	0.0 ± 0.0	5,903.3 ± 2,676.0	0.0 ± 0.0	829.9 ± 491.3	4,269.2 ± 2,082.0	3,247.3 ± 1,243,4
2-Crop 2	1,551.6 ± 716.4	1,282.8 ± 270,2	451.0 ± 351.0	4,837.3 ± 1,317.7	22.3 ± 21.5	456.66 ± 191.1	2,644.7 ± 744.6	1,249.9 ± 1,354.5
2-Crop 3	53.9 ± 41.1	1,453.1 ± 566.4	42.3 ± 94.5	15,383.3 ± 4,444.9	748.6 ± 1,015.4	2,462.4 ± 669.4	1,190.8 ± 703.8	39.45 ± 41.7
3-Crop 1	35.3 ± 54.5	354.4 ± 188.0	164.4 ± 100.1	1,652.5 ± 384.0	88.6 ± 47.0	23.6 ± 39.7	15.3 ± 5.9	0.0 ± 0.0
4-Crop 1	580.5 ± 624.4	200.4 ± 47.0	47.5 ± 58.2	1,120.9 ± 394.5	30.3 ± 37.3	1,446.2 ± 908.9	26.3 ± 30.8	0.0 ± 0.0
4-Crop 2	14.6 ± 32.7	149.6 ± 82.9	47.1 ± 61.9	1,011.6 ± 673.3	11.0 ± 15.1	114.5 ± 98.9	0.0 ± 0.0	0.0 ± 0.0
	Amount of roots in proportion of the total production (%)							
1-Crop 1	0.3 ± 0.5	0.3 ± 0.2	0.0 ± 0.0	0.2 ± 0.2	0.0 ± 0.0	2.5 ± 1.2	1.2 ± 0.7	0.0 ± 0.0
2-Crop 1	0.2 + 0.2	0.7 ± 0.6	0.0 ± 0.0	5.6 ± 2.7	0.0 ± 0.0	0.8 ± 0.4	4.0 ± 2.0	3.0 ± 1.1
2-Crop 2	2.4 ± 1.2	2.0 ± 0.3	0.7 ± 0.1	7.4 ± 1.8	0.0 ± 0,0	0.7 ±0.3	4.2 ± 1.3	1.8 ± 1.9
2-Crop 3	0.1 + 0.1	2.1 ± 0.8	0.1 ± 0.1	22.5 ± 6.2	1.1 ± 1.6	3.6 ± 1.1	1.7 ± 1.0	0.1 ± 0.1
3-Crop 1	0.1 + 0.1	0.8 ± 0,4	0,4 ± 0,2	3.8 ± 1.1	0.2 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0
4-Crop 1	1.6 + 1.6	0.6 ± 0.2	0.1 ± 0.2	3.3 ± 0.1	0.1 ± 0.1	4.7 ± 3.3	0.1 ± 0.1	0.0 ± 0.0
4-Crop 2	0.0 ± 0.1	0.3 ± 0.2	0.1 ± 0.1	2.0 ± 1.3	0.0 ± 0.0	0.2 ± 0.2	0.0 ± 0.0	0.0 ± 0.0

Fotos: Milza Moreira Lana

Figure 4. Examples of edible and inedible misshapen roots discarded on farm, due to the market demand for straight roots. Each photo represents a harvest in a single farm.

Fotos: Milza Moreira Lana

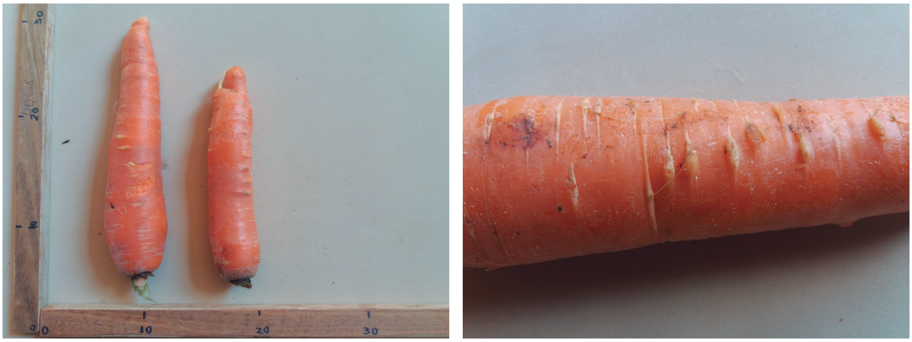

Figure 5. Carrot roots with nematode knot discarded in the farm.

Causes of loss in the packing house

The causes of carrot roots discard in the packing house and the amount of discarded roots in each category are presented in Table 4 and expressed as the mass of roots in kg/hectare and as a proportion (%) of the total production. Broken and damaged by pest were the main causes of root discard in the packing house in 4 and 3 of the 7 surveys, respectively. Misshaped root was the second main cause in 5 of the 7 surveys.

Carrots roots can be broken during harvest, transport and washing. A separate study to determine the critical points for root breakage in Farm 2 in 2019, revealed that the critical point for root breakage was the stage where the roots are loaded in a dry tank at the beginning of the packing line (Figure 6; data not published). Although not measured, it is not expected that the same condition happens in Farm 3 where the roots are loaded in a water tank (Figure 6). On Farms 1 and 4, breakage during washing was not an issue.

The quantity of carrot retained in the washer could be estimated in all surveys except on Farm 3. In the last, where 2 large packing lines operate simultaneously, it was not feasible to collect this fraction. In farms 1 and 4, where small cylindrical washers were used, there was no root retention.

Reduction of carrot loss at primary production

Due to the small number of surveys carried out in this research it is not possible to recommend actions for reducing carrot losses at primary production at regional or national level. To do so, it would be necessary to repeat the surveys on the same properties for at least 2 years, during the dry and rainy seasons, and increase the size and diversity of the sample. However, it is possible to carry out an exercise to discuss the potential actions and the challenges to reduce losses under the conditions reported here.

On Farms 1 and 4, the actual volume of discarded roots per day was very small, because a typical daily harvest varied between 10 and 50 crates of 25 kg each. In addition, most of the discard was not edible since the tolerance for shape defects and small size is high in these farms, and these roots are either sold (Farm 1 and 4) or used in their own fresh-cut industry (Farm 1). Most of the waste consists of rotten roots or much damaged or very small

Table 4. Mass of carrot loss in the packing house (kg/ha) and proportion in relation to the total production (%) according to the cause of loss.

Farm-crop	Washer retention	Pest	Broken	Pest & broken	Shape	Shape & broken	Small	No defect	Big	Not identified
	Amount of roots (kg/hectare)									
1-Crop 1	0.0 ± 0.0	3.3 ± 7.3	110.3 ± 79.6	0.0 ± 0.0	91.8 ± 90.4	0.0 ± 0.0	78.7 ± 37.6	0.0 ± 0.0	0.0 ± 0.0	2.0 ± 4.6
2-Crop 1	639.1 ± 351.7	331.1 ± 91.0	5,221.2 ± 722.5	200.0 ± 158.5	152.5 ± 67.8	432.8 ± 187.1	0.0 ± 0.0	251.8 ± 87.0	0.0 + 0.0	0.0 ± 0.0
2-Crop 2	897.6 ± 132.9	2,555.8 ± 806.3	3,338.0 ± 830.4	1,220.2 ± 276.4	941.8 ± 392.0	83.7 + 84.1	47.5 ± 28.0	947.4 ± 395.9	0.0 ± 0.0	0.0 ± 0.0
2-Crop 3	184.12 ± 77.9	102.6 ± 55.6	816,1 ± 508.6	87.4 ± 157.7	200.7 ± 147.0	34.3 ± 24.6	50.7 ± 27.5	95.0 ± 59.0	0.0 ± 0.0	0.0 ± 0.0
3-Crop 1	Not measured	127.9 ± 117.6	13.2 ± 18.1	84.0 ± 57.6	108.5 ± 55.0	14.9 + 28.9	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
4-Crop 1	0.0 ± 0.0	5,385.7 ± 2,901.7	274.0 ± 59.8	140.1 ± 172.3	336.3 ± 80.0	0.0 ± 0.0	50.0 ± 111.8	25.0 ± 34.4	0.0 ± 0.0	0.0 ± 0.0
4-Crop 2	0.0 ± 0.0	2.131.15 ± 797.4	494.2 ± 357.4	0.0 ± 0.0	657.4 ± 578.9	19.7 + 44.1	197.1 ± 108.0	29.0 ± 65.0	0.0 ± 0.0	0.0 ± 0.0
	Amount of roots in proportion of the total production (%)									
1-Crop 1	0.0 ± 0.0	0.0 + 0.1	0.7 ± 0.5	0.0 ± 0.0	0.5 ± 0.5	0.0 ± 0.0	0.5 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
2-Crop 1	0.6 ± 0.3	0.3 ± 0.1	4.9 ± 0.6	0.2 ± 0.1	0.1 ± 0.1	0.4 ± 0.1	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0
2-Crop 2	1.4 ± 0.1	4.0 ± 1.4	5.2 ± 1.4	1.9 ± 0.5	1.5 + 0.6	0.1 ± 0.1	0.1 ± 0.0	1.5 ± 0.7	0.0 ± 0.0	0.0 ± 0.0
2-Crop 3	0.3 ± 0.1	0.1 ± 0.1	1.2 ± 0.6	0.1 ± 0.2	0.3 ± 0.2	0.0 ± 0.0	0.1 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0
3-Crop 1	Not measured	0.3 ± 0.3	0.2 ± 0.1	0.2 ± 0.1	0.0 + 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
4-Crop 1	0.0 ± 0.0	15.3 ± 6.1	0.8 ± 0.3	0.4 ± 0.5	1.0 ± 0.3	0.0 ± 0.0	0.2 ± 0.4	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0
4-Crop 2	0.0 ± 0.0	4.1 ± 1.3	1.0 ± 0.7	0.0 ± 0.0	1.2 ± 0.9	0.0 ± 0.1	0.4 ± 0.2	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0

Figure 6. Carrot dumping in the packing line on Farm 2 (upper photos) and on Farm 3 (lower photos).

underdeveloped roots. For that, there is practically no potential for reducing waste through gleaning or food donation or through the relaxation of quality specifications. Improvements on the production system can, on the other hand, increase the proportion of premium roots and reduce the incidence of crop disease. As observed for Farm 4-crop 1, losses due to fungal and bacterial diseases can be substantial during the rainy season, at harvest and in the packing house, in both farms.

In Farms 2 and 3 the situation was quite different. Even a small percentage of carrot loss represents a substantial mass of roots since tons of carrots are harvested daily. Part of this discard is edible and could be redirected to gleaning, food banks, processing (fresh-cutting or drying) or to alternative markets.

Roughly, the sum of the amount of broken, misshaped, small, big and with no defect roots would give the amount of edible root. However, these classes do not differentiate between light and severe defects and, although most of it is edible, inedible roots are also included (Figure 4).

Several authors recommend the relaxation of vegetable quality requirements by the retail market, the permission to sell non-standard produce at a lower price and the establishment of fairer contracts that take into account the variation in the volume and quality of the vegetable during the year (Mckenzie et al., 2017; Redlingshofer et al., 2017; Ludwig-Ohm et al., 2019) in order to reduce food loss. In Brazil, the large supermarket chains are very demanding regarding the absence of defects and uniformity in the size of the roots, while at local street markets and small supermarkets it is possible to find a greater proportion of roots with small defects. At the same time, in some supermarkets, mainly restricted to more affluent urban areas, it is possible to find the so-called “ugly vegetables”. However, solutions such as the sale of “ugly” vegetables at reduced prices may not be attractive to farmers, since the production and marketing costs of “ugly” and “perfect” vegetables are the same. The best situation for the farmer is the one in which the totality of his production has a high commercial value.

Adjustments in crop density, soil preparation, harvest index, irrigation volume and frequency, among others, can significantly increase the proportion of premium roots in the total production and hence, reduce losses related to root size and shape. In view of the results reported here (Tables 1-4), Farm 2 implemented a set of measures to reduce carrot loss. They included: changes in plant density to reduce the proportion of carrots outside commercial size; greater rigor in monitoring the harvest to reduce the proportion of unharvested roots without defects left in the field and to properly place the harvested roots in the crates to reduce breakage during transport; improvement in sales schedules to guarantee harvesting the roots at the right time and for that reducing the disposal of very small or very large roots.

Under the conditions of Farms 2 and 3, there is an enormous potential for food donation and animal feeding and Farm 2 does sell, at a very low price, a small part of its waste for horse feeding. However, on both farms most of the packing house loss is just dumped and the harvest losses are incorporated in the soil. The challenges to connect potential donors and beneficiaries for the wasted carrot include: 1) donors and beneficiaries are largely unaware of each other's existence; 2) there is a logistic cost to collect, pack, and transport a large amount of carrot concentrated in one location and later to distribute small quantities of carrot to multiple locations, such as food banks, schools, social assistance institutions and others; 3) both farmers and social institutions struggle with shortage of labor force; 4) the volume and the quality of the disposed carrot is quite variable along the year.

Difficulties in carrying out on-farm data collection

Conducting field surveys to quantify carrot root loss in primary production is, in theory, relatively straightforward. Farms differ in relation to crop size and equipment used but the flux of work is basically the same in all of them: harvesting – washing – selection and packing. Besides that, there are no successive harvests in the same plot, as in leafy and fruit vegetables, and for that, the amount harvested and discarded in a single day, provides a good estimation of the harvest and packing house losses of the sampled crop. The difficulties, as in most cases, live in the details and they are both operational and methodological.

1. Partnership with farmers

The degree of cooperation from farmers and their staff usually decreases in successive surveys. After the first results are known, what is perceived by the researcher as the "critical points that demand improvements" are seen by the staff as "negative reviews on their work which is already very hard to do". Some partners and their staff do not differentiate the mandate of the many governmental institutions and consider the researcher to be either a government inspector who will apply fines over the "wrong doings" or an inspector hired by the bosses to inspect and evaluate their work.

If losses are perceived as high in the first surveys, changes in production, harvest or postharvest are implemented to minimize loss. Successive surveys, which were planned to measure the intrinsic variation under a given condition, become new surveys under new conditions. More importantly, changes based on a single survey can prove to be very poor choices over time, when they are made in response to conditions that were circumstantial and not will not be repeated over time.

2. Labor force

On-farm data collection includes a lot of physical work, travelling long distances, waking up very early in the morning and working long shifts in order to evaluate the samples before they lose weight or deteriorate.

Under these conditions, it is very hard to have assistants from the research institutions themselves or internship program. The first due to the bureaucracy involved in working outside the research unit and in working long shifts for few days. The second due to students not being available in the morning shift or in the afternoon shift depending on class schedules.

3. Representativeness of losses in the packing house

On-farm data collection should be done with the minimal possible interference on the way the work is done in the farm. In the packing house, the roots are washed, selected and packaged. The daily routine involves performing these operations rapidly due to the perishability of vegetables.

To wash the roots, Farm 1 used a cylindrical washer that is fed in batches; Farm 4 used a cylindrical washer with continuous feeding; Farms 2 and 3 used packing lines with continuous feeding. During data collection, there is an interval between samples to clean the washer and collect the roots trapped in the equipment. Under the conditions of Farm 1, the sample size should be equal to the batch size. Under the conditions of Farms 2, 3 and 4, the sample size should be equal to the smallest amount of roots that allow the equipment to operate under conditions that mimic real life, in view that too small samples will overestimate the amount of root breakage and the amount of roots retained in the washer.

During root selection, it is important to advise the staff to reproduce the same criteria and method they use to separate commercial and damaged roots in their routine. The amount of roots in each sample is much smaller than the normal amount of roots selected by the staff and the selection of the samples tends to be more careful. With that, the staff tends to eliminate common mistakes in their daily routine such as, placing undamaged roots in the discard and damaged roots in the commercial fraction. Furthermore, it is common do include some roots with small defects in the commercial fraction not by mistake, but intentionally, within the tolerance limits of each class. When selecting samples, they tend to be more rigorous, which can result in overestimation of loss at this stage.

4. Causes of loss

Identifying the causes of carrot loss is essential to elaborate solutions to reduce these losses. Depending on the cause, the solution will be related to improvements in the production system, in postharvest operations or in the operation of the market, among others.

However, despite its importance, this step limits the number of farms that can be included in the research, because it is time consuming and requires specialized labor to identify the defects.

Even for trained eyes there is an additional difficult: where to place roots which present more than one defect? Should they be included in one single class according to a scale of priority? Should they have a class of their own (simple sampling)? Should they be included in as many classes as the number of defects they have (systematic sampling)?

For this research, it was chosen to use a combination of simple sampling and order of priority. Damage caused by pests was considered the most important defect because these roots are always discarded, whether or not they have any other defects. However, it is very important to determine the quantity of broken roots (clearly resulting from poor handling) and the quantity of misshaped carrots (clearly resulting from errors in the production system). This was the reason to have 3 classes with roots damaged by pest, so that it is possible to know the total production of misshaped and broken carrots, with and without another associated defect. Arguments for establishing other classes are equally valid, depending on the research question to be answered.

A second difficult is related to whether, or not, to consider the extent of the damage (Figure 7). Should broken carrots be considered broken when only the tip is broken? How much deformed should a root be, to be considered misshapen?

5. Loss at harvest: food loss or yield loss?

Food loss at primary production is mainly understood by many researchers as the edible fraction discarded or not harvested, because it does not have the quality required by the market (size, shape, color), there is no market available or prices do not cover harvest costs. Decreases in production that occurs during cultivation, due to weather events, deficiencies in cultivation practices or biological agents, are not understood as food loss but as yield loss. According to this definition, a young carrot root damaged by bacterial soft rot before reaching harvest maturity is understood as yield loss, while a carrot damaged by bacterial soft rot after harvest is understood as food loss.

The boundaries are not so clear when a damaged root is ploughed from the soil and because it is damaged, it is discarded in the field. A carrot root damaged by pest, was infected before or after reaching harvest maturity? A split carrot was probably split before reaching maturity (yield loss) but it is edible and it is discarded because the market demands straight roots (food loss). Roots with growth cracks are discarded either because the crack is big enough to render the carrot inedible (yield loss) or because the market demands spotless straight roots and rejects edible cracked roots (food loss).

In the present research, the interest lies in estimating the proportion of the total production which is sold and discarded in the farm, and the reasons for that. From the farmer's point of view, this difference determines his profitability and, from the point of view of food security, it determines the amount of food available to the population. In both cases, it does not matter whether the cause of the loss arouse before or after harvest, but how it can be eliminated. Still, valid arguments can be used to decide otherwise, depending on the research question.

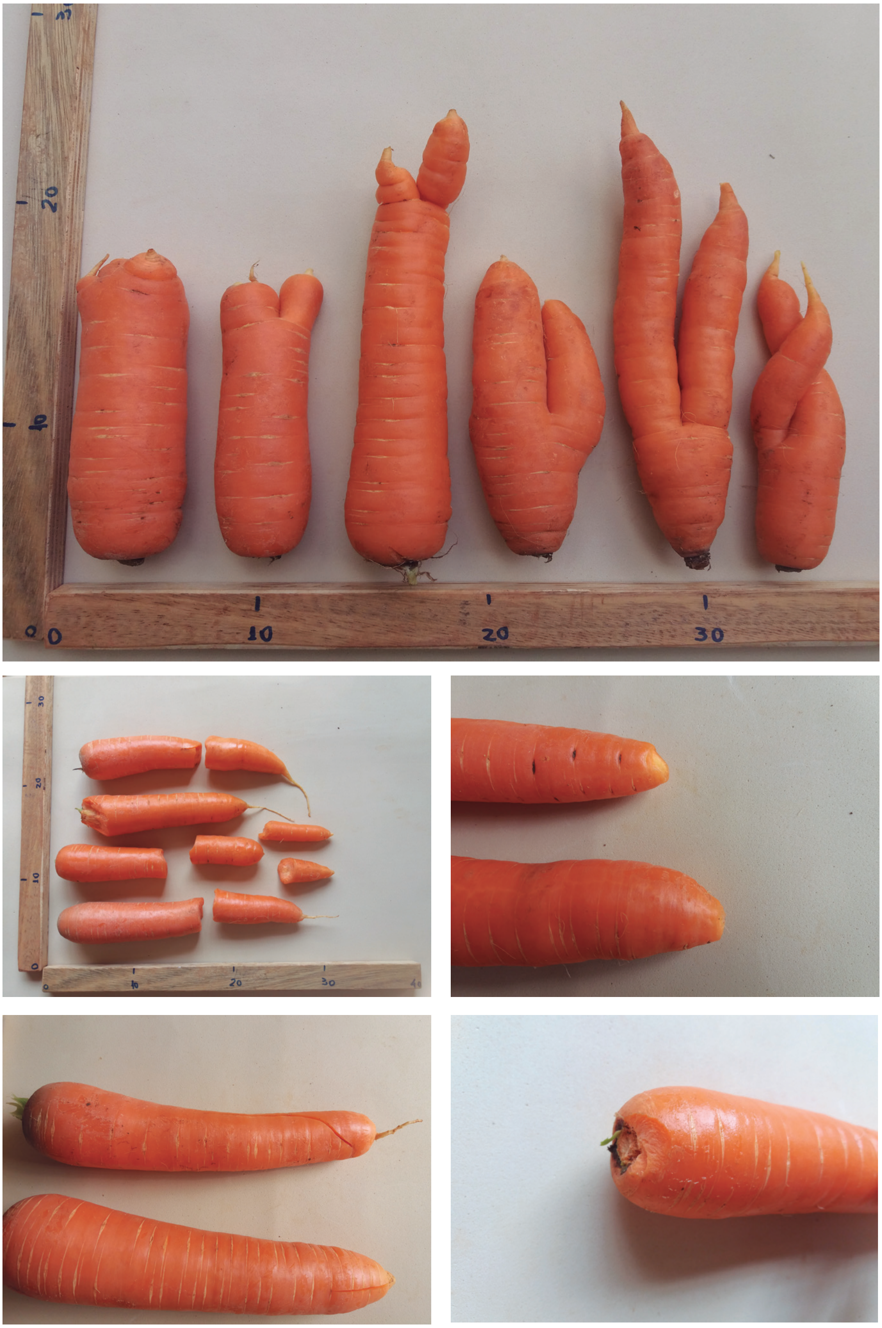

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Figure 7. Extent of damage in misshapen and broken roots.

Conclusions

The preliminary results reported here indicate that there is not one, but several carrot losses depending on the time of year, the production system and the farm evaluated. The accentuated differences in the volume of losses, between farms and between successive harvests in the same establishment, demonstrate the need for successive surveys throughout the year to obtain a reliable estimate of these losses.

Overall, the causes of loss, both in harvesting and in processing, were the same in both establishments, that is, roots outside the size and/or format accepted by customers and roots with symptoms of pest attacks. However, the limits that define each of these categories were different in each of them, as well as the destination of the fraction that could not be sold as whole carrots. The limits for each category may also vary in the same establishment throughout the year, depending on market behavior.

The obtained results also demonstrate that the losses in primary production can be reduced by adjustments in the production system to decreases the production of “damaged” roots as well as by changes in the demand from the market to increase the acceptance of “damaged” roots. In the first case, the benefits for the farmer are direct and more profitable as he manages to increase the proportion of the total production that is sold with the best classification and highest prices.

On large farms, there is enormous potential for donating roots with aesthetic defects to institutions such as food banks. To do so, however, it is necessary to overcome several difficulties, including: the lack of knowledge on both sides about each other’s existence; the supply of carrots is very variable throughout the year and the collection-transport-distribution infrastructure, established by the food bank to receive large donations, may be idle for part of the year; farms are far from food banks, which are mostly located in large cities. In the case of field loss, there is the additional difficulty of the farmer not having the interest or conditions to harvest and wash defective roots from which he will not obtain financial income. In this case, the food bank would need to have employees for these operations.

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