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Quantification of leafy vegetables loss at primary production – research limitations and proposed methodology for on-farm data collection

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ABSTRACT

Research discussed in this paper reports the difficulties related to on-farm data collection of leafy vegetables loss and proposes a method to estimate vegetable loss in an exploratory survey. Loss was estimated for rocket (*Eruca sativa*), coriander (*Coriandrum sativum*) and lettuce (*Lactuca sativa*) in two farms located in Federal District, Brazil. The best index to express loss due to unharvested plants was different whether the vegetable was marketed as plant units (lettuce) or bunches (rocket and coriander). The discard of rocket varied substantially between farms and between successive crops in the same farm. On Farm 1, it varied from 80.6% to 0.0% of the crop area and on Farm 2 from 42.4% to 72.4%. Loss of coriander on Farm 1 varied from 0.0% to 10.8% of the area, compared to 2.3% to 34.5% on Farm 2. The total loss for each lettuce type varied between and within farms. Considering individual surveys on both farms, the losses of lettuce varied from 1.6% to 84.8% of the plant population at harvest, depending on the lettuce type, crop and farm. Measuring losses of leafy vegetables at primary production proved to be quite challenging and time consuming. Two boundaries were particularly difficult to establish: marketable versus unmarketable produce and pre-harvest loss versus harvest loss. In view of the difficulties faced during the measurement of leafy vegetables loss at primary production, the methodology was changed in order to decrease the number of visits and the time of permanence in the farm necessary to accomplish a survey; be independent of data collection by the farmer and by the farm' staff; reduce the costs of displacement to the farm.

Keywords: *Eruca sativa*, *Coriandrum sativum*, *Lactuca sativa*, primary production, postharvest loss, food waste.

RESUMO

Limitações e proposta de metodologia para coleta de dados de perdas de hortaliças na produção primária

A pesquisa discutida neste artigo relata as dificuldades relacionadas à coleta de dados de perda de hortaliças folhosas na colheita e no beneficiamento e propõe um método para estimar as perdas em uma pesquisa exploratória. A perda foi estimada para rúcula (*Eruca sativa*), coentro (*Coriandrum sativum*) e alface (*Lactuca sativa*) em dois estabelecimentos agropecuários (EA) localizados no Distrito Federal, Brasil. O melhor índice para expressar a perda foi diferente se a hortaliça é comercializada em unidades (alface) ou em maços (rúcula e coentro). A perda de rúcula variou entre estabelecimentos e entre safras sucessivas em um mesmo estabelecimento. No EA 1, ela variou de 80,6% a 0,0% da área plantada e no EA 2, de 42,4% a 72,4% da área. A perda de coentro no EA 1 variou de 0,0% a 10,8% da área, comparada à variação de 2,3% a 34,5% no EA 2. A perda total para cada tipo de alface (crespa, lisa, roxa e mimosa) também variou entre estabelecimentos e entre safras sucessivas em um mesmo estabelecimento. Considerando os levantamentos individuais em ambos EA, a perda de alface crespa variou de 1,4% a 84,8% da população de plantas no início da colheita, a depender do EA, da safra e do tipo de alface. Medir as perdas de hortaliças folhosas na produção primária mostrou-se bastante difícil e demorado. Dois limites foram particularmente difíceis de estabelecer: produtos comercializáveis versus não comercializáveis e perda de produtividade versus perda de alimentos. Tendo em vista as dificuldades enfrentadas durante a mensuração da perda de hortaliças folhosas na produção primária, a metodologia foi alterada para diminuir o número de visitas e o tempo de permanência nos EA necessários para a realização do levantamento; ser independente da coleta de dados pelo agricultor e pela equipe do EA; reduzir os custos de deslocamento para os EA.

Palavras-chave: *Eruca sativa*, *Coriandrum sativum*, *Lactuca sativa*, perdas pós-colheita, desperdício de alimentos.

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Vegetable loss at primary production includes vegetables that are harvested and discarded during harvest or during preparation for the market and vegetables left unharvested in the field. Data on vegetable loss at primary production are important, at a national level, to support public policies on food security and on sustainable agriculture. At farm level, they are an important tool to increase the marketable yield (Johnson, 2018; WRAP, 2021a,b). By identifying the volume and causes of loss, it is possible to identify which actions are the most appropriate to reduce these losses. The necessary actions may include changes in production systems (e.g. planting schedule, harvest maturity), farm management (e.g. harvest crew size and training), market and consumer preference (e.g. standard specifications, creation of alternative market), among others.

The most used methods to study food loss on-farm level are the analysis of secondary data (Redlingshofer *et al*., 2017; Porter *et al*., 2018; WRAP, 2019); interviews (Roels, 2017; 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,b; Baker *et al*., 2019) and the combination of two or more methods (Franke *et al*., 2016).

The method of choice will depend on the purpose of the study, the needed effort and the cost. Interviews are easier to do compared with on-farm data collection but they tend to underestimate the amount of food loss. In the United Kingdom, levels of lettuce loss found through data collection were consistently higher than loss determined through interviews, respectively 33% and 17% on average (WRAP, 2017).

The geographical location of the farms, scattered and far from the research centers, makes on farm data collection very time consuming and costly. On the other hand, this kind of research is a unique opportunity to identify critical points and to identify the need for innovation, public policies and intervention, in order to reduce food loss.

In Brazil, the limited availability of consolidated data for vegetable production and marketing makes analysis of secondary data quite challenging, compared with the same analysis in more organized supply chains like grains and meat. The main sources of data are the agricultural census by IBGE (Brazilian Institute of Geography and Statistics) and market data provided by CEASA (wholesale fresh food market). The difference between the amount planted (IBGE) and marketed (CEASA) could be a rough estimate of food loss. However, data from CEASA do not include vegetables sold directly to supermarkets, main market channel for leafy vegetables in Brazil.

There are other difficulties involved in obtaining primary data on losses in primary production. One of them is to decide how it should be classified. Johnson *et al*. (2018a,b), sorted the vegetables left in the field after harvest in three classes, namely marketable, edible but unmarketable, and inedible. The main problem of this approach is that the boundaries of each class are changeable. Defects that render the produce unmarketable when prices are high are accepted when prices are low or when there is shortage of the produce. In a country as economically unequal as Brazil, it should be taken into account that quality standards are not uniform in markets that serve different income groups.

Ward (2018) proposed that wastes generated during primary production can be broadly summarized as 'practice based', the waste generated during the operations of growing and harvesting the crops and 'market based', the waste generated as a result of external market events that influence production on the farm. This classification does help to identify the need for before and for post-gate-oriented solutions. However, it does not take into account the very frequent overlapping of causes that happens on the vegetable supply chain. For example, predation by trips on leaf vegetables can result in spots that do not render the vegetable inedible but decreases visual quality ('practice based') and this produce is rejected by the marker because it does not meet cosmetic specifications ('market based').

The distinction between yield loss and food loss is another topic of debate. FAO (2018) excluded pre-harvest and harvest losses from the Global Food Loss Index. Similarly, Strid & Eriksson (2014) considered that damaged lettuce heads left on the field are part of yield loss and only unharvested high-quality heads were considered food loss. On the other hand, WRAP (2017) considered loss due to pest and disease damage arising after the crop had matured as food loss.

In studies related to food security, the interest lies in the part of the plant which is used as food and for that, inedible parts of the plant left in the field and damaged parts that are trimmed should not be considered food loss. However, in studies related to the potential for re-use, recycling or composting (Rogers *et al*., 2013), both inedible and edible parts are of interest. In this case, the distinction must be made between organic waste and food loss.

Discard due to delivery return from the retailer do not happen at farm level but when the economic cost of it is taken by the farm, it can be considered part of the food loss at primary production. However, it is not easy to measure this fraction, in part because it occurs in a very irregular frequency. In order to express it a proportion of total production, it would be necessary to have data from both the retailer and the supplier in the same period, what can be quite difficult to do.

After defining which fractions are part of food loss and which are part of organic waste, comes the question on how to express food loss. The most intuitive index is the proportion of the total yield represented by the loss (mass of loss / mass of total yield) expressed as a ratio or as a percentage. In order to compare the index measured in different farms, these data should be calculated in terms of area covered by the crop.

Research discussed in this paper aims to propose a method to estimate the losses of leafy vegetables at primary production as much as to report the difficulties and limitations encountered in this kind of study. The study took place on two farms differing in the adoption of good practices during harvest and post-harvest and involved three crops: lettuce, rocket and coriander.

MATERIAL AND METHODS

The methodology was based on the one used to estimate carrot losses in primary production (Lana & Moita, 2020). Its principle is to measure the area harvested, the amount of produce harvested and discarded during harvest, the amount of produce which is discarded later in the packing house and the amount of plants not harvested in the same area.

For leafy vegetables, the numbers of unities (head or bunch) are counted and loss can be expressed as a proportion of the number of unities harvested or as the number of unities per area. By sampling and weighting a number of unities, it is possible to estimate the discard, the total production and the commercial production as mass/area (e.g. kg/hectare). The total loss is estimated by the sum of losses in each harvest day plus the loss represented by the unharvested plants after both are converted to a common index, namely number or mass of plants per hectare.

Scope and fractions

In this study, the vegetable loss at primary production was studied from the point of view of food security and the farmer profitability and it included plants harvested and discarded in the field and in the packing house and plants left unharvested in the field. The study aims to estimate which fraction of the total production the farmer is not able to sell because the produce has low quality for the market intended; the market price does not cover the costs of production and/or harvesting and delivery; there is no client for the produce.

The resulting decrease in the offer of vegetables to the market can impact food security through the decrease in the amount and diversity of food available and/or the increase in price when the demand is higher than the offer. Leaves discarded due to trimming in the field and in the packing house were not considered part of food loss. A more or less intense trimming will impact the amount of food available but this was considered an aspect of production yield and not food loss. Nonedible parts, left in the field, were not considered food loss either because they are not part of the commercial produce and do not impact the farmer's profit. The final destination of the unharvested fraction was considered as food loss, independently of its destination (incorporation into the soil, animal feeding, donation or other).

Study site and plant material

Loss at primary production was estimated for rocket (*Eruca sativa*), coriander (*Coriandrum sativum*) and 4 types of lettuce (*Lactuca sativa*), namely green leaf, butterhead, purple and oakleaf.

The research was conducted in two farms in Federal District, Brazil. Farm 1 is a small farm producing only leafy vegetables by conventional open-field production. The postharvest infrastructure in this farm is precarious and handling during harvest and preparation of the produce to the market is poor. The vegetables are delivered by the farmer to supermarket chains or sold at the farm to intermediaries. Farm 2 is a medium organic farm, producing a large range of leafy, fruit and root vegetables. Leafy vegetables are produced in open-field or under plastic tunnels depending on the time of the year. The farm has a well-structured packing house including a refrigerated room where the vegetables are stacked before delivery and handling follows good practice guidelines. The vegetables are delivered by the farmer to supermarket chains and to their own-brand stores.

Both farms produce the studied vegetables all over the year. New crops are planted at regular intervals to guarantee a constant supply and harvest of each crop typically lasts for 1 to 2 weeks in Farm 1 and 1 week in Farm 2.

Workflow description from harvest up to before shipment

The first stage of the research was to build a flux of work, to identify the potential critical points for food loss and differentiate food loss from yield loss. This was done by *in situ* observation. The first stage of the study was the mapping of all operations starting with harvesting the product in the field until it is ready for shipment. Then, the operations were described together with the identification of the steps in which there is any disposal of the whole vegetable or parts of the vegetable to separate food loss and yield loss and ultimately to determine at which point loss should be measured.

Rocket and coriander loss quantification

Each crop was surveyed three times in each farm along the period from June 2021 to Abril 2022.

The study was carried out in two stages.

1) During the harvest period: measurements were made daily, from Monday to Friday, for the duration of the harvest period. At each evaluation day, the following data were collected:

- Length of harvested bed.
- Number of bunches harvested.
- Number of bunches discarded in the field.
- Weight of 15 bunches (Farm 1) or of 5 crates containing twelve bunches of rocket or twenty-five bunches of coriander (Farm 2).
- Number of bunches discarded in the packing house.

2) After the harvest period, the following data were collected: area harvested and area not harvested. Weight of remaining plants in 5 representative samples, 1 meter long, in each area, harvested and not harvested.

Vegetable loss was estimated as number of bunches per area, mass of bunches per area and area not harvested.

The number of bunches harvested and discarded at each measuring day, as well as the area where they were harvested, were summed and this total extrapolated to bunches per hectare. Yield and loss as mass (kg)/area (hectare) were calculated on an overall basis, i.e., considering the area from mid-wheeling to mid-wheeling equal to 1.5 meters, so that every bed length of 1 meter corresponded to an area of 1.5 square meter. To estimate the mass of plants per hectare, the average mass of a single bunch was multiplied by the number of bunches per hectare.

To estimate the proportion of the crop area that was not harvested, the total length of the beds not harvested was divided by the total length of the beds in the total crop field.

Lettuce loss quantification

Each crop was surveyed three times in each farm along the period from June 2021 to Abril 2022.

The study was carried out in three stages.

a) Before the harvest period: plant population was estimated by counting the number of plants in 5 representative areas 5 meters long. The number of plants per hectare was calculated on an overall basis, i.e., considering the area from mid-wheeling to mid-wheeling equal to 1.5 meters, so that every bed length of 5 meters corresponded to an area of 7.5 square meters.

b) During the harvest period: measurements were made daily, from Monday to Friday, for the duration of the harvest period. At each evaluation day, the following data were collected:

1) Length of harvested bed.

2) Number of unities harvested.

3) Number of units discarded in the field.

4) Weight of 15 units (Farm 1) or 5 crates containing 10 units of leaf lettuce or twelve units of purple, oakleaf and butterhead lettuce (Farm 2).

5) Number of units discarded in the packing house.

The number of unities harvested and discarded at each measuring day, as well as the area where they were harvested, were summed and this total extrapolated to unities per hectare. Yield and loss as mass (kg)/area (hectare) were calculated on an overall basis, i.e., considering the area from mid-wheeling to mid-wheeling equal to 1.5 meters, so that every bed length of 1 meter corresponded to an area of 1.5 square meter. To estimate the mass of plants per hectare, the average mass of a single unit was multiplied by the number of unities per hectare.

c) After the harvest season/period: all the plants remaining in the field were counted.

Total loss was obtained as the sum of loss at harvest, in the packing house and the plants remaining in the field, after each fraction was converted to the same basis, namely number of plants per hectare.

Statistical treatment of data

Descriptive statistics were used to calculate the mean and the standard deviation of three surveys, for each variable of study.

RESULTS AND DISCUSSION

The loss at primary production for each leafy vegetable studied varied between and within farms. To allow the reader to have a full extent of these variations the result of each individual survey is shown together with the mean obtained for each vegetable. Data report is followed by the discussion of the limitations and difficulties encountered during the survey and the methodology proposed in view of those.

Rocket and coriander workflow description and loss quantification

The first steps of the study were to describe the flux of work, identify the potential critical points for food loss and differentiate food loss from yield loss.

The flux of work for both coriander and rocket from Farm 1 was the following:

1) The plants are cut with a knife or pulled out of the ground, cleaned to remove damaged leaves and tied in bunches that are placed over the beds. Harvest is done in the afternoon and always preceded by a short irrigation of the crop.

2) The bunches are collected, placed in a wheelbarrow and transported to the packing house. The bunches are compressed to make it possible to transport hundreds of bunches in a single wheelbarrow.

3) The bunches are immersed in a water tank for few minutes, removed and placed in plastic crates.

4) The bunches are packaged in plastic bags, placed in plastic crates and

Table 1. Rocket and coriander production and loss due to unharvested plants. Brasília, Embrapa Hortaliças, 2022.

Item	Survey	Rocket		Coriander	
		Farm 1	Farm 2	Farm 1	Farm 2
Vegetable loss in the field (% of the crop area)	1	80.6	42.4	5.9	28.7
	2	2.1	72.4	10.8	34.5
	3	0.0	44.0	0.0	2.3
	Average ± standard deviation	27.6 ± 45.9	52.9 ± 16.9	5.6 ± 5.4	21.8 ± 17.1
Average weight of the harvested bunch (g)	1	0.268	0.298	0.148	0.154
	2	0.183	0.319	0.143	0.147
	3	0.171	0.339	0.114	0.132
	Average ± standard deviation	0.207 ± 0.053	0.319 ± 0.021	0.135 ± 0.019	0.144 ± 0.011
Estimated number of harvested bunches/ hectare	1	13,301	37,710	100,74	31,546
	2	70,809	44,250	88,749	9,438
	3	41,874	47,458	75,309	37,383
	Average ± standard deviation	41,995 ± 28,754	43,140 ± 4,968	88,266 ± 12,723	26,122 ± 14,741
Estimated mass (kg) of harvested bunches/ hectare	1	3,558	11,234	14,910	5,868
	2	12,958	14,098	12,721	1,389
	3	7,170	16,103	8,560	4,919
	Average ± standard deviation	7,895 ± 4,742	13,282 ± 2,447	12,063 ± 3,225	4,059 ± 2,360

loaded in the truck later in the evening.

The flux of work for both coriander and rocket from Farm 2 was the following:

1) The plants are pulled out of the ground, cleaned to remove damaged leaves and tied in bunches that are placed over the beds. Harvest is done early in the morning.

2) The bunches are collected, placed in harvest plastic crates (12 bunches of rocket and 25 bunches of coriander per crate) and transported to the packing house by a wagon covered with canvas, attached to the tractor. The crates of rocket are pilled under shadow soon after harvest, in a mobile unit stationed at the side of the field.

3) The plastic ribbon holding the bunches is removed, the bunches are trimmed to remove remaining damaged leaves, washed under running water and placed untied in plastic bags.

4) The plastic bags are placed in clean plastic crates used to transport the vegetables to the market, stacked in a refrigerated room and loaded in the truck later in the evening.

In order to identify which fractions should be considered food loss, during

Table 2. Leaf and purple lettuce loss during harvest (in the field) and during preparation for the market (in the packing house). Brasília, Embrapa Hortaliças, 2022**.**

Item	Survey	Leaf lettuce		Purple lettuce	
		Farm 1	Farm 2	Farm 1	Farm 2
(I) Average weight (kg) of one unit (head)	1	0.429	0.383	0.315	0.314
	2	0.598	0.355	0.209	0.290
	3	0.429	0.295	0.347	0.288
	Average ± standard deviation	0.485 ± 0.098	0.344 ± 0.045	0.290 ± 0.072	0.297 ± 0.014
(II) Number of plants / hectare, before harvest	1	61,054	70,181	67,512	65,300
	2	54,942	78,160	47,059	79,631
	3	43,490	74,766	62,554	79,783
	Average ± standard deviation	53,162 ± 8,916	74,369 ± 4,004	59,042 ± 10,669	74,905 ± 8,318
(III) Number of plants /hectare not harvested	1	13,723	2,203	9,049	226
	2	8,380	5,265	2,810	2,232
	3	5,634	5,608	8,796	1,065
	Average ± standard deviation	9,246 ± 4,113	4,479 ± 1,971	6,885 ± 3,531	1,174 ± 1,008
(IV) Number of plants/ hectare harvested (IV) = (II) – (III)	1	47,331	67,978	58,463	65,074
	2	46,562	72,895	44,249	77,399
	3	37,856	69,158	53,758	78,718
	Average ± standard deviation	43,916 ± 5,262	70,010 ± 2,567	52,157 ± 7,241	73,730 ± 7,526
(V) Number of plants discarded at harvest and in the packing house (% of the total number of harvested plants)	1	5.2	1.3	2.6	1.3
	2	5.5	1.3	1.4	1.2
	3	1.7	0.5	0.7	0.7
	Average ± standard deviation	4.1 + 2.1	1.0 + 0.5	1.6 + 1.0	1.1 + 0.3
(VI) Number of plants /hectare discarded during harvest and in the packing house (VI) = (IV)*(V)/100	1	2,461	884	1,520	846
	2	2,561	948	619	929
	3	644	346	376	551
	Average ± standard deviation	1,889 ± 1,079	726 ± 331	839 ± 603	755 ± 199
(VII) Total loss in number of plants / hectare (VII) = (III) + (VI)	1	16,184	3,087	10,569	1,072
	2	6,149	6,213	3,429	3,161
	3	6,302	5,954	9,172	3,348
	Average ± standard deviation	9,545 ± 5,570	5,084 + 1,735	7,724 ± 3,784	3,393 ± 2,445
(VIII) Total loss in % of the number of plants before harvest (VIII) = (VII) * 100/ (I)	1	26.5	4.4	15.7	1.6
	2	11.2	7.9	7.3	4.0
	3	14.5	8.0	14.7	4.2
	Average ± standard deviation	17.4 ± 8.1	6.8 ± 2.1	12.5 ± 4.6	4.4 ± 2.9

and after harvest, it was considered that the farmer harvests and sells bunches of rocket and coriander and expects to harvest 100% of the planted area. How many bunches are harvested per area, the bunch size and the mass of leaves discarded during trimming are related to crop yield and not to food loss. Loss would be then composed by the plants not harvested and by bunches harvested and later discarded in the field or in the packing house (Box 1). On both farms, the discard of bunches during harvest was quite rare and usually due to operational errors such as harvesting more bunches than demanded or leaving bunches behind by mistake.

To quantify the losses in the packing

Table 3. Oakleaf and butterhead lettuce loss during harvest (in the field) and during preparation for the market (in the packing house). Brasília, Embrapa Hortaliças, 2022**.**

Item	Survey	Oakleaf lettuce		Butterhead lettuce	
		Farm 1	Farm 2	Farm 1	Farm 2
(I) Average weight (kg) of one unit (head)	1	0.455	0.319	416	0.316
	2	0.439	0.303	424	0.305
	3	0.493	0.316	457	0.351
	Average ± standard deviation	0.462 ± 0.028	0.313 ± 0.009	0.432 ± 0.022	0.324 ± 0.024
(II) Number of plants / hectare, before harvest	1	60,473	67,498	63,857	74,964
	2	38,961	83,599	59,048	83,433
	3	54,805	85312	36,786	87,281
	Average ± standard deviation	51,413 ± 11,150	78,803 ± 9,828	53,230 ± 14,443	81,893 ± 6,301
(III) Number of plants / hectare not harvested	1	5,306	514	7,574	1,869
	2	33,053	18,648	49,003	1,468
	3	42,690	3,126	23,514	1,544
	Average ± standard deviation	27,016 ± 19,409	7,429 ± 9,803	26,697 ± 20,897	1,627 ± 213
(IV) Number of plants/ hectare harvested (IV) = (II) – (III)	1	55,167	66,984	56,283	73,095
	2	5,908	64,951	10,045	81,965
	3	12,115	82,186	13,272	85,737
	Average standard deviation	24,397 ± 26,828	71,374 ± 9,419	26,533 ± 25,814	80,266 ± 6,490
(V) Number of plants discarded at harvest and in the packing house (% of the total number of harvested plants)	1	5.9	1.2	4.9	1.4
	2	0.0	2.6	7.3	1.7
	3	3.4	0.8	0.0	0.9
	Average ± standard deviation	3.1 ± 3.0	1.5 ± 0.9	4.1 ± 3.7	1.3 ± 0.4
(VI) Number of plants / hectare discarded during harvest and in the packing house (VI) = (IV)*(V)/100	1	3,255	804	2,758	1,023
	2	0	1,689	733	1,393
	3	412	657	0	772
	Average ± standard deviation	1,222 ± 1,772	1,050 ± 558	1,164 ± 1,428	1,063 ± 313
(VII) Total loss in number of plants / hectare (VII) = (III) + (VI)	1	8,561	1,318	10,332	2,892
	2	33,053	22,120	49,736	2,861
	3	43,102	3,126	23,514	2,316
	Average ± standard deviation	28,239 ± 17,767	8,855 ± 11,524	27,861 ± 20,059	2,690 ± 324
(VIII) Total loss in % of the number of plants before harvest (VIII) = (VII) * 100/ (I)	1	14.2	2.0	16.2	3.9
	2	84.8	26.5	84.2	3.4
	3	78.6	3.7	63.9	2.7
	Average ± standard deviation	59.2 ± 39.1	10.7 ± 13.7	54.8 ± 34.9	3.3 ± 0.6

house, the first step was to identify which discards are made at this stage (Box 1). During the washing of the bunches on Farm 2, a new cleaning is carried out, discarding old and damaged leaves. Eventually, whole bunches with nonconformities are discarded during washing or during quality control before shipping the produce. On Farm 1, no further trimming is done after harvest.

Both farmers reported no discard of rocket in the packing house, informing they harvest the exact amount they need and that they perform the selection during harvest. Farm 1 reported no discard of coriander in the packing house and Farm 2 reported respectively 8.7% and 1.0% and 0.0% of the number of harvested bunches for the three successive harvests evaluated. However, we collected information that sometimes there was discarding during preparation for the market and occasionally it was necessary to harvest extra amounts to complete the cargo. In view of that, loss due to discard in the packing house could not be estimated with accuracy but all evidence points to it being much smaller than loss due to unharvested plants, when the whole harvest season is considered.

The mass of rocket plants left in the field in the harvested and in the unharvested area was respectively 0.09 ± 0.08 kg/meter and 3.96 ± 0.75 for Farm 1 and 0.27 ± 0.31 kg/meter and 3.17 ± 1.37 kg/meter for Farm 2. However, in both areas, the plants were left behind because they were either too small or too big for the market. Estimating loss by the weight of these plants results in under or over estimation, respectively, in comparison with the mass of plants at marketable size. These numbers are more important to estimate the amount of organic waste available for any other use alternative to human feeding, than to estimate food loss. When the unharvested vegetables are proper for human consumption, it is also an estimate of food available for gleaning.

The same line of reasoning applies to coriander. The mass of unharvested plants in the harvested and in the unharvested area were respectively 0.05 ± 0.02 kg/meter and 3.53 ± 0.53 for Farm 1 and 0.29 ± 0.32 kg/meter and 1.17 ± 0.36 kg/meter for Farm 2.

As the work progressed, it became clear that a more representative estimation of the loss experienced by the farmer is the proportion of the area of the crop that is not harvested and from the second survey on, this was the method used.

Loss of rocket varied substantially between farms and between successive crops in the same farm (Box 1). On Farm 1, it decreased from 80.6% of the planted area in the first survey to 0.0% in the last. This was due, at least in part, to the awareness of the farmer, after the first survey, that the area planted was far above the amount demanded by his clients and when it was not possible to sell all the crop at due time, the plants grew above the market standard. When the planted area was reduced, and the plants were harvested earlier, there was no discard. On Farm 2, the area not harvested varied from 42.4% to 72.4% of the crop area.

Loss of coriander on Farm 1 varied from 0.0% to 10.8% of the area, compared to 2.3% to 34.5% on Farm 2 (Box 1). However, on Farm 1, the loss of coriander reached 59.2% of the area in a preliminary survey where only the final area was measured. This indicates that higher losses may happen when the survey is extended for a longer time period.

Losses of rocket and coriander were, on both farms, due to plant size above or under market standards. The plants were

Box 1. Identification of fractions of rocket and coriander loss at primary production, field and packing house. Brasília, Embrapa Hortaliças, 2022.

Aim	Fraction	Conclusion
To identify which fraction constitutes food loss during harvest, in the field.	Mass of damaged leaves discarded when tying the bunch in the field.	Considered agricultural or yield loss, linked to crop productivity.
	Number of bunches harvested and discarded in the field.	Considered food loss.
	Mass of remaining plants, made up of very small plants, in a previously harvested area.	Considered agricultural or yield loss, linked to crop productivity.
	Mass of plants left unharvested after the harvest period is over.	Considered food loss.
	Area left unharvested after the harvest period is over.	Considered food loss.
To identify which fraction constitutes food loss during preparation of the produce to the market, in the packing house.	Mass of damaged leaves discarded when washing and packing the bunch in the packing house.	Considered agricultural or yield loss, linked to crop productivity.
	Number of bunch unities discarded in the packing house.	Considered food loss.
	Number of bunch unities packed together as one, so that 2 harvested bunch yield 1 commercial bunch.	Considered agricultural or yield loss, linked to crop productivity.

edible and could have been donated to food banks or gleaned. Exceptions for this were the second field of rocket on Farm 1 and the third field of coriander on Farm 2 where the plants were damaged. However, in both cases the mass of plants was negligible and they corresponded to about 2% of the total area of the crop.

It is worthy to mention that although the losses of rocket were due to plant size on both Farms, the reasons for that were not exactly the same. On Farm 2, a much-planned weekly planting scheme, linked to the programmed sale volume, and a very strict quality control results in crops being abandoned when plants are above standard size and the next crop is already on the required size. The bigger plants cannot be used as raw material for the minimally processed salads in the same farm either, because they are considered of low quality due to the larger petioles and midrib compared to younger plants. On Farm 1, a larger range of sizes is sold and the farmer is used to planting more that is already programmed to sell, so that in case a not expected client arrives, he will have produce to buy. When this client does not show up, the crop is lost.

Lettuce workflow description and loss quantification

The flux of work for lettuce from Farm 1 was the following: the plants are cut with a knife, cleaned to remove damaged leaves and placed on the beds. Harvest is done in the afternoon and always preceded by a short irrigation of the crop.

1) The plants are collected, placed in a wheelbarrow and transported to the packing house. The plants are compressed to make it possible to transport dozens of plants in a single wheelbarrow.

2) The lettuce heads are immersed in a water tank for few minutes, removed and placed in plastic crates.

3) The lettuce is packaged in plastic bags, which in turn are placed in plastic crates and loaded in the truck later in the evening.

The flux of work for lettuce from Farm 2 was the following:

1) The plants are cut with a knife, cleaned to remove damaged leaves and placed on the beds that are covered by plastic mulching. Harvest is done early in the morning.

2) The plants are collected and packed in open plastic bags.

3) The bags are placed in plastic crates (10 units of leaf lettuce and 12 units of butterhead, purple and oakleaf lettuce per crate) and transported to the packing house by a wagon covered with canvas, attached to the tractor.

4) The plastic crates are stacked in a refrigerated room and loaded in the truck later in the evening.

The fractions that should be considered food loss, during and after harvest, are described in Box 2. For that, it was considered that the farmer harvests and sells units (heads) of lettuce and expects to harvest 100% of the heads present in the field when harvest begins. Loss would be then composed by the unharvested plants and by those harvested and later discarded in the field or in the packing house. For each harvest day the proportion of discarded units was calculated in relation to the number of harvested units and this proportion was later extrapolated to the whole field. Leaves discarded by trimming were not considered food loss under the same line of reasoning described for rocket and coriander.

When measuring the loss of lettuce, from the point of view of the farmer's profitability, the best way is to count the number of units that were not sold. Most of the unharvested or discarded lettuce heads are the ones that are too small or too big for the market. If loss is estimated by weighing instead of counting, it will be underestimated in the first scenario and overestimated in the second. They represent an equivalent loss in mass of lettuce, estimated from the average marketable weight of a lettuce head.

When counting the unharvested

Box 2. Identification of fractions of lettuce loss at primary production, field and packing house. Brasília, Embrapa Hortaliças, 2022.

Aim	Fraction	Conclusion
To identify which fraction constitutes food loss during harvest, in the field.	Mass of damaged leaves discarded when trimming the plant in the field.	Considered agricultural or yield loss, linked to crop productivity.
	Number of plants harvested and discarded in the field.	Considered food loss.
	Number of plants left unharvested after the harvest period is over.	Considered food loss.
To identify which fraction constitutes food loss during preparation of the produce to the market, in the packing house.	Mass of damaged leaves discarded when washing and packing the plant in the packing house.	Considered agricultural or yield loss, linked to crop productivity.
	Number of plant unities discarded in the packing house.	Considered food loss.
	Number of pair of unities packed together as one, so that 2 harvested plants yield 1 commercial package.	Considered agricultural or yield loss, linked to crop productivity.

plants, it was particularly difficulty to decide whether plants that were partially or totally rotten should be considered food loss or yield loss. If one follows the criteria used by WRAP (2017), rotten plants would be part of food loss when they were damaged after attaining commercial size and part of yield loss when they were damaged before attaining commercial size. In practice, these boundaries are not that clear. At this stage of the research, when no previous information about the amount and cause of leafy vegetables loss at primary production was available, it was chosen to count all plants left behind, no matter the reason for that. If the extent of loss due to unharvested plants showed to be economically important, the determination and quantification of each particular cause would then be considered in the next stage of the research.

The total loss for each lettuce type varied between and within farms. Considering individual surveys on both farms, the losses of leaf lettuce varied from 4.4% to 26.5% of the plant population at harvest (Table 2). The values obtained for purple lettuce varied from 1.6% to 15.7% (Table 2). The loss of oakleaf and butterhead lettuce varied even more, respectively from 2.0% to 84.8% and from 2.7 to 84.2% (Table 3).

The number of plants discarded during harvest and in the packing house was superior to the number of unharvested plants in two surveys: survey 1) purple lettuce and survey 2) oakleaf lettuce, both on Farm 2. However, when the average for the harvest season was calculated, the loss due to unharvested plants was superior to that due to discard during harvest and preparation for the market.

The causes for discard of lettuce were more varied than that observed for rocket and coriander. They were, in order of importance, improper size, disease and flower initiation. On Farm 1, the incidence of rots and virus diseases was visibly higher than that observed on Farm 2 and contributed to its higher loss. On the other hand, Farm 2 had a more adjusted production system, which resulted in a more uniform plant growth and a higher proportion of plants with the quality demanded by the market. Farm 2 also benefited from a processing plant which provided an outlet for out of specification lettuce, similar to what was reported by Rogers *et al*. (2013) in Australia. However, processing had a lower effect on preventing the loss of rocket because the demands for a specific size are equally strict when the rocket is sold un-processed or minimally processed.

Farm 1 serves a much less demanding market in terms of quality compared to Farm 2, which does not prevent it from having higher volumes of lettuce loss (Tables 2 and 3). This is largely due to failures in the production system and in the production planning in relation to market demand. In the expectation of serving occasional customers, Farm 1 plants an area larger than the one that would serve regular customers. In the case of oakleaf and butterhead lettuces, the demand is very small, few units per day, and most of the plants grow beyond the standard size and start flowering before they are harvested. Even so, the farmer grows them because of the mixture demanded by the customers. All growers interviewed in a survey made in UK by Ward (2018) reported over-production on the range of 10 to 15% because they consider that it is much more costly to not have enough produce to supply their clients than to have a certain level of loss.

The quantification of each particular cause of discard in relation to the total loss was not done at this stage of the research. This was due to shortage of specialized labor, necessary to identify the causes; very short time available to analyze the samples, because the farmer wants to prepare the area for new crops immediately after finishing harvest; and methodological uncertainties to differentiate the reasons for discard when the plants are damaged or rotten. In the last case, it was not clear whether damaged plants were not harvested due to the damage or for another reason that preceded the damage visible at the time of the survey, when the crop had been abandoned by the farmer.

Methodological uncertainties also prevented the quantification of the inedible and the edible but unmarketable fractions of the discard. In this case, it is necessary to establish a clear boundary that separates each fraction taking into consideration that different markets have different quality standards. Part of the edible but unmarketable fractions of the discard on Farm 2, for example, are considered marketable on Farm 1.

Difficulties and limitations encountered during the survey

Measuring losses of leafy vegetables at primary production proved to be quite challenging. To start with, the harvest of a field lasts for many days, the amount harvested in each day is relatively small, successive harvests are done in the same plot, and it was rarely possible to survey all the vegetables of interest in the same day. All together demanded many displacements to the farm, making the research costly and time-consuming. Some surveys could not be concluded because the fields were deactivated by the farmer, before the plants not harvested were counted by the researcher.

Differences among farms in relation to their field size, spatial design, harvest and post-harvest practices demanded small adjustments in the size of the samples and at which point the samples were weighed to accommodate for these differences.

On both farms, when the crop growth was uniform, the plants were harvested in a continuous length of the bed, making it possible to estimate the productivity and the discard as number and mass of plants per harvested area, at each harvest day. The daily harvested bed length, number of unities harvest and discarded, and mass of plants left in the harvested bed length were summed and this value was extrapolated for a hectare.

However, when the growth of the plants was not uniform, the bigger plants were harvested earlier in a scattered way, followed few days later by the harvest of some of the plants that were left behind in the same area. Under the last condition it is not possible to estimate loss at harvest as done for single harvest crops (Lana & Moita, 2020) where the production and the loss are calculated in relation to the area harvested. Instead, loss at harvest had to be calculated in relation to the amount harvested the day of the survey. The best index to express loss due to unharvested plants was different whether the vegetable was marketed as plant units (lettuce) or bunches (rocket and coriander) as discussed in detail further on.

Measuring packing house losses proved to be even more challenging than measuring field losses. In theory, it is a very straightforward measurement where loss is the difference between the number of vegetable units entering and leaving the packing house. One can count the number of discarded units or the number of units actually sold to calculate the loss as a proportion of the number of units harvested. In practice, it is very difficult to collect these data in real time because the preparation of the produce for the market is done late in the day or in the evening; the operations are very speedy, and the presence of the researcher collecting data does disturb the flux of work.

Initially, an attempt was made to sample 5 crates in the field and quantify the losses of these samples in the packing house, in a repeated measurements design. This proved unfeasible without changing the way the produce is handled in the packing house. Afterwards, the following approaches were tried without success: count the discarded units that were separated by the staff, the day after the operation; to ask the staff to write down the number of units discarded; use the sales data supplied by the farmer. All of them provided inconsistent data.

Sales data do not include bonus given to the clients; part of the discard was given to animals and this amount was not reported; Farm 1 had no routine to register these data and the staff had difficulties do it just for the sake of this survey. Counting the numbers of units actually sold, on the other hand, can lead to an overestimation of food loss when small units are packed together to reach marketable size. If 100 units are received by the packing house, 5 are discarded and 10 are made into 5, the loss is 5% and not 15%. When 10 units are made into 5 there is no actual vegetable discard, and this difference represents a reduction in yield and it should not be considered food loss.

Proposed methodology

In view of the difficulties faced during the research, the methodology was changed in order to: decrease the number of visits and the time of permanence in the farm necessary to accomplish a survey; be independent of data collection by the farmer and by the farm' staff; reduce the costs of displacement to the farm.

For that, the measurement of the loss per harvest day during the entire harvest period was replaced by the measurement of the loss only after the harvest of the whole crop was finished and the crop was abandoned by the farmer (research in progress). This approach underestimates the total loss because it does not include eventual discards during harvest and in the packing house. However, it decreases significantly the cost of the survey without severally compromising the loss estimation since the unharvested plants are the most important loss for these crops. The maximum daily loss (number of unities discarded per number of harvested plants) registered in our survey was 8.7% for coriander in the packing house on Farm 2 and 7.3% for butterhead lettuce during harvest on Farm 1. These values were reduced when all the harvests were considered and the averaged discard for the season was calculated (Tables 2 and 3).

Under the conditions of an exploratory research, when no previous data is available, this approach is robust enough to indicate for what crops and under what conditions the loss is important, as well as the need for further and more detailed studies.

Rocket and coriander

The vegetable loss is estimated as the proportion of unharvested area in relation to the total area of the crop (sum of harvested and unharvested). All the measurements are done after the area is abandoned by the farmer. For that:

- Measure the total length of beds harvested totally or partially in meters (A).
- Measure the total length of beds not harvested in meters (B).
- Calculate loss:

Equation 1

$$Loss\ (\%) = \frac{B}{B + A} * 100$$

- It is possible to estimate the amount of organic waste and/or the amount of vegetable available for gleaning. For that:
- Choose randomly 5 samples, corresponding to 1-meter-long bed, in the harvested area of the crop.
- Harvest and weight (kg) all the plants of each sample and calculate the average mass of plants in one 1-meter-long harvested bed (C).
- Repeat the procedure in the not harvested area to obtain the average mass of plants in one1-meter-long unharvested bed (D).

Equation 2

$$Mass_{harvested} area(kg) = A * C$$

Equation 3

$$Mass_{unharvested} area(kg) = B * D$$

Equation 4

$$Waste(kg) = (A * C) + (B * D)$$

Lettuce

In this case, measurements are done before harvest (plant population) and after the crop is abandoned by the farmer (food loss). The vegetable loss is expressed as the proportion of unharvested plant units in relation to the total number of plants in the area (population) before harvest.

In the surveys reported in this paper plant population was estimated by counting the plants in 5 representative areas of the crop. However, we observed that it is common to have unharvested plants concentrated in the final portion of the beds because the farmer starts harvesting close to the road and progress towards the end of the bed. These plants have then more chance to grow beyond commercial size or to be damaged by pests and abiotic agents. Because of that, it is recommended to take the whole bed as the sampling unit and to count the plants in the same beds before and after harvest.

For that:

1 - Before harvest

- Sample the area to estimate plant population counting the number of plants in 5 beds of the crop, numbered as replicates 1 to 5. When the crop has less than 5 beds, consider all of them. Calculate the average number of plants per unit of bed length (E).

2 - After the harvest

- Count the number of remaining plants in the same areas sampled to estimated plant population. Calculate the average number of plants per unit of bed length (F).

3 - Calculate loss as a proportion of the population.

Equation 5

$$Loss\ (\%) = F/E*100$$

As reported for rocket and coriander, measuring the mass of plants actually left in the field does not represent the real loss experienced by the farmer in terms of revenue, because it will underestimate (plants smaller than the standard) or overestimated (plants bigger than the standard) the loss, compared with what would have been harvested in the area when the plants had the quality demanded by the market.

To be able to calculate the loss in terms of estimated mass of plants not harvested, one should use the average weight of a commercial lettuce unit. For that:

- Weigh 50 commercial lettuce units individually, in order to calculate the average head weight (G). This measurement can be done in the field, during harvest, or later in the packing house.
- Multiply this value by the average number of unharvested units per bed length (F).

Equation 6

$$Loss\ (kg/m) = G * F$$

To estimate the amount of organic waste and/or the amount of lettuce available for gleaning:

- Weigh 50 unharvested lettuce units individually, in order to calculate the average head weight (H).
- Multiply this value by the average number of unharvested units per per unit of bed length (F).

Equation 7

$$Organic\ waste\ (kg/m) = H * F$$

Final considerations

Loss of leafy vegetables at primary production is characterized by a high variability. It varies between farms, depends on the vegetable crop considered and on the time of the year. Successive crops of the same vegetable, in the same farm, can present large differences in the amount of loss.

There is not a one-fits-all solution to recommend to the supply chain of leafy vegetables at a regional level, even less at a national level. The market demand for vegetable quality (size, shape, color, absence of dirtiness) was an important reason for discard of lettuce on Farm 2. However, its loss was much smaller than that experienced by Farm 1, which attended a much less demanding market. The lack of coordination between supply and demand and failures on the production system were more important reasons for lettuce discard on Farm 1. For rocket the opposite was observed and Farm 2 experienced a higher loss. This was at least partly due to demand for a very strict size range and to failures in growth linked to soil fertility and soil structure, depending on the crop field.

The discard of plants with the sole defect of being too big or too small for the market indicates a potential for gleaning, in particular by food banks. However, the great variability in volume of discarded edible plants along the year; the very short time between deciding not to harvest anymore and cleaning the area; the shortage of labor to harvest plants that will not give economic return to the farm and the distance between the farms and the food banks, make this operation, quite challenging.

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