Scaling the Fight Against Food Loss and Hunger in Mexico

Case studies on banana and broccoli food loss reduction options

H.B. (Heike) Axmann MSc, dr.ir. J.M. (Han) Soethoudt, ir. B.H. (Bert) Dijkink, dr.ir. J. (Jan) Broeze, R.J.A. (Rene) Oostewechel BSc

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(photo: BAMX team)

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Institute: Wageningen Food & Biobased Research

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PO box 17, 6700 AA Wageningen, The Netherlands, T + 31 (0)317 48 00 84, E info.wfbr@wur.nl, www.wur.eu/wfbr.

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Abstract

Currently, the Network of Food Banks in Mexico 'Red de Bancos de Alimentos de México' (short: BAMX) is receiving and/or collecting products from various stakeholders in the food supply chain to donate to the beneficiaries of the food bank services. BAMX has to decide whether a certain food flow can go to a BAMX location or not upon receiving and/or collecting. In many cases transport costs and capacity play an important role. This decision making is extremely difficult in the case of supply from farmers because their supply is quite unpredictable. In this report three directions for improving access to food losses were addressed: (1) improve predictability of volumes and quality per supplier (supporting a better cost-benefit analysis for deciding whether or not to collect material from the supplier), (2) identifying options for valorising more of their lost products (including assessment of feasibility and greenhouse gas (GHG) emissions of their valorisation), including streams that are commonly not used for food but have a potential for food and food ingredients, and (3) improve post-harvest handling.

To enhance the predictability of supply, it is recommended that BAMX invests in the quantitative analysis of available materials and their volume:

- To carry out a number of measurements to quantify products suitable for donations, including residual flows, in the main broccoli supplying regions. Combined with farmer-data collected by BAMX in combination with farmer characteristics this enables BAMX to get good insight in the residual flows that can be expected.
- Apply this to other vegetables and fruits categories (preferably build a database and expand your network with farmers and their characteristics).
- In the measurements not only the products that are commonly considered food products should be considered, but also other residue streams that potentially may be used for food application.
- To evaluate costs of collection and distribution internally (what is wasted from the incoming donation, how much is the total recovery fee) in such a way that every donation can be checked on financial feasibility, and learn from that when making decisions.
- Acquire relevant infrastructural data like amount and size of cold storages from all BAMX locations to improve decision making.

For broccoli, interesting residue streams were identified that are promising for food: florets, stems and leaves. The volume of florets that was not valorised was actually relatively small. Substantially larger volume products can be obtained as stems and leaves. These products can be obtained and may be donated as-is as fresh food products (like packaged fresh leaves, fresh stems or cubes), processed to food products (like broccoli soup) or to food ingredients (like broccoli powder). For exploitation of such products, it is recommended to first consider collection from processors only, since they are available at processors at large volume, whereas at farmers extra effort would be required for collection. For processing to food ingredients techno-economic and GHG emission analyses show that the stems have more potential in comparison to the leaves.
Based on a very conservative estimate, the total annually available volume of broccoli stems in Mexico is estimated at 100,000 ton. Per ton of this stream that would be utilised, and would replace dedicated broccoli production (with an assumed – conservative estimate – GHG emission intensity of 0.048 kg CO_2-eq. per kg harvested crop) 48 million kg CO_2-eq. GHG emissions is prevented.
We recommend BAMX to consider (1) collecting broccoli stems from processors and offer them either fresh or use them in sauces and/or soups for BAMX's beneficiaries, and (2) assessing interests of entrepreneurs in developing processing pathways for this material to food ingredients. Optionally collection logistics for both pathways (products for fresh donation and products for processing) can be combined.

For bananas, data from measurements have been obtained from only one actor involved in export chains (because of unsafety situation in the region). The percentage of rejected bananas turned out to be very substantial. These rejected bananas can be processed into products such as paste, snacks or flour. From techno-economic and GHG emission analyses for these applications it was concluded that the business case of such processing pathway can be attractive, depending on volume and market access. Furthermore,

banana flour derived from bananas rejected by exporter (considered as a gluten-free flour) has substantially lower GHG emission impacts than most other gluten-free flour product types in the market.
From the responses obtained from the banana company it was concluded that in the current practice most rejected bananas are already collected by a processing company; therefore by the company who responded to the measurements this stream is not considered promising.

Reduction of Food Loss and Waste (FLW) is most effectively done at primary production level (first mile after harvest) and midstream. For food banks, postharvest handling to reduce FLW is viewed from a different angle. Food banks can transfer food waste from elsewhere in the supply chain into a consumable product. The most suitable products for this are consumable products that cannot be sold commercially due to market disruptions, irregular shape and appearance, inadequate consistency as raw material ingredients for processed products, or an edible parts that is not yet marketed (e.g. broccoli stems). Food banks need to ensure they receive consumable produce, coordinate and manage the throughput effectively, and focus on postharvest handling, including temperature-, relative humidity- and ethylene management during storage.

Preface

By Esther Escárzaga García, Gerente Nacional de Alianzas Agrícolas Bancos de Alimentos de Mexico (BAMX), May 2024

English
The Network of Food Banks in Mexico ('Red de Bancos de Alimentos de México', BAMX) extends sincere gratitude to Wageningen University Research, specifically Wageningen Food and Biobased Research, and the Ministry of Agriculture, Nature, and Food Quality of the Netherlands for their support. Their collaboration has proven indispensable, not only in developing protocols and conducting case studies to gather reliable data on food loss but also in providing essential training sessions. Furthermore, this collective effort has led to the creation of a robust model for valorisation. The insights gained from this comprehensive partnership will not only enhance our capacity to coordinate food rescues more effectively but also specifically enable the rescue of more and higher-quality food, thereby allowing us to serve a larger population and improve their nutritional intake significantly.
Contributing to the sustainability agenda necessitates quantifiable actions to address the challenge of feeding a growing population. One such impactful action involves the recovery of surplus foods, a resource that can significantly augment food security while mitigating environmental pressure. BAMX is able to redistribute surplus produce and side streams, redirecting it from waste streams to those in need. This not only addresses immediate hunger but also promotes a more sustainable food system by minimizing waste and optimizing resource utilization.
According to the findings, our collaborative efforts can lead to the rescue of huge amount of additional food. This information leads us to continue looking for ways to improve our operation and logistics capacity. Simultaneously, it prompts us to consider the necessity of seeking alliances with companies capable of manufacturing processed foods from these raw materials that are currently discarded. Achieving the rescue of these products, in addition to being used to nourish people in food insecurity, would contribute to avoiding the generation of greenhouse gases, the waste of natural resources, such as water, which were used in their production and would contribute to the good management of crops to avoid pests and diseases, thus reducing the excessive use of agrochemicals. In all cases, the result is positive.
In BAMX, we plan to scale this developed methodology and approach to other crops and integrate it into our operations. As our team's expertise does not lie in post-harvest, agro-logistics, and valorisation, we hope to continue working as a team with Wageningen University and Research and the Ministry of Agriculture, Nature, and Food Quality of The Netherlands to develop new projects focused on reducing food losses and waste for the benefit of all.

Spanish
La Red de Bancos de Alimentos de México (BAMX) extiende su sincero agradecimiento a Wageningen University and Research, específicamente a Wageningen Food and Biobased Research, y a la Secretaría de Agricultura, Naturaleza y Calidad de los Alimentos de los Países Bajos por su invaluable apoyo. Su colaboración ha demostrado ser indispensable, no solo en el desarrollo de protocolos y la realización de estudios de casos para recopilar datos confiables sobre la pérdida de alimentos, sino también en la impartición de sesiones de formación esenciales. Este esfuerzo colectivo ha llevado, además, a la creación de un modelo robusto de valorización. Los conocimientos adquiridos de esta asociación integral no solo mejorarán nuestra capacidad para coordinar los rescates de alimentos de manera más efectiva, sino que también permitirán específicamente el rescate de más alimentos y de mayor calidad, lo que nos permitirá servir a una población más grande y mejorar significativamente su ingesta nutricional.
Contribuir a la agenda de sostenibilidad requiere acciones cuantificables para abordar el desafío de alimentar a una población creciente. Una de esas acciones impactantes involucra la recuperación de excedentes de alimentos, un recurso que puede aumentar significativamente la seguridad alimentaria y mitigar la presión ambiental. BAMX es capaz de redistribuir los excedentes de producción y subproductos, redirigiéndolos a la población vulnerable. Esto no solo aborda el hambre inmediata, sino

que también promueve un sistema alimentario más sostenible al frenar el desperdicio la pérdida y optimizar la utilización de los recursos.

Según los hallazgos preliminares, nuestros esfuerzos de colaboración pueden llevar al rescate de una gran cantidad adicional de alimentos. Esta información nos lleva a seguir buscando formas de mejorar nuestra capacidad operativa y logística. Al mismo tiempo, nos lleva a considerar la necesidad de buscar alianzas con empresas capaces de fabricar alimentos procesados a partir de estas materias primas que actualmente se desechan.

Lograr el rescate de estos productos, además de ser utilizados para alimentar a personas en situación de inseguridad alimentaria, contribuiría a evitar la generación de gases de efecto invernadero, el desperdicio de recursos naturales, como el agua, que se utilizaron en su producción y ayudará al buen manejo de los cultivos para evitar plagas y enfermedades, reduciendo así el uso excesivo de agroquímicos. En todos los casos, el resultado es positivo.

En BAMX, planeamos escalar esta metodología y enfoque desarrollados a otros cultivos e integrarlos en nuestras operaciones. Dado que la experiencia de nuestro equipo no radica en la postcosecha la agrologística y la valorización, deseamos seguir trabajando en equipo con la Universidad e Investigación de Wageningen y el Ministerio de Agricultura, Naturaleza y Calidad de los Alimentos de los Países Bajos para desarrollar nuevos proyectos centrados en reducir las pérdidas y el desperdicio de alimentos en beneficio de todos.

Acknowledgments

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1. Introduction

1.1. Project Overview

The project was initiated with the aim of providing innovative solutions to increase access to nutritious food for low-income communities in Mexico by addressing food loss and losses of side streams in the country's primary production level (first mile after harvest). Collaborating with BAMX, the second-largest food bank globally, alongside farmers and the processing industry, our efforts from 2023 to 2024 focused on developing tools aimed at reducing and valorising unconsumed food and side streams.

Our efforts concentrated around three key areas:

1. **Development of a Farm-level Food Loss Data Collection Methodology:** Chapter 2 presents the developed protocols, which serve as the foundation for gathering accurate data on losses of food, including crop components that could serve for food application but are commonly overlooked, at farm level. Accurate and reliable data is crucial for making feasible decisions on whether to focus on food loss reduction, redistribution, or valorisation.
2. **Exploration of Sustainable Valorisation Pathways:** Chapter 3 illustrates the results of our exploration into sustainable pathways for valorising unconsumed food and side streams (crop components identified in chapter 2). The developed approach aims to assist BAMX in efficiently identifying options for utilizing alternative resources as nutritious food for those in need via alternative routes than the regular supply of surpluses from food chains.
3. **Enhancement of Post-harvest Management:** Whereas the subjects addressed in Chapters 2 and 3 are aimed at new potential sources of food, Chapter 4 is aimed at optimizing common operations of BAMX. This chapter underscores the significance of proper post-harvest product management for minimizing food loss throughout the supply chain. It includes the slides of a tailored training course provided by WFBR to BAMX-employees and farmers.

This final report aims to empower BAMX to implement and expand upon the tools and methodologies developed. Furthermore, it seeks to pave the way for sustainable food loss solutions in other regions facing similar circumstances.

1.2. The Problem

The problem at hand is addressing food loss and food insecurity among Mexico's vulnerable low-income population, comprising around 46.8 million individuals (about twice the population of Mexico City) in the country, out of which 9.1 million[1] live in extreme poverty. The aim is to establish sustainable solutions that reduce food loss while increasing access to nutritious food. Limited data and knowledge on food loss hinder the expansion of foodbanks.

Our partnership with BAMX aims to develop scalable tools and methodologies targeted to this need. The employed approach involves implementing a system to measure food losses at the farm level, encompassing not only what is currently being lost from the traded food, but also including plant parts with high nutritional value that are often overlooked and do not reach consumers. Additionally, we considered how to valorise these products, which may require processing steps to make them more accessible and appealing to consumers. Finally, we provide strategies for keeping donated food products with minimal loss within the BAMX chain. Through this comprehensive approach, we aim to tackle food loss and enhance food security effectively.

[1] The numbers come from www.coneval.org.mx 2023, which is the Institution that measures poverty in México.

1.3. General information on BAMX

BAMX was founded more than 28 years ago. It is the world's second largest food bank network. Its primary goal is to combat food insecurity by redistributing surplus food to those in need. Redistribution is facilitated through 57 food banks operating at regional and local levels across Mexico. These food banks collaborate with various stakeholders, including farmers, processors, retailers, government agencies, businesses, hotels and restaurants, and non-profit organizations, to rescue surplus food that would otherwise go to waste. BAMX plays a crucial role in addressing food security by ensuring surplus food reaches individuals and families facing hunger and poverty. In 2023 alone, BAMX collected over 170,000 tons of food that would have otherwise been lost or wasted, distributing it to a regular client base of almost 2,4 million food-insecure people. The network prioritizes providing nutritious food items such as fruits, vegetables, grains, and proteins to ensure recipients have access to a balanced diet.

In addition to food distribution, BAMX engages in community outreach and educational programs to raise awareness about food waste, nutrition, and food security issues. By collaborating with local communities and implementing sustainable practices, the network strives to develop long-term solutions for reducing hunger and food waste in Mexico.[2]

Currently, most donated food is sourced from farmers, manufacturers, retailers, and hospitality services. As the need for healthy food among Mexico's most vulnerable populations increases, it is crucial to fully explore potential food surpluses at the various levels of the food chain and assess opportunities to redistribute it to those most in need.

1.4. Definition of Food Loss and Waste

Until today, there is no universally agreed consensus worldwide on what comprises FLW. For instance, the EU exclusively uses the term 'food waste' (EU, COMMISSION DELEGATED DECISION, 2019), whereas international organizations like the FAO and the UN in Sustainable Development Goal (SDG) 12.3 distinguish between 'Food Loss' and 'Food Waste'. Therefore, it is crucial to establish clear definitions prior to the start of a project to ensure a mutual understanding of what falls within the scope. Given that FAO and the SDG targets in 12.3 have a global scope and encompass all countries, including Mexico, the FAO and SDG 12.3 are adopted for this project (FAO, 2019).

As per this definition, the focus of this work isn't on Food Waste, but instead on measuring, valorising, and reducing Food Loss in the early stages of the food supply chain. Hence, throughout this document, the term 'Food Loss' (FL) will be consistently used.

The definition of Food Loss and Waste utilized for this project is as follows:

FLW refers to all food intended for human consumption that is finally not consumed by humans. Food Loss is the decrease in the quantity or quality of food resulting from decisions and actions by food suppliers from the production stage in the chain, excluding retail, food service providers and consumers. Food Waste is the decrease in the quantity or quality of food resulting from decisions and actions by retailers, food services and consumers (FAO, 2019). Under this definition, FLW does not include side streams such as stems or leaves.

[2] All figures and information are sourced from BAMX internal statistics and other internal sources and cover the year 2023.

2. Analytical Framework for Identifying Food Loss and Root Causes

2.1. Introduction

BAMX collects unsold food from various supply chain links, like farmers, processors, retailers, exporters and the foodservice sector (hotels, restaurants). This chapter is aimed at getting better insight of under-explored potential at farm level. Some interesting residue streams generated by farmers may be more effectively obtained via food processing or packaging actors; where relevant they will be referred to as well. Currently, the food loss supply from farmers to BAMX is very irregular and it is impossible to anticipate this. Therefore, this project wants to propose changes that lead to reduction of FL and an improved modus operandi for BAMX in order to provide more food to the poor.
The following issues are investigated:

1) Better insight in the size of the organic residual flows that could be used for food per product per ha at farm level. If BAMX contacts a farmer, BAMX has no estimate of the FL on beforehand. By doing pilot measurements with farmers with products that lead to significant loss volumes, these estimates will be more accurate. Developing a methodology for these measurements is the first step to anticipate better and earlier to FL supply.
2) Better match between potential FL supply and feasible collection by BAMX. Based on the results from 1) and data of residual flows from processors, it is possible to analyse the way of working of BAMX and provide directions for improvement.

In order to do so two products are selected in the project. Since animal products are more difficult to handle (especially with respect to food safety) and BAMX has no processing for it, the focus is on horticultural products. One vegetable, *broccoli*, and one fruit, *banana*, are chosen by BAMX. At farm level significant loss volumes occur for these product categories.

2.2. Methodology

FL quantification at farm level is done mainly by interviewing farmers (Joensuu, 2020). Real measurements are time-consuming and more costly than sending questionnaires or calling producers. However, research has shown that the farmer very often underestimates his food loss](FAO-MEX, 2020; FAO-ZIM, 2020), and hence field measurements increasingly take place, especially if you want to cooperate on an operational level. In many cases FL data at farm level are used on a strategic level for monitoring as part of a governmental statistic on many products. This way policy makers can prioritize their actions and measures. The latter is at a much larger scale, leading to cost effective, but mostly less accurate, quantification methods. BAMX needs accurate data to decide whether it is feasible and/or possible for them to collect (part of) the food loss.
FL quantification by measurements on farm level are not new. In fact, FAO studied the losses at farm level in Mexico for exactly the selected products broccoli and banana (FAO-MEX, 2020). They studied the regions Guanajuato and Jalisco, both states located in the main broccoli production area (Central Mexico). Their definition of food loss was: any quantity of food that is withdrawn from the supply chain in any point from harvest up to retail level, independently of its intentionality. Our assumption is that this includes the florets and part of the stem, since broccoli is sold to clients (retailers, processors, out of home, exporters, …) with a part of the crop’s stem. Note that this definition is slightly different from the other definition from FAO, mentioned earlier (section 1.4).
This project looked more broadly at organic residual flows. BAMX wanted to consider not only the food losses, but at all organic materials that are present above ground on the land. Some of these components may be interesting for food application. In the case of broccoli, these are florets, stems and leaves. The idea here is that stems and possibly leaves also can be used as food or food components. In chapter 3 processing pathways for valorising such streams is discussed in more detail.

In general, the approach for vegetables and fruit is different, because of the different plant characteristics (plant material of the tree, wood, is not considered edible). Hence, two methodologies are presented, based on the two selected products.

2.2.1. Broccoli

Two types of residual organic flows are considered. One is structural, i.e. the leaves and (parts of) stems that, in general, are not sold as food for humans. The size of these flows is expected to show less relative variation because they are always present and directly related to the number of plants. The second residual organic flow consists of the florets (also called 'heads' or 'crowns') with some stem length, that are rejected for the market. The fluctuation per harvest in this flow is expected to be higher, since unpredictable variable conditions (like weather) determine its size. Everything that is not harvested is ploughed under. The goal is now to develop a two-pronged approach for addressing both structural and variable food loss.

Figure 1: Broccoli in Puebla (source: BAMX team)

Remark: these considerations hold for 'business as usual'. However, in case of diseases and/or rodents, stems and leaves can be infected as well, and therefore it is wise not to collect from these farms at all.

2.2.1.1. Protocol for measurement of above ground residual flows of broccoli at farm level

In this research, farmers and processors are included to look for residual flows. Processors monitor the residual flows themselves, and some of the data are discussed later, but at farm level measurements are rare. Field measurements at farm level are carried out for many purposes. E.g., estimates for yield, average harvest time, harvest efficiency and food loss. In general the following steps are taken:

1) *Select a broccoli farmer that is willing to cooperate*: BAMX has already a lot of contact with farmers, since they have collection points all over the country. The main production area for broccoli is Central Mexico with e.g. Guanajuato producing 70% of the national broccoli volume (Producepay, 2022). But also Jalisco and Puebla are among the top 5. In these regions BAMX has contacts with farmers as well as processors.
2) *Collect relevant data by a questionnaire*: farmer plot data (e.g. how many ha of broccoli is he growing/harvesting?) and business characteristics (required diameter of floret) are necessary to calculate the total available residual flows, based on the measurements. The questionnaire can be found in Annex 1.
3) *Determine the date for data collection in the field*: keep in touch with the farmer in such a way that direct measurements can take place the day after the last harvest (or sooner).
4) *Prepare team, template and materials for data collection*: all team members should understand the entire protocol. The template is partly showing outcomes from the questionnaire (basic information) and includes tables for the measured data. The required materials for measurements are
   - Scale that can measure at decimal level (all weighing data should be at decimal level)
   - Boxes to put in what is left on the field (1) floret/head 2) stem 3) leaves)
   - Tapeline (to mark a distance of 25 meters)
   - Data sheet
   - Pen
   - Smartphone for taking pictures

Select and mark sample plots in a randomised way. This can be done scientifically (see Statistics, 2017), but in most cases arbitrary selection by individuals on the spot is the way to go, whereas the difference is expected to be negligible. Of course more samples lead to higher reliability. In this set up three plots are selected in the following way: Select three arbitrary spots (at least 10 meter distance and a least 5 rows away from one another). These spots should not be close to the side of the plot (at least 5 rows and 10 meters away). On each spot take a length of 25 meters from the row you are in (this leads to 75 meters of sampling per farmer) and <u>count</u> the number of plants for

each of the three rows (even if only leaves are left) as well as the florets that are not harvested *(see* The template to take in the field is shown in *Table 1:*

5) Table 1, Q2. Mark start and end point for each row of 25 meters by putting a stick/flag in the ground.

Do the measurements and write the data in the template. Therefore, take 3 similar empty boxes that are not too big to carry along and weigh the total of the 3 empty boxes. Write the result of the total on the score sheet *(see* The template to take in the field is shown in *Table 1:*

6) Table 1, Q3. For each sample of 25 meter 3 parts of the broccoli, that are left on the field, are collected: 1) floret/head, 2) stem, 3) leaves. Then carry out 2 runs per 25 meter (a. and b. below)

You take two boxes, one for the unharvested broccoli heads (cut the stem according to requirements), and second for the stems that are removed from the leaves, once the head is cut (cut during harvest or measurement cut). At the end of the 25 meter you weigh both boxes. Write down the results in the Data sheet *(see* The template to take in the field is shown in *Table 1:*

a. Table 1, Q4 and Q5.

Because the leaves are a lot of weight, a separate run for them is needed. After all leaves of the 25 meter are cut and put in a box (or maybe more boxes if needed), weigh the box(es) and write it down in the Data sheet *(see* The template to take in the field is shown in *Table 1:*

b. Table 1, Q6.

7) *Carry out data analysis*: based on the measurements and the data from the questionnaire the weight of all three organic residual flows can be estimated per plant and on farm level. The measurement data show, on average, how many plants are in a row of 25m and how much the residual flows weigh. The distance between rows in the field (normally 90 cm) is used to calculate the number of plants per ha and for the entire farm. Combining the results leads to the estimated weight for all three residual flows on the farm.

The template to take in the field is shown in *Table 1*:

Table 1 Template for broccoli organic residual flows measurement

Farmer 1			
Name			
Village/city			
Area of broccoli production (take from questionnaire)			
Date of measurement			
Q1: client requirements (take from questionnaire)	Floret/Head	Stem	Other:...
Q2: how many ... (count, not weigh!) are in:	Floret/head left on plant (not harvested)	Broccoli plants	
Sample 1/ Row 1			
Sample 2/ Row 2			
Sample 3/ Row 3			
Q3: the total weight of 3 empty boxes (in kg)			
Q4, Q5 and Q6: weight of the waste flows (in kg)	Floret/Head	Stem	Leaves
Sample 1/ Row 1			
Sample 2/ Row 2			
Sample 3/ Row 3			

It is important to stress that such a measurement provides estimates for a particular farm, and not for a broccoli farmer in general, although it is expected that the size of residual flows in tons/ha from other farmers are in the same range. However, significant variations occur and seem to have some clear causes. Whereas modelling of food loss often relates to inputs like 'farmer experience', 'seed quality' and 'level of education' that clarify the variation, there are other characteristics that influence the weight of the residual flows as well. These are related to the modus operandi of the farmer and his clients. Think of the distance between plants in a row. The data in Table 3 show one example with 22 cm between plants (116 plants on 25m) and one with 42 cm. Furthermore, the distance between the rows may vary as well as the client requirements. Especially the required size of the floret and the length of the stem impact the residue per plant as well as does the moment of harvesting (for larger florets you need to grow more days). This insight is new and currently not applied in modelling, and can be used by BAMX by looking at residual flow sizes per ha of reference farms with similar requirements and characteristics.

2.2.1.2. Results

The measurements are carried out at three farms in Puebla, since in Guanajuato the farmers already harvested the broccoli. As noted earlier, the setup of such a measurement has several statistical choices, like where in the field to take random samples and how many. In this case, per farm BAMX selected three rows of 25m randomly in the field (Figure 2), to retrieve an indicative result[3].

Figure 2 Broccoli field measurement by BAMX in Puebla (source: BAMX team)

The results are shown in Table 2.

[3] The confidence level and margin of error can be improved by increasing the sample size. See https://www.calculator.net/sample-size-calculator.html

Table 2 Results from field measurement at three broccoli farms in Puebla

Name	Farmer 1			Farmer 2			Farmer 3		
Village/city	Jesús Carranza, Oriental, Puebla			Jesús Carranza, Oriental, Puebla			San Salvador el Seco, Puebla		
Area of broccoli production	11 ha			6 ha			10 ha		
Date of measurement	29-8-2023			29-8-2023			29-8-2023		
Q1: client requirements	**Florets/Head**	**Stem**	**Other:...**	**Florets/Head**	**Stem**	**Other:...**	**Florets/Head**	**Stem**	**Other:...**
	6-7 inches	5 cm		6-8 inches	3 in		6 inches	1 cm	
Q2: How many ... (count, not weight!) are in:	**Florets/Head**	**Broccoli plants**		**Florets/Head**	**Broccoli plants**		**Florets/Head**	**Broccoli plants**	
Sample 1/ Row 1	6	87		7	116		5	88	
Sample 2/ Row 2	12	92		15	114		6	107	
Sample 3/ Row 3	4	99		15	101		5	60	
Q3: the total weight of 3 boxes (in kg)	500.38			891.09			404.81		
Q4, Q5 and Q6: weight of the waste flows (in kg)	**Florets/Head**	**Stem**	**Leaves**	**Florets/Head**	**Stem**	**Leaves**	**Florets/Head**	**Stem**	**Leaves**
Sample 1/ Row 1	2.31	48.34	123.28	1.89	68.44	184.44	5.07	55.44	149.6
Sample 2/ Row 2	10.54	52.31	101.65	10.8	74.10	220.02	5.4	34.24	62.06
Sample 3/ Row 3	2.64	53.05	106.26	18.3	68.68	244.42	2.4	29.40	61.2
Total	15.49	153.70	331.19	30.99	211.22	648.88	12.87	119.08	272.86

Remark: note that the answers in Q3 are not the weight of the three empty boxes, but the total of all weights in the last row. The protocol was adjusted to avoid the error next time. The results were calculated correctly though.

There are clear differences between the three farmers. Farmer 2 has the highest weights of residual flows, followed by farmer 1 and then farmer 3. This might relate to the client requirements, with stem length declining in the same order. However, other explanations like variety or different weather conditions are not excluded. Some minor calculations clearly show how different the farmers operate, sometimes induced by clients:

Table 3 Characteristics of the three sampled farms in Puebla

Characteristics	farmer 1	farmer 2	farmer 3
Average number of plants per row of 25 m	93	110	85
nr of rows per ha (assuming 100mx100m) (all have 90 cm between rows)	112	112	112
Estimated nr of plants per ha	41556	49478	38118

Combining the data from Table 2 and Table 3 leads to the estimated weight of the three residual flows per farmer per plant and per ha:

Table 4 Average weight per plant and per ha for the three residual flows

Average weight of what is left on field per plant (gram)				Average weight per ha (kg)		
part of plant	**farmer 1**	**farmer 2**	**farmer 3**	**farmer 1**	**farmer 2**	**farmer 3**
- floret	55.72	93.63	50.47	2315	4632	1924
- stem	552.88	638.13	466.98	22975	31573	17800
- leaves	1191	1960	1070	49507	96996	40788

According to (Producepay, 2022) the average broccoli production per ha is 17.5 tons. This implies a food loss (only florets are food loss) of 13%, 26% and 11% for farmer 1, 2 and 3 respectively, but take into account that the production weight per ha of farmer 2 is expected to be higher than 17.5 tons/ha.
Finally, to calculate per farm the total amount of each flow the farm size in ha is multiplied with the average weight per ha, and this is the basis for BAMX to decide whether or not it is feasible for them to collect it:

Table 5 Weight in tons on farm level for all three residual flows of broccoli

part of plant	farmer 1	farmer 2	farmer 3
Farm size (in ha)	11	6	10
- floret	25.5	27.8	19.2
- stem	252.7	189.4	178.0
- leaves	544.6	582.0	407.9

The results are on farm level, but it may happen that farmers have different clients, each having different requirements and different timing for supply and hence not all is harvested in one batch. Therefore, BAMX needs to ask how many ha are harvested and what requirements are applied, in order to get a good estimate of the weight of each residual flow to be expected. Keep in mind that the structural flows of stems and leaves are relatively more stable than the variable loss of florets. Again, one should realize that this protocol is meant to support operational decisions, and if more accuracy is required, it can be achieved by increasing the sample size (more plots per farmer, and/or more farmers), but it is assumed that the current information is sufficient to make the right decisions for BAMX.

The protocol for broccoli can be applied to all broccoli farms. It is important to realize that regional differences exist in productivity (e.g., variety) and within regions clients requirements have significant impact on residual flows, structural (stems and leaves) as well as variable (florets). Therefore, the advice is, in the major broccoli production states, to measure on three farms these residual flows and identify the farm characteristics with the questionnaire. This way a first estimate of the residual flow size can be made, whereas more measurements will of course improve the accuracy.
Extension to other vegetables is also possible, by applying the same structure: first the questionnaire, then address the relevant residual flows and finally follow the measurement protocol and perform the data analysis.

The main causes of florets wasted mentioned by the farmers are too small for the market, yellowish florets and plague damage. The latter two cannot be used by BAMX.

2.2.1.3. Residual flows from broccoli processors

BAMX has contacts with a number of broccoli processors, especially in Guanajuato, the state with the highest broccoli production by far. A number of processors also own the supplying farms (e.g. Frescos Don Gu). There is a large variety of processed products with broccoli, and some examples are shown in Figure 3.

***Figure 3** Some examples of products with broccoli processed in Mexico*

Three interviews with processors showed that the variable food loss of florets is between 6% and 20%, which depends on the type of end product and the quality requirements. The amount is between 25 and 120 tons per week (broccoli processing takes place from 10-12 months per year, depending on the company) for these processors. Rejections occur because of low quality and small size. If the quality is low the food loss is collected by a waste company, and the processor has to pay for it. For the stem this is different. These flows go to livestock of farmers in the neighbourhood, and no costs are involved. Farmers collect every day, which is important for the processor in order to get rid of these large volumes of stems.

2.2.1.4. Rescues

The amount of broccoli florets that is collected by BAMX in all of Mexico between January 2019 and March 2023 was 355 tons in 70 rides (confidential collection data from BAMX). This is from farmers and processors together. So, on average 5 tons per ride and every 22 days a ride. These flows were delivered to 13 different BAMX locations, and the highest volumes were sourced in Guanajuato; the highest volume delivered was in BAMX Leon. On the other hand in 2022, about 800 tons (40 rides of 20 tons each) of broccoli stems were not rescued from processors, as well as a 100 ton mix of stems and florets (also 5 rides). The supply of stems is exceeding the capacity of BAMX locations by far. This not only holds for transport, but for storage as well. Since processors may have to pay for waste collection, it happens that material of too low quality is collected by BAMX.

2.2.2. Banana

Bananas are available year round in Mexico. Throughout the year the production shifts from the south, Chiapas and Tabasco (the two states that cover about 60% of the production) to Colima, Jalisco and Nayarit, close to the north. This fruit is the biggest in trade worldwide, and, with 2.5 million tons, the production in Mexico is five times higher than broccoli. Banana is completely different from broccoli. Many fruits grow on trees, implying a completely different dynamic in the sense of plantation structure, harvesting and residual flows as resulted from the interviews with four banana growers.

Figure 4 Banana farm from Pro Organic Tropical Fruit SAPI de CV (source: BAMX team)

A distinction can be made between exporters, with mainly own farmers, and farmers for the domestic market. The first group works with written contracts and has very large plantations (production around 200,000 tons per year) to guarantee the continuity and quality for the foreign (often American) market. These farmers work very professionally. The farmers for the local market have much less hectares and produce up to about 15,000 tons per year.
With respect to residual flows, the focus is on the banana only and not on its stem or leaves. Furthermore, banana processors are currently no suppliers to BAMX. Hence, they are not discussed here, neither are ripening and storage activities, since they take place on another location. The FL in the field was not measured in this research, because of practical reasons. It is very costly to collect discarded bananas from the field, since they cannot use the cable system for losses, and the plantation area is often very large. Moreover, a part of these bananas have low quality or are too mature. These are FL bananas, but not relevant for BAMX, since they cannot be used for human consumption anymore.

Remark: since left in field bananas are not measured, the food loss data derived in this project are less than the total food loss at farm level, and can only be used as a lower bound in e.g. national statistics.
Based on the interviews with banana farmers, the following scheme shows the flows at the farm level in the packing facility

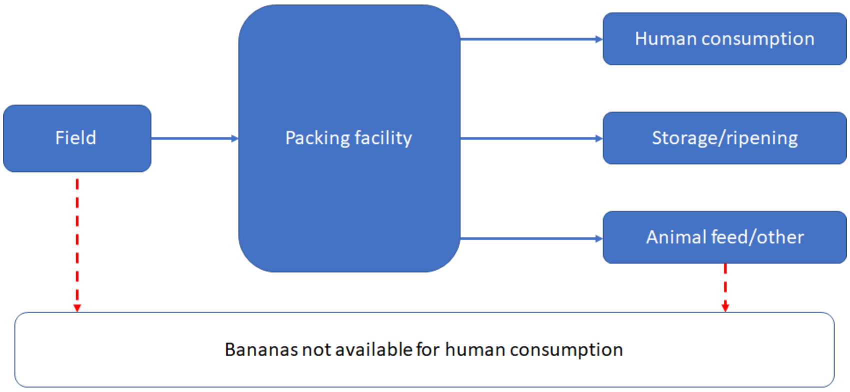


Figure 5 Activities on banana farm with food loss

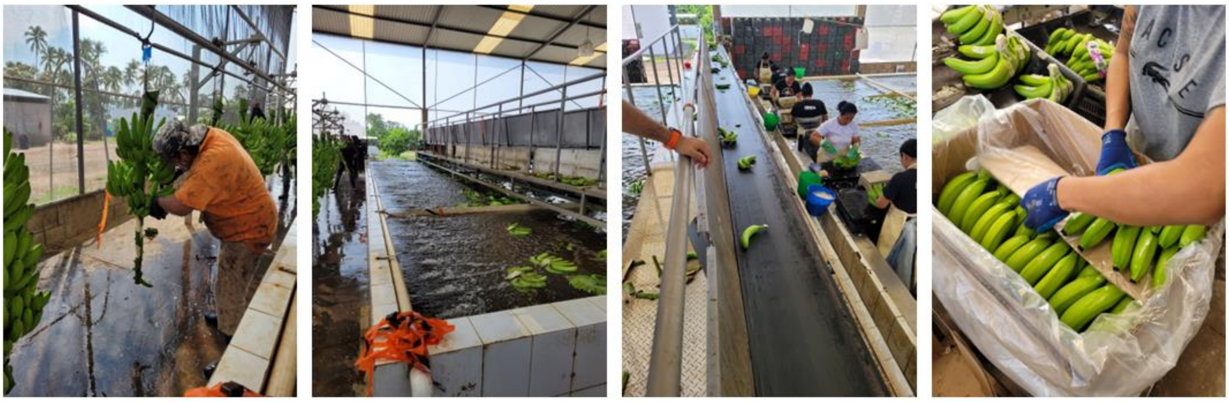
There are three types of banana flows leaving the pack house:

a. (Direct) human consumption: bananas for the intended markets, for processors (less quality) and small stores (e.g. fingers)

b. Some of the bananas can go to storage/ripening, and enter the market later (indirect human consumption)
c. If not to a) or b) then in most cases it is used for animal feed.

For the FL measurement only flow c) needs to be considered. In the pack house various activities (can) take place:

- De-handing
- Washing (latex removed)
- Grading
- Drying
- Packing



De-handing | Washing | Sorting/grading | Packing

Figure 6 Activities in banana exporter packhouse in Colima (source: BAMX team)

The measurement should take place at all activities where flows of type c) arise.

2.2.2.1. Protocol for measurement of banana food loss

For the measurements we assume that banana harvesting is year-round (at least for a very large part of the year). The handling in the packhouse is every day also. At the activities where FL arises large boxes are placed to collect what becomes flow c) for one hour (30 minutes if the throughput is very high). This will be done for two days and two times per day (1 morning, 1 afternoon). So, four measurements.
The protocol consists of the following steps:

1) *Select a banana farmer that is willing to cooperate*: BAMX knows several banana farmers in the South of Mexico, especially Chiapas, which has the highest banana production of the country. But other banana farmers in their network will do.
2) *Collect relevant data by a questionnaire*: farmer plot data (e.g. how many ha of bananas is he growing/harvesting per time unit (year, week, …)?) and business characteristics (required diameter or size) are helpful to understand why bananas become food loss. The questionnaire can be found in Annex 2
3) *Determine the dates for data collection in the field*: the protocol requires two days of measurements, but since bananas are harvested almost every day, it should be easy to agree on the dates (see Q1a and Q1b in Table 6).
4) *Prepare team, template and materials for data collection*: all team members should understand the entire protocol. The template is partly showing outcomes from the questionnaire (basic information) and includes tables for the measured data. The required materials for measurements are
   - Boxes to put in what is left per activity in the packhouse where food loss occurs (often the farmer himself has boxes available)
   - Scale: here are two options. Either the farmer has a large scale to weigh large boxes (e.g., 1m x 1m x 1m), or you quantify the food loss weight otherwise. This can be done by weighing manageable quantities on a normal scale for humans (until 120 kg) until the box is

empty, or by counting all bananas and determining an average weight (for example, take 10 bananas and divide the total weight by 10)

- Data sheet
- Pen
- Smartphone for taking pictures

5) *Identify the activities in the packhouse where food loss arises (earlier described as flow c))*: e.g. washing, grading and packaging. Note that bananas that do not comply with the client requirements are very often sold to processors or the local market and hence are no food loss. Ask the farmer only those activities where rejections arise that are not destinated for some human consumption market anymore. Write these activities in the template (Q5a and Q5b).
6) *Put boxes at the activities where bananas are discharged as food loss*: this is necessary only if the farmer doesn't separate the rejections for processing from the food loss.
7) *Write down the start time and the end time 4 times*: 1 in the morning, 1 in the afternoon, and for 2 days (Q4a and Q4b).
8) *Do the measurements and write the data in the template*: the weighing can be done as described in point 4). Write the results per activity in the row 'weight FL bananas'.
9) *End of day data*: ask for the amount of bananas harvested (Q2a and Q2b) and also how many hours the packhouse was in operation (Q3a and Q3b). This should be done for both days of measurement. Maybe these data are available one day later. Please verify.
10) *Carry out data analysis*: based on the measurements and the other data in the template, the food loss per day can be estimated.

Remark: doing the measurements in banana production areas is not always safe. During our project we noticed that several times the measurements did not take place because of safety reasons. In the end no real measurement was carried out, but relevant data could be provided by the large exporters, since they monitor it on a daily basis. Hence, measurements are sometimes not necessary, if the farmer is collecting these data and willing to share them.

In addition to the measurements, the amount harvested of that day is collected in the data, as well as the total amount of hours the pack house is in operation per day (on average). For four (or 3, 1 big, 2 small) banana farmers fill in the following data:

Table 6 Template for banana food loss measurement at farm level

Farmer 1			
Name:			
City / Village:			
State:			
Measurement 1 and 2	Date (Q1a)		
	harvested weight that day (Q2a)		
	Hours packhouse in operation that day (Q3a)		
		Morning	Afternoon
1 hr or 30 minutes measurement period	starting time (Q4a)		
	time stopped (Q4a)		
weight FL bananas	activity 1: ……………. (Q5a)		
	activity 2: ……………. (Q5a)		
	activity 3: ……………. (Q5a)		
Measurement 3 and 4	Date (Q1b)		
	harvested weight that day (Q2b)		
	Hours packhouse in operation that day (Q3b)		
		Morning	Afternoon
1 hr or 30 minutes measurement period	starting time (Q4b)		
	time stopped (Q4b)		
weight FL bananas	activity 1: ……………. (Q5b)		
	activity 2: ……………. (Q5b)		
	activity 3: ……………. (Q5b)		

2.2.2.2. Results

The banana protocol could not be tested due to the safety of BAMX personnel. It is recommended to test it if that can be safely done. The food losses from the warehouse of one farmer (large exporter) have been made available and the result is shown in Table 7.

Table 7 Food loss from a large banana exporter in Colima

Mass flow (tons)	2019	2020	2021	2022
Production per year	18135	19603	17074	19635
residual flow per year	3125	2967	5317	5796
to processor	3029	2876	5156	5620
% of production to processor	16.7%	14.7%	30.2%	28.6%
food loss	94	89	159	174
% of production to food loss	0.5%	0.5%	0.9%	0.9%

The data from this large exporter show that in 2022 there was a food loss of 174 tons, which is 3 tons per week. Contrary to broccoli, banana harvest takes place almost every day with little variation in the amounts throughout the year. Therefore, the expected food loss per day is 450 kg, which might be financially feasible for foodbanks nearby the donor farm only. If there are more locations from which bananas can be picked up, then it would be interesting for more BAMX locations. Also on the positive side is the fact that this is a structural flow, while broccoli has larger volumes at harvest, it is only twice a year.

2.2.2.3. Rescues

Between January 2019 and December 2022 about 1854 tons of bananas were rescued in 132 transportations to 33 BAMX locations across Mexico, which results in an average weight over 14 tons per ride. Sourcing was mainly from Chiapas (74%) and Jalisco (15%). In 2022 749 tons of bananas were available but not rescued. Some of these options are over 180 tons or more, which cannot be handled by BAMX. Considering these data, in Mexico, there is sufficient potential supply of fresh bananas from farmers/exporters to BAMX.

2.3. The way of working at BAMX

At BAMX the various sectors have their own contact person, who is responsible for the decision making and arranging of collection from donator to BAMX location(s) (e.g. retail, restaurants, farmer). In case of farms a production manager of an organization of farmers (or farmer himself) calls to the central office of BAMX. Depending on the farm location, BAMX contacts foodbanks in the neighbourhood of the farm, and discuss the conditions. These foodbanks make decisions based on several criteria like:

- Storage space at the food bank (capacity)
- Infrastructure differs between food banks. Mostly, they have refrigeration, but e.g. no ripening rooms (so bananas are more difficult to handle)
- Is there a demand for the product
- Logistics can be organized (some food banks have their own truck, whereas the central organization has none; sometimes transports are sponsored by companies and no fee is charged)
- Distance
- Status of products (e.g. ripeness; green bananas are a problem, since nobody eats green bananas)
- Financial feasibility

Remark: during the project it was not possible to get the detailed information on storage or other facilities at the BAMX locations in the country. This is crucial information when making decisions on the deal or not, and should be easily accessible by the central BAMX organisation.

Once the targeted BAMX foodbank(s) (1 or more) are identified and the weight is determined per food bank, the logistics need to be arranged. This can be a truck from a BAMX food bank, but often logistic companies are hired. A truck driver will not check the produce. At farm level there is no quality check by BAMX. This takes place at the warehouse of the food bank. During the first contact about the food loss flow, BAMX talks with the representative of farm(s) about the quality they would like/need. The lack of quality control at farm level leads to significant losses at the foodbanks. The background of this is the fact that BAMX is evaluated on the amount of food they rescue, and not how much they distribute to the poor. The amounts that are supplied to all the food banks are registered, but what is lost at the foodbank not.

Example: If 7 tons of bananas can be transported from a farmer in Chiapas to Mexico city for 10,000 MXN (≈ 545 €), the sales value would be between 14,000 – 21,000 MXN (BAMX asks between 2 and 3 MXN/kg when tey sell to the poor) so BAMX would possibly approve the collection transport. However, BAMX is not evaluating the sales nor what is wasted of these 7 tons of bananas. Maybe part of the bananas are too green, or overripe or even damaged (when they leave the farm or on arrival at BAMX). In case of 50% rejection this leads probably to a negative financial result if

The advice is to incorporate the cost of these losses in their decision making on collecting or not. Currently, the following financial consideration applies: the food that is collected is sold to the (registered) poor people for a so-called 'recovery fee'. This is equal or less than 10% of the purchase price on the regular market where consumers buy food. For fruits and vegetables they often pay for logistic costs only (transport), which comes down to 2 or 3 Mexican peso per kg. An example (see box) shows that although the financial feasibility of a collection transport has been estimated, it is not evaluated afterwards and might lead to a negative balance of the transaction.

BAMX very much depends on donations, and to get proper food sometimes includes taking some low quality products along the way. Being in a weak power position makes it difficult to optimize their work.
The purchase price for consumers is an important reference value for BAMX when selling products for a recovery fee. The price information is collected by BAMX from the following websites:

- http://www.economia-sniim.gob.mx/Nuevo/Home.aspx?opcion=Consultas/MercadosNacionales/PreciosDeMercado/Agricolas/ConsultaFrutasYHortalizas.aspx?SubOpcion=4|0 (*wholesale market*)
- https://smattcom.com/ (*platform for farmers selling their produce*)
- https://agrooferta.gob.mx/e-commerce/ (*platform for farmers selling their produce*)

The market price is not only important for the level of the recovery fee; it plays a strategic role in the food loss availability. If prices are low, farmers will not sell/harvest, since the costs are higher than the revenues. BAMX checks a website to see the price development of the food products, in order to anticipate (if possible) to certain flows that might become available.

2.4. Conclusions

First of all, there seems to be a lot of supply of bananas and broccoli florets/heads in Mexico, that could potentially be rescued by BAMX to provide food products for their beneficiaries. Whether or not rescue takes place, depends on the financial feasibility of the deal, and hence it is important to get a good estimate of how much produce is rejected by the farmers as well as by the processors. For estimating volumes of such streams at farmer level a methodology is described how such an estimate can be derived by sample measurements.

For broccoli this methodology was tested successfully. New in this measurement protocol is the inclusion of other residual flows, stems and leaves, that are commonly not considered as (potential) food yet. The results show a food loss (florets only) between 11% and 26% (or 2.0-4.6 tons/ha) for the three farmers involved. The other identified potential resources for food are much larger: the estimated amount of stems was between 18-32 tons/ha and for leaves between 41-97 tons/ha. The results are shown below.

Average weight of what is left on field per plant (gram)				Average weight per ha (kg)		
part of plant	**farmer 1**	**farmer 2**	**farmer 3**	**farmer 1**	**farmer 2**	**farmer 3**
- floret	55.72	93.63	50.47	2315	4632	1924
- stem	552.88	638.13	466.98	22975	31573	17800
- leaves	1191	1960	1070	49507	96996	40788

Processors collect data themselves. For the three processors interviewed in this project the food loss of florets was between 6% and 20%, in weight between 25 and 120 tons. With respect to stems processors offered several times large amounts of 200 tons, which is even far more than BAMX could manage.
Since the processors provide large volumes of stems, it is considered more economically attractive to collect stems from processors than from farmers, since extra handling and extra collection point would be required for collecting these materials from farmers. This will keep the (collection) costs lower.
Large part of the broccoli stem can be used as a vegetable food with high nutritional value. This sounds interesting for both regular supply as well as peak supplies.
With an eye on the high volume, it may also be processed to a high-value food ingredient. Possibly BAMX can find an entrepreneur who would be willing to develop such process; he/she could supply part of the products to BAMX. In chapter 3 a techno-economic analysis is presented on feasibility of such development.

For bananas data were obtained from one large exporter. He sends about 29% of the incoming volume as residual flows (not matching market requirements) to the processor and 1% is food loss, the latter being 3 tons per week on average.
Looking at the data from BAMX it seems that farmer/exporters sometimes allow BAMX to take the 'rejection to processor flow', since the average supply to BAMX is about 14 tons per stop. Note that several times the food loss was between 100 and 200 tons per stop, and BAMX is of course not able to collect and process such amounts.
The protocol for bananas has not been further tested yet, because of challenges regarding safety to execute this work in many of the production areas.

Next to developing insight in average availability of resources, another new element is that when more measurements are done, BAMX can gain insight in the correlation between farmer characteristics and food loss. For example, for broccoli if the farmer's client demands for large floret/head, the food loss will be higher. If the field pattern (e.g. distance between rows) and production area are known, a good estimate is possible based on statistics from other broccoli farmers. So, at a certain moment, no more measurements are required to estimate the residual flows of a new farmer that wants to donate to BAMX.

A very important conclusion is about the way of working: BAMX lacks insight into financial feasibility, since there is no internal evaluation on the incoming food flows about what is sold and what becomes waste. Moreover, all kind of relevant information about logistic infrastructure per BAMX location seems not available in the head office. Some investment to acquire this information from locations could help BAMX to professionalize at short notice.

3. Unlocking Value: Strategic Approaches to Enhance Food Product Valorisation

3.1. Introduction

Previous chapter identified diverse product streams from farmers and processors that can serve as food. As indicated, some products, like part of the broccoli stems, can be directly used as food; this and other parts may as well be processed to food ingredients. In this chapter processing pathways (from residue generation to consumer product) are explored, aimed at maximising food production from the field.

Through converting residue streams and products that are lost or wasted along food supply chains to food, feed or other valuable product, value is created (both economic value and fulfilment of demands from society, contributing to food security). Since waste management often induces substantial environmental impact, the valorisation also contributes to reducing environmental impact. Valorisation, especially valorisation for valuable products, reduces the negative side effects, but goes along with specific requirements and its own impact. The product should for instance be sorted upstream rather than downstream, selection should take place in a controlled environments, waste products should be separated per product category and/or even per defects, quantities should be ensured year-round, and so on.
The aim of the work reported in this chapter is to find feasible ways to rescue lost food products, to contribute to food security and value generation for low-income populations in an economically feasible and environmentally sustainable way.

Identifying promising valorisation pathways requires notion of:

- products that may potentially be generated from the residue stream(s),
- relevancy of that product in the market,
- processing pathways and the integration of this processing in a logistic chain (either connected to the product value chain or in a separate chain),
- quantitative understanding of yields of processing and product quality (like nutritional value),
- a business case,
- sustainability impacts (like net greenhouse gas impact of deriving the product from current waste management to the value-added application).

For identifying valorisation options (products and markets) we propose to use the 'Decision tree for valorisation options' (Axmann et al., 2023), whereas for process design and preliminary estimates of yields, sustainability impacts and business cases the *Procestimator* (as introduced by Nieuwland et al., 2022) is recommended.
Below, after a short introduction of suggested tools, the approach will be demonstrated for two case studies: rejected bananas (mainly from export chains) and broccoli stems.

3.2. Methodology: Decision tree for valorisation option

Essential characteristics of the Decision tree (Axmann et al., 2023):

The Decision tree is based on a number of guiding principles for prioritising valorisation options, in short:

- For a potential new application, the material should fulfil associated safety and quality requirements (like maintaining food-grade or feed-grade status). Only applications that are considered feasible according to this principle should be considered.
- For rapidly perishable materials and materials with low economic density, local solutions (mostly with small volumes) seem preferrable over solutions that require long-term transport.

- For losses/residue streams with large variations in volume mostly capital-intensive solutions are considered less appropriate than low-tech valorisation options.
- Market positioning: In case the product cannot compete with "virgin" materials in the intended market, possibly the reputation of "sustainable" food ingredient or product can strengthen the business case.
- Economic benefits: Savings because less material is sent to waste processing forms an essential part of the business case. Furthermore, the derived food product, food ingredient or other valuable application should either (a) serve as a (cheaper) replacement for a "virgin" source, (b) deliver a final product with higher price than the replacement product delivers, or (c) induce a new service.
- Sustainability impacts: valorising a food loss stream as replacement of a "virgin" source reduces the demand for production (with sustainability impact); furthermore, the volume ending in waste management is reduced.

In order to support the process of identifying promising food loss valorisation an 8-stage decision tree approach was developed. This (generic) decision tree supports the identification of potential FL valorisation options in any application area, varying from alternative waste management to (relatively high value) food applications. The decision tree facilitates the process through the sequence of questions and considerations given per question. The process is kept lean and mean: the greater part of the questions can be based on expert judgement.
The following steps are distinguished in the decision tree:

1. Food loss inventory.

   This steps requires understanding of the actual food losses along the chain and the continuity of their occurrence (on the scale of days, weeks and seasons, as well as over years). Furthermore, the characteristics of the food loss stream (type and status of products, current use, etc.) and logistic situation must be understood. For this, the method presented in the previous chapter may be used. Optionally, expert estimates may be used.
2. Prioritize identified streams with high volume and substantial nutritional value and/or energy
3. In case of a mixed stream: Explore whether it is possible to isolate a single product from the mixed stream
4. Assess whether it is realistic to expect whether the stream could be used for food, feed, or biobased application, based on safety considerations
5. Explore options for food application, based on quality considerations and potential relevancy for (local) markets.

   Ideas for valorisation might be expected from international food database on new food products introductions (like Innova Database), but this is not considered most adequate for food losses along the value chain because new types of food products require substantial investment in technology and market development. More simple solutions, replacing existing products in the market, with cost price advantage because of the low costs for the 'lost' food products seem more appropriate. Ideas for such products may be derived from existing fresh and (semi-)prepared food products and food ingredients on the market.
6. Explore options for food ingredient extraction (most relevant for materials with relatively high contents of valuable components; may require capital-intensive processing and is therefore most promising for large volumes).
7. Explore options for feed application (direct application, via processing or other intermediate steps like insects)
8. Explore options for non-food application: materials & biochemicals. Of these options, extraction and conversion processes for biochemicals required capital-intensive processes that are only considered relevant for large scale.
9. Explore options for energy (biogas) and fertilizer application through bio-digestion

For making well-considered decisions, various databases can be used, like:

- foodwasteexplorer.eu, which presents relevant compositional information as well as nutritional and energetic value of a large set of food waste streams,
- www.feedipedia.org, which lists many sources for feed ingredients: dedicated feed crops as well as food processing by-products and (processed) food products (presents amongst others nutritional value for feed application),
- Garcia et al. (2019), which provides bio-methane estimates in digestion processes for a large number of food products, crop by-products, processing by-products,
- Ratu et al. (2023), which explains how diverse groups of by-products are utilized in food production,
- https://eu-refresh.org/waste-pyramid.html presents 76 practical examples on applications of wasted food and by-products in diverse applications.

When ideas are derived from pilots on new types of valorisation, we recommend to critically analyse scalability of solution: with respect to availability of the food. This involves assessing available volumes of the food waste streams, expected continuity of that, market potential, insights in the economic viability of the proposed (processing and distribution) solutions and evaluating the needs of the industry in order to implement the solutions.

For food streams that have an incidental character, the methodology leads to solutions ('common' application domains of agri-food products: food, feed, energy and/or fertilizer production) that require little investments in process and chain design or solutions that are flexible with respect to the material, so that they can be implemented quickly in response to unexpected loss streams. Such applications are commonly relatively low-value applications (low-priced food, feed or bio-energy feedstock). For structural residual streams or food losses, long-term investments in infrastructure, equipment, and processes are more realistic.

Environmental sustainability benefits of food loss valorisation comes from the replacement of dedicated crop production by the rescued food loss. However, the benefit may become negative if operations that induce relatively high environmental impact would be needed to rescue the lost products. For valorisation pathways that require substantial amounts of energy in processing and/or substantial transport, it is recommended to pre-assess net effect of the intervention per unit product supplied: comparing environmental sustainability impact of the rescued food product with dedicate produced crops.

A more extensive elaboration of the methodology and supporting information sources can be found in the report by Axmann et al. (2023).

3.3. Methodology: *Procestimator*

The *Procestimator* (Nieuwland et al., 2022) is a powerful tool for estimating product composition, APEX, OPEX and GHG-emissions of processing pathways for agro-food products. It can be used for assessing new and alternative process routes and applications of residue streams to evaluate the feasibility with a minimum use of resources.
The *Procestimator* was built to get more insight in how upcycling (or valorisation) can be realised to support companies in decisions on food loss and waste upcycling. Next to estimates of composition, APEX, OPEX and GHG-emissions, it also gives insights in sensitivity of these outcomes to product and process parameters.

3.3.1. Goal

The *Procestimator* aims to create information on processing costs and resulting end material properties for process designs, including upcycling of food side streams towards economic positive applications (including food, feed and non-food products). The tool allows for screening of multiple upcycling ideas to identify interesting possible applications.

The *Procestimator* aims to help experts to:

- Select and lay-out possible process routes to turn a side stream into valuable ingredients.
- Calculate mass balances to end-product compositions and estimate their feed values (including of newly occurring side streams).
- Estimate the required process resources, costs and CO2-equivalents footprint.
- Conduct variation analysis in order to aid optimization and scenario comparison.
- Report feasibility analyses and process solutions.

The tool is equipped with databases with inherent properties of side stream and expert knowledge on a broad range of processes, in order to facilitate feasibility studies in a consistent and complete manner. It is not intended as a detailed process design tool, but instead focusses on the overall picture, so that the critical aspects of a processing scenario in terms of performance and costs can be identified with relatively limited efforts.

3.3.2. Total use principle

The *Procestimator* is based on the principle of 'Total use'. That is, analysing the use of the entire material, not limited to the most valued fraction only. For upcycling of side streams this is of particular interest for the following reasons:

1. It is preferred to upcycle all material and not just a fraction.
2. If the end product is a fraction of the side stream the costs or benefits of the remaining material, newly appearing side streams, must be taken into account as well.
3. Costs or benefits of the remaining material can be influenced by the processing applied to obtain the intended end product. Different choices in this processing may lead to a better total upcycling option.

3.3.3. General use

Procestimator appears to the user as a simplified process flow sheeting tool. For a given choice of input streams and process sequence, *Procestimator* will show the cumulative effect on product composition, value and costs, as well the details for each intermediate stream and process.
The starting point is an input stream, which is defined by the volume, a basic composition specification, concentration of minor components of interest, but also characterising parameters such as the structure and various quality properties. Via a dialogue, an initial selection can be made from databases of food products and side streams currently used by the feed sector.
Next, successive unit processes can be added to get the required product transformation. Each process is characterised by specific key parameters / choices that determine its output streams, capacity, resource requirements and costs. For each unit process, these parameters can be set. *Procestimator* contains a collection of simplified process models for which default parameters are provided. For the cost estimation, the availability of process can be varied from installed to green field, or external tolling when available. Also operations as (cold)storage, packing and transport are included to complete the overall cost estimation.
Composition and cost data are based as much as possible on reliable databases. Multiple relevant costs and benefits are incorporated in the *Procestimator*. This includes transport, packaging, discard of material (sewage or incineration costs), labour, energy, investments, maintenance, interest and feed value.
The tool is intended to be used by process and food engineers, it is an expert tool. Given the large number of food processing technologies and the large variety in starting food side stream materials it is nearly impossible to realise a selection tool that can guide a layman user sufficiently. A layman tool requires too much limitation in the degree of freedoms that come with both the food processing technologies and the food materials.
The *Procestimator* supports the following functions:

1. Process selection and design by guiding tools based on material properties towards a process sequence blueprint.
2. Detailed costs estimate of investments and of processing.
3. Yield and Mass balances of (intermediate) outputs.
4. Output value indication based on feed value.

These results allow for several types of analyses:

1. Optimisation of output value towards various output streams based on production costs and composition of the material streams.
2. Analysis of capacity dependency. For instance, on the available volume in time of the side stream material or on labour supply in one or more shifts per day.
3. Analysis of required output value for break-even analysis.
4. The resulting blueprint of the process set-up is input for impact analysis. For example, expressed in kilogram CO2-equivalents per kilogram intended end product, or in water use per kilogram intended end product.

3.4. Explanation of the strategic approach in case study: valorisation of rejected banana from exporters

3.4.1. Introduction

In Mexico the total production of banana was in 2020, 2.4 million Metric Ton, whereby 75% of the production produced in the states Chiapas, Tabasco, Veracruz and Colima. Looking at the very high-density production areas, at municipality level, just seven areas account for more than 50% of the total production.

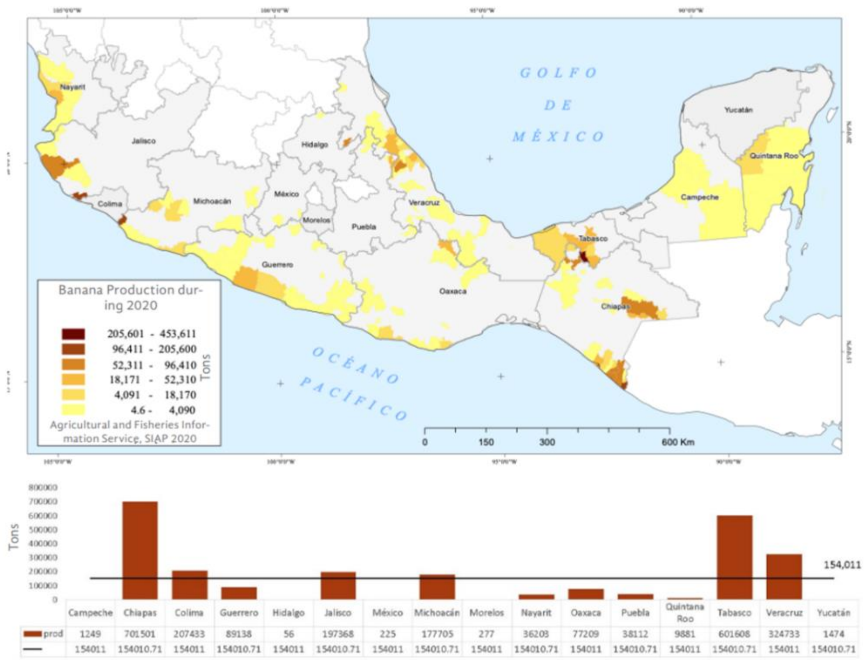
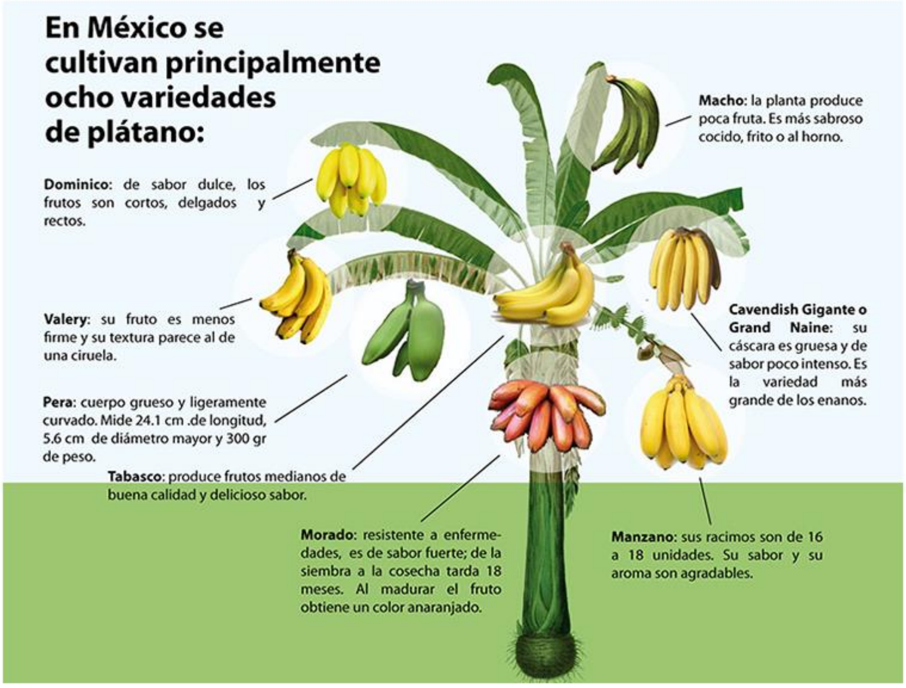


Figure 7 Production of banana in Mexico 2020, data from SIAP-AGRICULTURA (2020) (copied from Ibarra Zapata 2023)

There are 8 varieties of bananas produced in Mexico, see Figure 8. However, as a raw material for processing, four different groups can be distinguished: dessert banana (ripe and unripe) and cooking banana/plantain (ripe and unripe). Cooking banana/plantain is different from dessert banana, but both categories have similar composition.

During ripening a substantial amount of starch is converted to sugar. However, ripe cooking banana/plantain bananas still contain a substantial amount of starch, and have a low flavour profile. Due to their starch content they need to be cooked before consumption. After ripening, dessert banana contain only small amounts of starch, this banana has much more flavour and a lower dry matter content than cooking banana/plantain (see
Table 8).



Eight kinds of bananas grown in Mexico. Click to enlarge. Credit: SAGARPA

Figure 8 ***Varieties of Bananas produced in Mexico (copiedfrom:http://siaprendes.siap.gob.mx/contenidos/2/04-platano/contexto-4.html#)***

Table 8 ***Typical macro-nutrient composition of ripe (Nevo table 2021) and unripe banana (Borges 2020)***

nutritional values in 100 g	**Dessert banana**		**Cooking banana/plantain**	
	ripe	unripe	ripe	unripe
Protein	**1.1**	**1.4**	**1.3**	**1.4**
Fat	**0.3**	**0.4**	**0.0**	**0.0**
Fatty acids total saturated	*0.1*	*0.1*	*0.0*	*0.0*
Fatty acids monounsaturated cis	*0.0*	*0.0*	*0.0*	*0.0*
Fatty acids polyunsaturated	*0.1*	*0.1*	*0.0*	*0.0*
Carbohydrates	**20.6**	**32.7**	**31.5**	**36.8**
Mono and disaccharides total	*15.5*	*9.0*	*14.8*	*10.1*
Polysaccharides total	*5.1*	*23.8*	*16.7*	*26.7*
Polyolen total	*0.0*	*0.0*	*0.0*	*0.0*
Dietary fibre	**1.9**	**2.4**	**2.3**	**2.5**
Ash	**0.8**	**1.0**	**0.0**	**0.0**
Water	**75.4**	**60.9**	**65.0**	**59.1**

Most of the bananas are grown for the export. After harvest, the bananas are graded and washed. This grading process results in a large stream of rejected bananas that must be locally marketed or disposed of. Common destinations are local food markets, to processors of banana products, for animal feed or to waste management (like composting or land fill).

3.4.2. Identification of potential value-added applications through the Decision tree

The process as described in section 3.2 was applied:

0. Food loss inventory

   Interviews by BAMX with banana farmers revealed the available volumes and discharge or revenues from the reject bananas on farm level. The volume of side streams for dessert banana is substantially higher than for cooking banana.

The information obtained by this is used later in the process for quantitative estimation of feasibility of identified options.

1. Prioritize identified streams with high volume and substantial nutritional value and/or energy

   The product category was selected before application of the protocol.

2. In case of a mixed stream: Explore whether it is possible to isolate a single product from the mixed stream

   Desert banana and cooking banana are distinguished because they have different characteristics. Since they are generated in distinct supply chains, sorting is not necessary for generation of more or less homogeneous streams.

3. Assess whether it is realistic to expect whether the stream could be used for food, feed, or biobased application, based on safety considerations

   Through prevention of physical damage, no safety problem is introduced.

4. Explore options for food application, based on quality considerations and potential relevancy for (local) markets

   Based on inventory of banana-derived food products, the following options are considered:

   - fried dry snack/chips
   - puree
   - jam.

5. Explore options for food ingredient extraction (most relevant for materials with relatively high contents of valuable components; may require capital-intensive processing and is therefore most promising for large volumes).

   Based on inventory of banana-derived food ingredients, the following options are considered:

   - flavour
   - powder/flour
   - starch
   - alcohol (obtained after fermentation).

6. Explore options for feed application (direct application, via processing or other intermediate steps like insects)

   With an eye on the relatively high nutritional energy content the option of direct application of feed was considered.

7. Explore options for non-food application: materials & biochemicals. Of these options, extraction and conversion processes for biochemicals required capital-intensive processes that are only considered relevant for large scale.

   Because of the high content of perishable components, application as material is not considered feasible.

   The volumes are considered too small for setting up processing facilities for conversion to biochemicals.

8. Explore options for energy (biogas) and fertilizer application through bio-digestion

   Because more options with higher value have been identified above, the options for bioenergy and composting are not explored.

3.4.3. Assessments of the valorisation options through the *Procestimator*: estimates of product cost prices

Based on their different composition and characteristics, the options for processing for the four groups of bananas will be different. In Table 9 the selected options are presented.

Table 9 Suitability of four banana groups to the identified potential applications

	state	fried dry snack/ chips	puree	jam	flavour	powder/ flour	starch	alcohol (digester)	animal feed	....
dessert banana	ripe	yes	yes	yes	yes	no	no	yes	yes	....
	unripe	no	no	no	no	yes	yes	yes	yes	....
cooking banana/plantain	ripe	yes	yes	no	no	yes	no	yes	yes	....
	unripe	no	no	no	no	yes	yes	yes	yes	....

Since the larger part of banana side streams consist of dessert banana (see step 0 in section 3.4.2), only options for dessert banana are considered. From the potential applications listed in Table 9 the options 'dried dry snack/chips', 'puree' and 'powder/flour' are considered most realistic. Processing pathways for these options are shown in
Figure 9.

For estimating cost prices and for assessing effects of scale size on the cost price, a range of volumes of reject banana is considered for the different processes. These parameters are presented in Table 10 together with other relevant parameters like the price for the disposed peels in the process and the costs for any additives. For the cost of the raw material the highest number is taken from the current revenue of a large farm in Calera, which sells the reject bananas to a puree processor. The low number is the calculated feed value based on its composition and current feed prices for digestible protein and energy. This estimation is done automatically in the *Procestimator* when feed value as raw material is selected for a specific target animal. When the bananas are processed, banana peels are a new created side stream that have their own feed value depending on ripeness or costs when it is discharged to a digester.

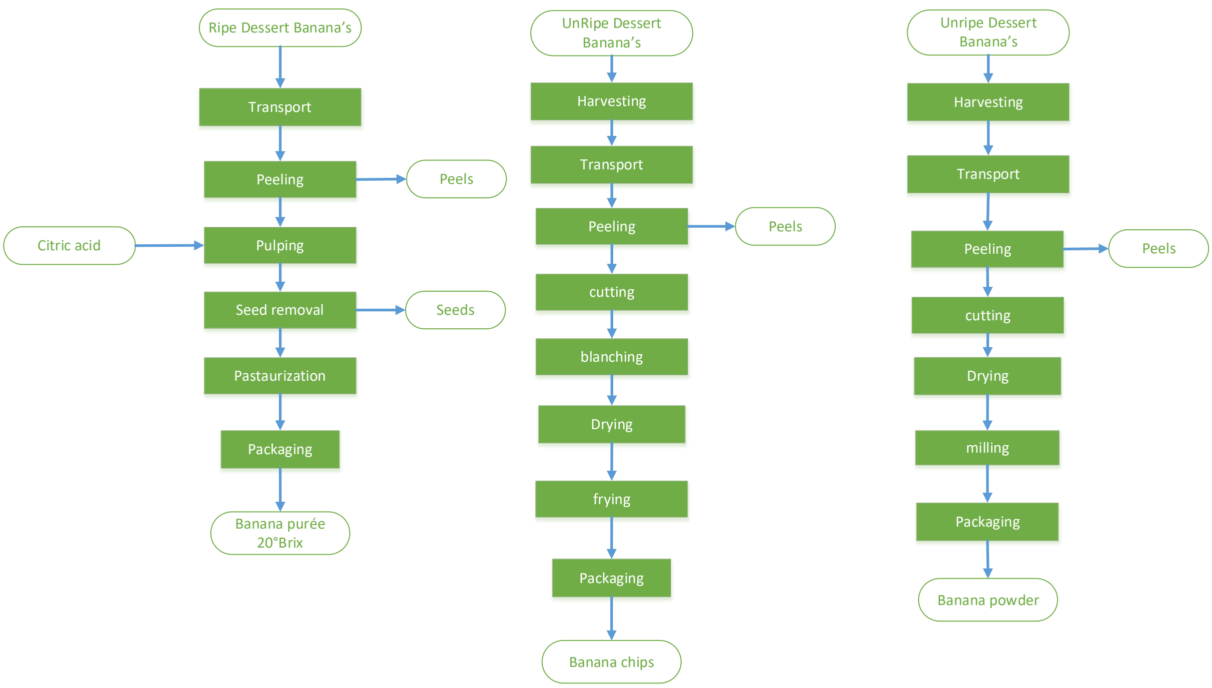


Figure 9 Processing pathways to food products

Table 10 Parameters used for the cost price calculations

Parameter		
Volume	325-30176 Metric Ton per year	On farm min Cihautlán 12.5% of 2600MT and max Calera 16% of 188600MT
Harvest costs	0	Product is coming from selection process after harvest
Price raw material	1$mex - 2$mex /kg DDP	Feed value estimated - sales to processor by Calera
Transport distance	0 km	Processing on farm
Unripe peel	Min -0.33$mex, max +0.24$mex	Min Digester, max animal feed (ruminants)
Ripe peel	Min -0.33$mex, max +0.46$mex	Min Digester, max animal feed (ruminants)
Sunflower oil	17peso/litre; 1.5 kg CO2-eq/kg	Bulk price nov 2023; https://apps.carboncloud.com/climatehub/product-reports/id/75429961523
Citric acid	28.3peso/kg; 20 kg CO2-eq/kg	Bulk price nov 202; https://apps.carboncloud.com/climatehub/product-reports/id/77828116298

Cost price calculated with the Procestimator

Below, per selected process the results are displayed in three tables. The first shows the calculated composition of the product (side) streams, the second the cost price, including breakdown on the processing steps, of the highest and lowest calculated cost price. As the lowest cost price is calculated with almost 100 times the throughput as for the lowest cost price, the difference in the required investment is also large. And the last table summarizes the effect on the cost price based on the high and low estimation for the raw material, the total volume and the price for the residual peels.

Cost price for on-site Banana Flour production

In this scenario banana flour is made from green bananas. The sugar content for this material is low enough to create a shelf stable not lumping flour. The peels from green bananas are less valuable when used as feed compared to peels from ripe bananas.

Table 11 ***Composition and (quality) state of the raw material and its main end-products***

	product in	products out		
	unripe Banana	unripe peel	flour	
fraction of start	100.0%	41.1%	24.3%	
Value	0.053	-0.017	1.334	€/kg
Take value from	Known price DDP	Digester	Primary stream (Calculate)	
feed value (franco farm)	0.077	0.013	0.186	ruminant meat €/kg
Nutritional values				
Energy	621.8	75.7	1501.2	kJ/100g
Protein total	1.4	0.5	3.4	/100g
Fat total	0.4	0.4	1.0	/100g
saturated	0.1	0.1	0.2	/100g
monounsaturated	0.0	0.1	0.0	/100g
polyunsaturated	0.1	0.1	0.2	/100g
Carbohydrates total	33.1	1.2	80.0	/100g
Mono and disaccharides	9.1	0.2	22.0	/100g
Polysaccharides	24.1	1.0	58.2	/100g
Polyolen	0.0	0.0	0.0	/100g
Dietary fiber	2.4	3.8	5.9	/100g
Alcohol	0.0	0.0	0.0	/100g
Ash	1.0	0.8	2.4	/100g
Water	61.7	93.2	7.3	/100g
structure category	chunks >5mm	fibrous	slurry/paste	
food category	wet	rich in liquid	dry, no fat	
State				
temperature	20.0	20.0	60.0	°C
pH	6.0	6.0	6.0	
particle size	50.0	2.5	0.2	mm
Quality				
Matrix Accessibility	no extraction	no extraction	max 100% extraction	
Protein Native	protein 100% native	protein 100% native	protein 100% native	
Starch Ungell.	starch 100% ungelatinized	starch 100% ungelatinized	starch 100% ungelatinized	
Enzyme stability	enzymes/substrate separated	enzymes are active	enzymes are stabilized	
Microbial stability	product slowly spoiled	product quickly spoiled	product stabilized	

Table 12 ***Cost break down for the production of Banana flour for the lowest (top) and highest (bottom) cost price based parameters from Table 10***

Streams In	**Volume**		**Price**		**Pricing Source**				
Green Banana		30176 MetricTon/year		1.00 MXN$/kg	Known price DDP				
Streams Out	**Volume**		**Price**		**Outlet**				
unripe peel		12401 MetricTon/year		0.24 MXN$/kg	Feed value ruminant meat				
waste water		1347 MetricTon/year		-0.09 MXN$/kg	Sewer				
banana flour		7318 MetricTon/year		12.36 MXN$/kg	Primary stream (Calculate)				
					2	3	4	6	8
process step			streams in	streams out	capital costs	man power	tolling cost	electricity	steam
	total k€/year	**4599**	**1599**	**-150**	**1402**	**1034**	**0**	**63**	**650**
Ba06_0START	35%	1601	1599			1.8			
Ba06_2manual peeling	20%	908		-156.5	15.1	1025.7		23.7	
Ba06_3knife cutter	0%	20			15.4	2.1		2.7	
Ba06_4blanching	3%	154		6.6	99.2	1.4			46.9
Ba06_5convection belt dryer	37%	1690			1085.1	1.4			603.2
Ba06_6impact mill	5%	226			187.6	1.4		36.8	
Streams In	**Volume**		**Price**		**Pricing Source**				
Green Banana		325 MetricTon/year		2.00 MXN$/kg	Known price DDP				
Streams Out	**Volume**		**Price**		**Outlet**				
unripe peel		134 MetricTon/year		-0.33 MXN$/kg	Digester				
waste water		15 MetricTon/year		-0.09 MXN$/kg	Sewer				
banana flour		79 MetricTon/year		25.16 MXN$/kg	Primary stream (Calculate)				
					2	3	4	6	8
process step			streams in	streams out	capital costs	man power	tolling cost	electricity	steam
	total k€/year	**100**	**34**	**2**	**35**	**21**	**0**	**1**	**7**
Ba06_0START	36%	36	34			1.8			
Ba06_2manual peeling	18%	18		2.3	1.2	14.2		0.3	
Ba06_3knife cutter	1%	1			0.1	0.7		0.0	
Ba06_4blanching	9%	9		0.1	6.5	1.4			0.5
Ba06_5convection belt dryer	23%	23			14.7	1.4			6.5
Ba06_6impact mill	14%	14			12.4	1.4		0.4	

Table 13 Effect of on cost price for the production of Banana flour using the different assumptions of the parameters from Table 10

Volume Metric Ton/year	***Raw material cost***	***Peel destination***	***Cost price peso/kg***
325; 79 Metric Ton flour	1$mex/kg (feed for ruminants)	feed ruminant	20.1
	2$mex/kg (sale to processor)	feed ruminant	24.2
	1$mex/kg (feed for ruminants)	Digester	21.1
	2$mex/kg (sale to processor)	Digester	25.2
30176; 7318 Metric Ton flour	1$mex/kg (feed for ruminants)	feed ruminant	12.4
	2$mex/kg (sale to processor)	feed ruminant	16.5
	1$mex/kg (feed for ruminants)	Digester	13.3
	2$mex/kg (sale to processor)	digester	17.5

Cost price for on-site Banana Chips production

Banana Chips are made from green bananas. This makes the cutting and blanching feasible and less sticky than with ripe bananas. The banana chips are fried in sunflower oil. The frying will increase the oil content to 25% in the end-product, due to the absorption of oil by the banana.

Table 14 Composition and (quality) state of the raw material and its main end-products

	product in	**products out**		
	Ripe Banana	**unripe peel**	**chips**	
fraction of start	100.0%	41.1%	33.3%	
Value	0.053	-0.017	0.162	€/kg
Take value from	Known price DDP	Digester	Primary stream (Calculate)	
feed value (franco farm)	0.077	0.013	0.269	ruminant ı
Nutritional values				
Energy	621.8	75.7	1982.1	kJ/100g
Protein total	1.4	0.5	2.5	/100g
Fat total	0.4	0.4	24.7	/100g
saturated	0.1	0.1	3.1	/100g
monounsaturated	0.0	0.1	5.3	/100g
polyunsaturated	0.1	0.1	15.8	/100g
Carbohydrates total	33.1	1.2	58.3	/100g
Mono and disaccharides	9.1	0.2	16.0	/100g
Polysaccharides	24.1	1.0	42.4	/100g
Polyolen	0.0	0.0	0.0	/100g
Dietary fiber	2.4	3.8	4.3	/100g
Alcohol	0.0	0.0	0.0	/100g
Ash	1.0	0.8	1.8	/100g
Water	61.7	93.2	8.4	/100g
structure category	chunks >5mm	fibrous	chunks >5mm	
food category	wet	rich in liquid	dry, high fat	
State				
temperature	20.0	20.0	30.0	°C
pH	6.0	6.0	6.0	
particle size	50.0	2.5	2.6	mm
Quality				
Matrix Accessibility	no extraction	no extraction	max 75% extraction	
Protein Native	protein 100% native	protein 100% native	protein 100% denaturated	
Starch Ungell.	starch 100% ungelatinized	starch 100% ungelatinized	starch 100% gelatinized	
Enzyme stability	enzymes/substrate separated	enzymes are active	enzymes are destroyed	
Microbial stability	product slowly spoiled	product quickly spoiled	product stabilized	

Table 15 Cost break down for the production of Banana chips for the lowest (top) and highest (bottom) cost price based parameters from Table 10

Streams In	**Volume**		**Price**		**Pricing Source**			
Green Banana	30176 MetricTon/year		1.00 MXN$/kg		Known price DDP			
Streams Out	**Volume**		**Price**		**Outlet**			
unripe peel	12401 MetricTon/year		0.24 MXN$/kg		Feed value ruminant meat			
waste water	1347 MetricTon/year		-0.09 MXN$/kg		Sewer			
banana chips	10044 MetricTon/year		13.70 MXN$/kg		Primary stream (Calculate)			
					2	3	6	8
process step			streams in	streams out	capital costs	man power	electricity	steam
	total k€/year	**7138**	**1599**	**-150**	**1116**	**1034**	**26**	**800**
Ba06_0START	22%	1601	1599			1.8		
Ba06_2manual peeling	13%	908		-156.5	15.1	1025.7	23.7	
Ba06_3knife cutter	0%	20			15.4	2.1	2.7	
Ba06_4blanching	2%	154		6.6	99.2	1.4		46.9
Ba06_5convection belt dryer	19%	1331			819.9	1.4		509.3
Ba06_6frying	44%	3123			166.1	1.4		243.2
Streams In	**Volume**		**Price**		**Pricing Source**			
Green Banana	325 MetricTon/year		2.00 MXN$/kg		Known price DDP			
Streams Out	**Volume**		**Price**		**Outlet**			
unripe peel	134 MetricTon/year		-0.33 MXN$/kg		Digester			
waste water	15 MetricTon/year		-0.09 MXN$/kg		Sewer			
banana chips	108 MetricTon/year		22.65 MXN$/kg		Primary stream (Calculate)			
					2	3	6	8
process step			streams in	streams out	capital costs	man power	electricity	steam
	total k€/year	**126**	**34**	**2**	**30**	**21**	**0**	**9**
Ba06_0START	29%	36	34			1.8		
Ba06_2manual peeling	14%	18		2.3	1.2	14.2	0.3	
Ba06_3knife cutter	1%	1			0.1	0.7	0.0	
Ba06_4blanching	7%	9		0.1	6.5	1.4		0.5
Ba06_5convection belt dryer	14%	18			11.1	1.4		5.5
Ba06_6frying	35%	44			11.0	1.4		2.6

Table 16 Effect on cost price for the production of Banana chips using the different assumptions of the parameters from Table 10

Volume Metric Ton/year	***Raw material cost***	***Peel destination***	***Cost price peso/kg***
325; 108 Metric Ton chips	1$mex/kg (feed for ruminants)	feed ruminant	18.9
	2$mex/kg (sale to processor)	feed ruminant	22.0
	1$mex/kg (feed for ruminants)	digester	19.6
	2$mex/kg (sale to processor)	digester	22.7
30176; 10044 Metric Ton chips	1$mex/kg (feed for ruminants)	feed ruminant	13.7
	2$mex/kg (sale to processor)	feed ruminant	16.7
	1$mex/kg (feed for ruminants)	digester	14.4
	2$mex/kg (sale to processor)	digester	17.4

Cost price for on-site Banana puree production

Banana Puree is made from ripe dessert banana. On the market, banana purees with a low and a high dry matter content are available, shown by the brix value. In below calculations puree with a brix value of 20° is described, meaning that no drying will be necessary, keeping the costs to a minimum. Through the addition of citric-acid and a pasteurization step the purée will be shelf stable at ambient temperatures.

Table 17 Composition and (quality) state of the raw material and its main end-products

	product in	products out		
	Ripe Banana	ripe peel	pasteurized pulp	
fraction of start	100.0%	32.6%	66.6%	
Value	0.053	-0.017	0.162	€/kg
Take value from	Known price DDP	Digester	Primary stream (Calculate)	
feed value (franco farm)	0.051	0.025	0.051	ruminant meat €/kg
Nutritional values				
Energy	395.6	156.7	394.4	kJ/100g
Protein total	1.1	0.9	1.1	/100g
Fat total	0.3	1.0	0.3	/100g
saturated	0.1	0.3	0.1	/100g
monounsaturated	0.0	0.3	0.0	/100g
polyunsaturated	0.1	0.3	0.1	/100g
Carbohydrates total	20.6	3.5	20.6	/100g
Mono and disaccharides	15.5	3.1	15.5	/100g
Polysaccharides	5.1	0.3	5.1	/100g
Polyolen	0.0	0.0	0.0	/100g
Dietary fiber	1.9	5.6	1.9	/100g
Alcohol	0.0	0.0	0.0	/100g
Ash	0.8	1.3	0.8	/100g
Water	75.4	87.6	75.3	/100g
structure category	chunks >5mm	fibrous	slurry/paste	
food category	intermediated rich in liquid	intermediated rich in liquid	intermediated rich in liquid	
State				
temperature	20.0	20.0	37.9	°C
pH	6.0	6.0	3.7	
particle size	50.0	2.5	2.0	mm
Quality				
Matrix Accessibility	no extraction	no extraction	max 100% extraction	
Protein Native	protein 100% native	protein 100% native	protein 100% native	
Starch Ungell.	starch 100% ungelatinized	starch 100% ungelatinized	starch 100% ungelatinized	
Enzyme stability	enzymes/substrate separated	enzymes are active	enzymes are destroyed	
Microbial stability	product slowly spoiled	product quickly spoiled	product stabilized	

Table 18 Cost break down for the production of Banana puree for the lowest (top) and highest (bottom) cost price based, parameters from Table 10

Streams In	Volume	Price	Pricing Source
Ripe Banana	30176 MetricTon/year	1.00 MXN$/kg	Known price DDP

Streams Out	Volume	Price	Outlet
ripe peel	9835 MetricTon/year	0.46 MXN$/kg	Feed value ruminant meat
seeds	304 MetricTon/year	-0.33 MXN$/kg	Digester
pasteurized pulp	20077 MetricTon/year	2.67 MXN$/kg	Primary stream (Calculate)

					2	3	6	8
process step			streams in	streams out	capital costs	man power	electricity	steam
	total k€/year	2819	1599	-236	174	1118	61	42
Ba06_0START	57%	1601	1599			1.8		
Ba06_2manual peeling	32%	910		-241.2	15.9	1111.2	23.7	
Ba06_4pulp machine	6%	163		5.3	140.4	2.8	14.7	
Ba06_4ad additive	2%	67			6.0	0.7	0.3	
Ba06_5Liq pasteurization	3%	78			12.1	1.4	22.8	41.9

Streams In	Volume	Price	Pricing Source
Ripe Banana	325 MetricTon/year	2.00 MXN$/kg	Known price DDP

Streams Out	Volume	Price	Outlet
ripe peel	106 MetricTon/year	-0.33 MXN$/kg	Digester
seeds	3 MetricTon/year	-0.33 MXN$/kg	Digester
pasteurized pulp	216 MetricTon/year	6.51 MXN$/kg	Primary stream (Calculate)

					2	3	6	8
process step			streams in	streams out	capital costs	man power	electricity	steam
	total k€/year	73	34	2	14	21	1	0
Ba06_0START	50%	36	34			1.8		
Ba06_2manual peeling	24%	18		1.8	1.2	14.2	0.3	
Ba06_4pulp machine	17%	12		0.1	9.3	2.8	0.2	
Ba06_4ad additive	2%	2			0.4	0.7	0.0	
Ba06_5Liq pasteurization	7%	5			2.8	1.4	0.2	0.5

Table 19 Effect on cost price for the production of Banana puree using the different assumptions of the parameters from Table 10

Volume Metric Ton/year	Raw material cost	Peel destination	Cost price peso/kg
325; 216 Metric Ton puree	1$mex/kg (feed for ruminants)	feed ruminant	4.6
	2$mex/kg (sale to processor)	feed ruminant	6.1
	1$mex/kg (feed for ruminants)	digester	5.0
	2$mex/kg (sale to processor)	digester	6.5
30176; 20077 Metric Ton puree	1$mex/kg (feed for ruminants)	feed ruminant	2.7
	2$mex/kg (sale to processor)	feed ruminant	4.2
	1$mex/kg (feed for ruminants)	digester	3.1
	2$mex/kg (sale to processor)	digester	4.6

3.4.4. Assessments of the valorisation options through the *Procestimator*: estimates of product greenhouse gas emission

Besides the cost price, also the minimization of greenhouse gas (GHG) emissions can be a driver for selecting a certain process or application. Below presented GHG-emissions of the selected processes were estimated through the *Procestimator* based on the use of the expected energy in the different processes, additions to the product, packaging and transport.

In below calculations the GHG emissions allocated to the obtained materials and emissions of processing up to the final product are taken in account.
Assumed GHG emission factors for utilities are given in Table 20. The greenhouse gas emissions of the utilities are derived from literature and data bases but needs careful reviewing as most of the numbers are depending on the production location of the source.
The GHG-emission intensity of fresh banana was estimated by Chalita (2022) at 0.117 kg CO2-eq/kg.

Table 20 Assumed GHG-emission factors of utilities for the different processes

Utility	Source	GHG-emission		Source/remark
gas	natural gas	2.1	kg CO2-eq/m3	chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.climateneutralgroup.com/wp-content/uploads/2022/01/220131-CNG-methodology-on-emission-factors.pdf
steam	natural gas	168	kg CO2-eq/MT	Assumption: 80% boiler efficiency. This requires re-use of condensate. The efficiency will be lower for high pressure steam. WTW emissions of natural gas, https://www.co2emissiefactoren.nl/lijst-emissiefactoren/
Elec-tricity	grey	386	kg CO2-eq/MWh	Value for Mexico 2022; for other countries see Source: ourworldindata.org (visited 4 December 2023)
water	Spring	0.20	kg CO2-eq/m3	Varies strongly depending on the pumping depth and treatment. Typically, 0.53kWh electricity is used per m3 (https://www.danfoss.com/en/about-danfoss/articles/dhs/the-carbon-footprint-of-potable-water/).

Table 21 shows the GHG-emission breakdown per step from raw material to final product for the banana flour production. Important parameters in the GHG emission analyses are starting value (primary production) of the raw material (yellow cells). The type of processing unit that is used in a process can also have significant influence on the outcome of the total GHG-emissions. E.g. the convection dryer in the banana flour case is using steam for indirect heating. If direct gas heating would be used it would save 0.23 kg CO2-eq/kg. Also in many processes, especially the high energy use processes, there is an option to recover a part of the used energy. This can also have a large impact on the outcome.

Different methodologic choices exist for allocating GHG-emissions to the raw material (i.e. the reject bananas): zero emissions, mitigating the GHG emissions associated to the reference (waste management), economical allocation, or primary production emission. The first option is used if the raw material has (currently) no application, no economic value or if the primary data are unknown. Using the economical allocation, the GHG-emission of the primary production will be divided between the main product and the used side stream based on the raw material cost and the value of the used by product in the process. This will be visible in column “stream in” in Table 21. Using this option, the economic value of the raw material and the GHG-emission of the primary production has to be known. This can influence the outcome e.g. in the case of the banana flour production at the farm where the surplus bananas are sold as feed for 2 pesos/kg.

Processing of side streams will inevitably induce extra GHG-emissions to the product. This does not mean that the calculated process will contribute always to a total higher emission worldwide. By using a side stream as raw material, less crops will be required, so that GHG emissions related to that production can be prevented. If the total GHG-emission of the process is than lower than such replaced product, it can be concluded that the valorisation contributes to net reduction of GHG-emissions for fulfilling a market demand. For the intensively processed banana-derived products considered here, it is not realistic that they would replace fresh bananas. More logical is the replacement of a flour product, like other flours:

- Wheat flour: For wheat flour various carbon footprint values have been reported in scientific and LCA domain, typically around 0.6 to 0.8 kg CO2-eq. per kg flour. The presented value for banana flour (Table 21), 0.75 kg CO2-eq. per kg flour) is in the same range.
- Rice flour, for which 2.5 kg CO2-eq. per kg and higher values are found. This is substantially higher than the presented value for banana flour.
- Almond flour, for which 1.2 kg CO2-eq. per kg and higher values are found. Also this is substantially higher than the presented value for banana flour.

From this is concluded that replacing a gluten-free flour by the food-rejects derived banana flour contributes to reducing GHG emissions. When assuming an average/typical carbon footprint of 2 kg CO2-eq. per kg of the replaced gluten-free flour and 0.75 kg CO2-eq. per kg for banana flour, the total GHG emissions reduction for 30176 ton bananas / 7318 ton banana flour is estimated at 9300 ton CO2-eq.

For banana puree and chips no reference carbon footprint was found; therefore, the consequential effect is not elaborated here. However, since the processing to such product is not different when sourced from dedicatedly produced bananas than when derived from reject bananas, it is expected that sourcing these materials from the reject bananas induces less GHG emissions than when sourced from dedicated banana production. Even if the replacement products would have been derived from reject bananas, when traded locally the local produced and marketed products would benefit from preventing long-distance transport.

Disclaimer: in the assessments estimates for diverse parameters were used; the practical values may deviate in practice.

Table 21 GHG-emission break down to produce Banana flour 20km from the farm, not packed. Dryer uses steam made of natural gas for its heat transfer and has no heat recovery

								information from primairy production			
Streams In	**Streams In**	**Volume**		**GHG**		**allocation type**		primair emmision		source	
Green Banana	Ba06_0START	30176	MetricTon/year	0.00	kgCO2/kg	Zero emmision		0.117	kgCO2/kg	https://doi.org/10.1051/e3sconf/20223550200	
Streams Out	**Streams Out**	**Volume**		**GHG process**		**incl savings primair production**		**based on**		GHG emission process (inc savings)	
unripe peel	Ba06_2manual peeling	12401	MetricTon/year	0.00	kgCO2/kg	0.00	kgCO2/kg	economical allocati		44 (16)	Metric Ton CO2_eq /year
banana flour	Ba06_6impact mill	7318	MetricTon/year	0.75	kgCO2/kg	0.27	kgCO2/kg	economical allocati		5460 (1958)	Metric Ton CO2_eq /year
					6	7	8	9	22		
process step			streams in	waste streams	electricity	gas	steam	water	nsport/additive		
					grey	natural gas	natural gas	spring			
	total MT CO2-eq/year	**5504**	**0**	**0**	**339**	**0**	**5123**	**0**	**42**	**0**	**0**
Ba06_0START	0%	0									
Ba06_1transport	1%	42							42		
Ba06_2manual peeling	2%	127			127						
Ba06_3knife cutter	0%	15			15						
Ba06_4blanching	7%	370					370	0.5			
Ba06_5convection belt dryer	86%	4753					4753				
Ba06_6impact mill	4%	197			197						

Table 22 ***GHG-emission for the production of banana flour, chips and purée not packed, from rejects of the on-farm selection process for export. Raw material zero emission, emission primary production (savings) 0.117 kg CO_2/kg, production factory located 20km from the farm***

	GHG-emission per kg product	
product	**process**	
flour	0.73	kg CO_{2-eq}/kg
chips	0.86	kg CO_{2-eq}/kg
puree	0.07	kg CO_{2-eq}/kg

3.4.5. Comparison of the processes and conclusions

Potential food applications of reject bananas were identified: chips, puree and flour. Developments in the market make especially banana flour an interesting products (gluten-free food ingredient); therefore a viable business case seems available (to be verified in practice).
For the resulting process design the expected cost price is obtained in the *Procestimator*. By using high and low estimates for input parameters the sensibility of these uncertainties on the cost price can be calculated. This will help to find the most important cost effecting parameters in the process. For the cost price of the different banana products this is summarised in Table 23. This table includes additional cost to the product when the process is not done on-site but in a separate factory 20km from the farm. The feasibility of the chosen process route and/or end-product can be estimated through comparing the cost price range with expected market price.
Results show that the cost price substantially depends on situational conditions (Table 10). The difference in available volume between the different farms has the largest effect on the cost price. Considering that global bulk market prices of e.g. banana flour (on Alibaba a price of 20 peso/kg, excluding transport was encountered) is within the range of estimated cost prices (Table 23) it is recommended to further analyse the local situation for decision taking on actual investments.

Table 23 **The min and max cost prices for the production of banana flour, chips and puree not packed from rejects of the on-farm selection process for export. Based on parameters from *Table 10*. Including additional price for transport and processing in a factory 20km from the farm**

	Cost price per kg product		
	Min	**Max**	**transport 20km**
Product	peso/kg	peso/kg	peso/kg
Flour	12.4	25.2	0.5
Chips	13.7	22.7	0.4
Puree	2.7	6.5	0.2

Evaluation of the cost break down into the different processing steps shows that for all processes, even for the low volume scenarios, the raw material price has a significant impact on the cost price. And that beside frying and drying, the peeling has also a high impact due to the amount of labour that is required.
For the greenhouse gas emissions, the peeling contributed only a small amount to the total emissions.

In the GHG emissions analysis, the carbon footprint for reject bananas-derived flour was quantitatively compared with the carbon footprint of other gluten-free flours. It was concluded that substantial GHG emissions can be reduced through introducing the flour as an alternative to common gluten-free flours. For other considered products that can be derived from reject bananas no quantitative data of the replacement products are available; however, we reasoned that also for these applications the valorisation of the reject stream as a replacement of other products in the market contributes to GHG emissions reduction.

3.5. Explanation of the strategic approach in case study: valorisation of broccoli side streams

3.5.1. Introduction

As for banana, Mexico is relatively large producer of broccoli; most of the broccoli production in Mexico is for export.

From broccoli only ~15 – 20% of the total plant is consumed: floret and (optionally) part of the stem (Figure 10, Domínguez-Perles 2010). The largest part of the plant (the leaves) is seldomly utilized for food, although leaves of kale (other varieties in the family of Brassica oleracea varieties) are utilized as the edible part. Some people consume broccoli stems, but this is not the norm. Commercial broccoli florets usually have ~10 cm of attached stem. Although the stems nearest to florets are tender and edible, the bottom stem is lignified and not acceptable for food consumption. The potential consumption of stems and leaves would increase productivity and sustainability of the World's broccoli crop by increasing yield from 15% up to as much as 83% (Liu 2018).

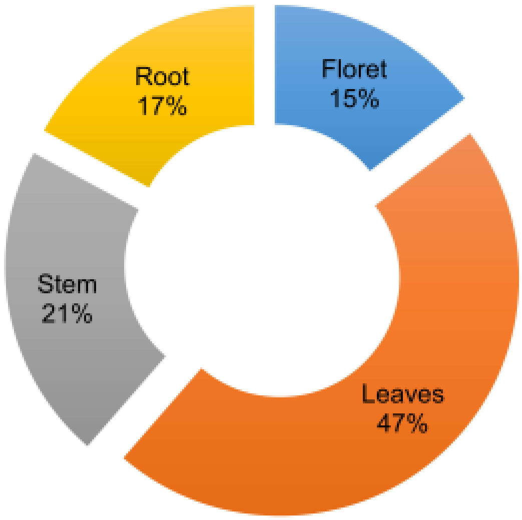


Figure 10 ***Broccoli ("Gypsy" cultivar, grown at the West Virginia Agronomy farm 2016 with conventional practice) individual tissue biomass (fresh weight) percentage to total biomass. The data collected from seven individual mature broccoli plants. Average of total biomass was 776 g per plant*** **(Liu 2018)**

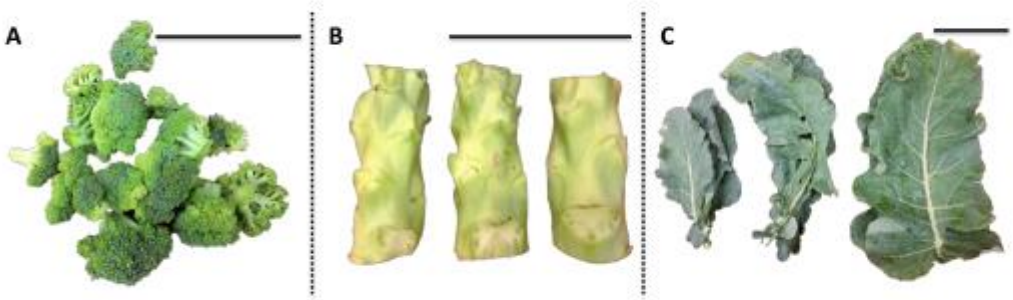


Figure 11 Representative image of various parts of the broccoli . The black scale bar at the right upper corner of each picture is 10 cm. (A) Broccoli floret; (B) broccoli stem; (C) broccoli leaf (Liu 2018)

Table 24 shows typical macro-nutrient composition of broccoli. There are some differences between presented composition data, especially on the moisture and protein content. The stem, however, has always the lowest dry matter content. Although the difference seems small, only 6%, it has large consequence on the required energy for drying. For the floret, stem and the average of the leaves, respectively 6, 11 and 5 kg water needs to be evaporated to get 1 kg of dry product.

Table 24 Typical composition of broccoli floret, stem and leaf

nutritional values per 100g	**floret** (NEVO table/Murcia 2002)	**stem** (AH broccoli rice/Murcia 2002)	**leaf*** (Devi 2022)	**Leaf** (Prade 2021)
Protein total	**4.7**	**2.0**	5.5	1.5
Fat total	**1.0**	**0.8**	1.2	0.8
Fatty acids saturated	*0.2*	*0.1*		
Fatty acids monounsaturated cis	*0.1*	*0.0*		
Fatty acids polyunsaturated	*0.8*	*0.6*		
Carbohydrates total	**0.8**	**0.7**	12.2	8.0
Mono and disaccharides	*0.0*	*0.5*		
Polysaccharides	*0.8*	*0.2*		
Polyolen	*0.0*	*0.0*		
Dietary fibre total	**2.7**	**3.1**	2.3	4.4
Ash	**1.1**	**1.0**		
Water	**85.6**	**91.7**	**81**	**87.5**
interesting micro components				
Beta-carotene	**0.7**	mg/kg		
vitamin C	**38.0**	mg/kg		
Lutein	**0.9**	mg/kg		
Folate Equivalents	**0.1**	mg/kg		
Vitamin K total	**0.2**	mg/kg		

*Based on DM content, Water content taken from Liu 2018

3.5.2. Identification of potential value-added applications through the Decision tree

The process as described in section 3.2 was applied:

0. Food loss inventory

   Measurements by the developed method explained in chapter 2 were executed by BAMX and showed that vast amounts of broccoli leaves and edible stems are available.

1. Prioritize identified streams with high volume and substantial nutritional value and/or energy

   The product category was selected before application of the protocol.

2. In case of a mixed stream: Explore whether it is possible to isolate a single product from the mixed stream

   It is evident that stems and leaves can be obtained separately.

3. Assess whether it is realistic to expect whether the stream could be used for food, feed, or biobased application, based on safety considerations

   No objection expected.

4. Explore options for food application, based on quality considerations and potential relevancy for (local) markets

   The edible part of the stem, processed into broccoli rice, was already produced in Mexico for the North American market before. This product was discontinued shortly after its introduction. The reason for this was not found. In the Dutch retail, it was also recently introduced (see figure 12**Fout! Verwijzingsbron niet gevonden.**) together with cauliflower rice, courgette spaghetti and others; this is so far more successful.

Figure 12 ***Broccoli rice and courgette spaghetti offered in a Dutch supermarket (photo: B.H. Dijkink)***

5. Explore options for food ingredient extraction (most relevant for materials with relatively high contents of valuable components; may require capital-intensive processing and is therefore most promising for large volumes).
   Broccoli by-products have also been used for protein extraction and healthy minor components by different authors (Prade 2021, Devi 2022, Domínguez-Perles 2010, Liu 2018). The extraction of the minor components/bioactive compounds is only interesting when it can be combined with the extraction of protein or fibre as it only accounts for a very small part of the total volume. This sort of operations is relatively capital-intensive and therefore not considered here.

Table 25 ***Food and food ingredient options for the broccoli by-products***

Application	**stem, top part**	**stem, bottom part**	**leaf**
Vegetable chips	yes	no	no
Rice-replacement, cubes for stews, soups, cooking	yes	no	no
Cut vegetable for stir-frying/cooking	yes	no	yes
Protein	yes	yes	yes
Fibre	yes	yes	yes
Minor components/bioactive compounds	yes	yes	yes
Animal feed	yes	yes	yes
Digester	no	no	yes
Flour	yes	no	yes
Soup	yes	no	yes

Since BAMX's preference is on food products that can directly be used by consumers, the ideas for food products made of the edible stem and leaves are selected. Other options (feed, biobased, energy) were not explored.

3.5.3. Assessments of the valorisation options through the *Procestimator*: estimates of product cost prices and greenhouse gas emissions

Both plant parts can be used for producing a chilled fresh food ingredient, a shelf stable powder or a shelf stable sterilized soup. Processing pathways for such products are shown in Figure 13 and Figure 14.

The edible stem is collected at the factory where the broccoli is prepared for the export. The leaves are normally left on the field and need therefore dedicated collection and transport to the factory.

Since the market for edible products from the broccoli stem and leaves is new and has to be developed, an approach with tolling factory(s) is considered most appropriate: utilizing capacity of an existing factory. By this choice, risky investments are prevented, at the cost of (likely) higher operational tariffs. Batch size may be based on the daily capacity of such existing facility. In this way, the total year volume will not affect the production costs, but additional transport or storage costs are foreseen.

Process selection/design

The process is designed for batchwise processing of the raw material to products in batches of one day in a tolling factory. This creates flexible yearly volumes, with acceptable daily capacity for efficient processing. Downside is that for the stems it is necessary to store the product, chilled or frozen, and additional transport(s) between factories can be required. To study the effect on the choice of the processing routes, schemes are developed for stem processing in 1 or 2 factories for the soup production, Figure 13. A more detailed process scheme of such a process with a tolling factory can be found in Figure 14.
For the leaves, storage and a second factory are not taken into account. As the leaves have to be harvested separately, it is more logical to bring the leaves in the right volumes on the right day directly to the processing factory.

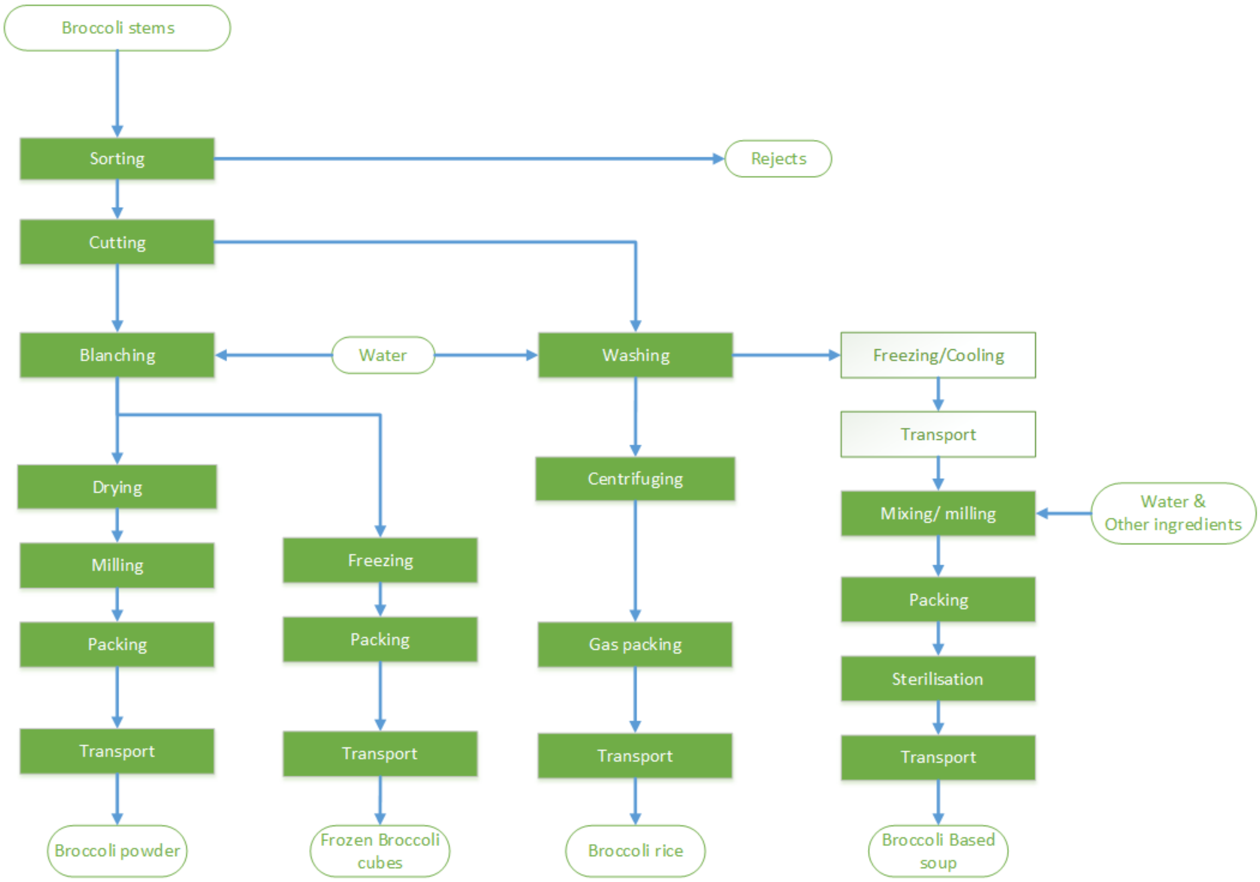


Figure 13 Processing of Broccoli stems to different end products. Open processes are optional, required if a second factory is used for the soup preparation

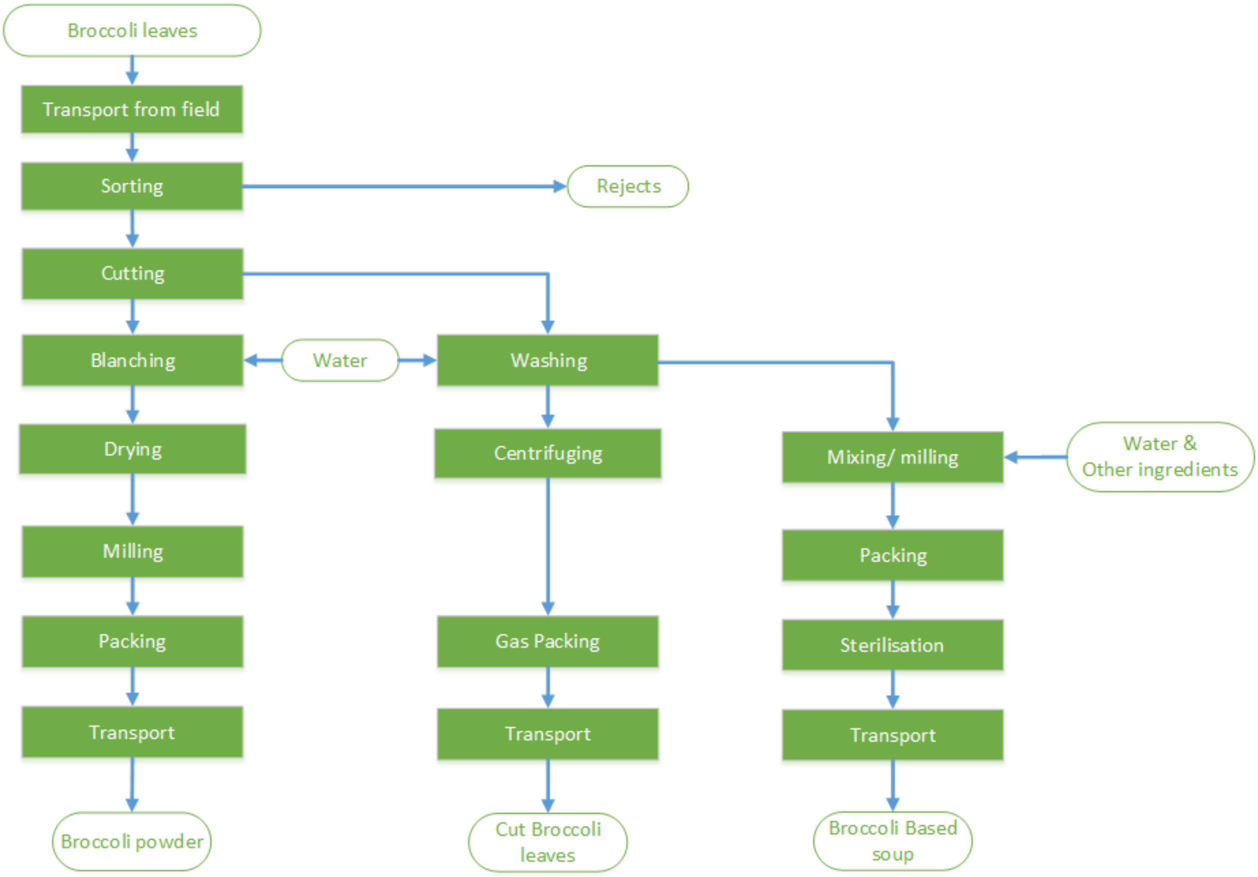


Figure 14 Processing of Broccoli leaves to different end products

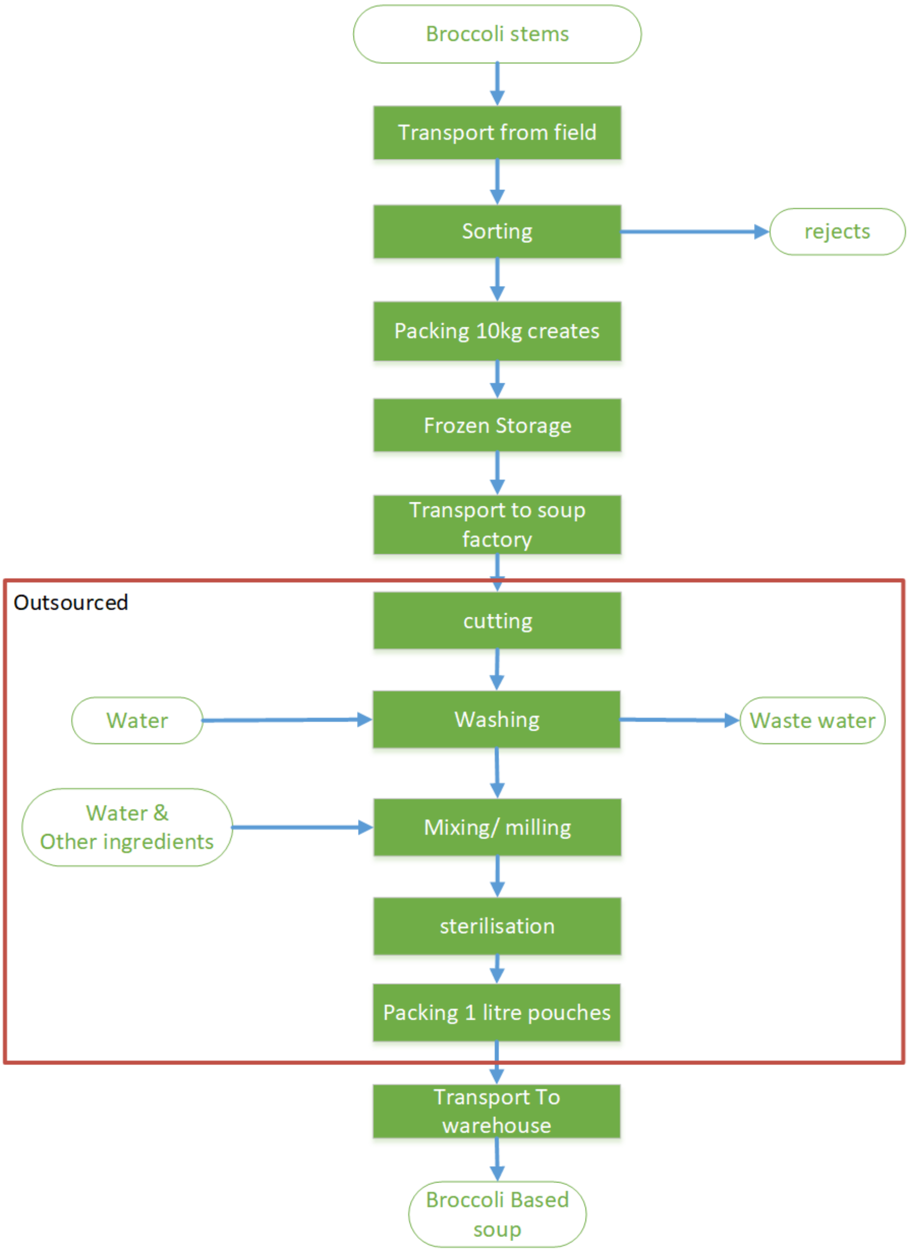


Figure 14 Example of detailed process scheme with 2 factories and frozen storage to be able to obtain large processing batches for efficient tolling

Cost price and GHG emission calculation with the *Procestimator*

In below calculations it is assumed that the raw materials are obtained without costs (economic price 0; associated GHG emissions 0). The (estimated) costs and GHG emissions of transport and processing up to the final product are taken in account.
The GHG-emission intensity of fresh broccoli was estimated at 0.048 kg CO2-eq/kg (Brenda et al 2022).
All calculations are based on the processing of 20 metric Ton per batch and a total of 20 batches per year, resulting in a total amount of 400 Metric Ton per year of processed raw material. The products are packed in consumer quantities of 200 gram , 500 gram or one litre prepared food. In Table 26 the most relevant used parameters for the calculations are summarized. Prices for utilities and labour are similar as in the calculations of the banana processing.

Table 26 Used parameters for the cost price calculations of the broccoli products

Fixed costs		
depreciation	5	years
prefinancing	1	year
interest rate	5%	
maintenance	2%	of capital cost
Factory status & application*		
status befor investment	building with utilities	
end-use of equipment	inline fully automated	
product application	food	
process hours	8	hours per day
*individual processes can be different depending on it's application		
raw material costs		
broccoli stems/leaves	0.0	peso/kg
harvest cost leaves	0.5	peso/kg
other soup ingredients	3.8	peso/kg
Transport distances		
Leafes from field to factory	5	km
product to soup factory	50	km
product to BMAX warehouse	50	km
Greenhouse gas emmission		
starting raw material	zero emission	
allocation between products	economical based	
other soup ingredients (bouillon 40g/l)	0.096	CO_{2-eq}/kg
primary production broccoli**	0.048	CO_{2-eq}/kg
**used for calculation CO2 savings		

Table 27 shows the different processing steps, the calculated cost price and GHG-emissions for the different products created from broccoli stems. For the products from broccoli leaves the calculation data are presented in Table 28.

Table 27 Represented processes (top) and the calculated cost price and GHG-emissions (bottom) from the* Procestimator *to produce the different products from Broccoli stems

broccoli cubes cool fresh	broccoli cubes frozen	broccoli stem powder	broccoli soup 1 factory	broccoli soup 2 factories cold storage	broccoli soup 2 factories frozen storage
Br73_0START	Br73_0START	Br73_0START	Br73_0START	Br73_0START	Br73_0START
Br73_2Sorting manual	Br73_2Sorting manual	Br73_2Sorting manual	Br73_2Sorting manual	Br73_2Sorting manual	Br73_2Sorting manual
Br73_6knife cutter	Br73_6knife cutter	Br73_6knife cutter	Br73_6knife cutter	Br73_3packing industrial	Br73_6knife cutter
Br73_14blanching	Br73_14blanching	Br73_14blanching	Br73_7washer	Br73_14Refrigerated Storage	Br73_14blanching
Br73_7basket centrifuger	Br73_15Freezing	Br73_7convection belt dryer	Br73_8colloid mill	Br73_5transport	Br73_15Freezing
Br73_12packing consumer	Br73_12packing consumer	Br73_8impact mill	Br73_9extra stream_1	Br73_6knife cutter	Br73_3packing industrial
Br73_13transport	Br73_13transport	Br73_12packing consumer	Br73_10mixer liquid	Br73_7washer	Br73_4Frozen Storage
		Br73_13transport	Br73_11Liq sterilization	Br73_8colloid mill	Br73_5transport
			Br73_12packing consumer	Br73_9extra stream_1	Br73_8colloid mill
			Br73_13transport	Br73_10mixer liquid	Br73_9extra stream_1
				Br73_11Liq sterilization	Br73_10mixer liquid
				Br73_12packing consumer	Br73_11Liq sterilization
				Br73_13transport	Br73_12packing consumer
					Br73_13transport

		yearly volume	cost price	GHG emission	
	packaging size	Metric Ton/year	peso/kg	CO_{2-eq}/kg	CO_{2-eq}/kg*
broccoli cubes cool fresh	500 gram	389	3.1	0.16	0.11
broccoli cubes frozen	500 gram	389	3.3	0.23	0.18
broccoli stem powder	200 gram	32	49	5.8	5.4
broccoli soup 1 factory	1 litre	799	4.2	0.15	0.13
broccoli soup 2 factories cold storage	1 litre	799	5.4	0.25	0.22
broccoli soup 2 factories frozen storage	1 litre	803	5.8	0.28	0.26

(* GHG emissions including savings)

Table 28 Represented processes (top) and the calculated cost price and GHG-emissions (bottom) from the Procestimator to produce the different products from Broccoli leaves.

Broccoli cut leaves cool fresh	Broccoli dry leaf flour	Broccoli leaf soup
Br73_0START	Br73_0START	Br73_0START
Br73_1transport	Br73_1transport	Br73_1transport
Br73_2Sorting manual	Br73_2Sorting manual	Br73_2Sorting manual
Br73_6knife cutter	Br73_6knife cutter	Br73_6knife cutter
Br73_14washing	Br73_14blanching	Br73_7washer
Br73_7basket centrifuger	Br73_7convection belt dryer	Br73_8colloid mill
Br73_12packing consumer	Br73_8impact mill	Br73_9extra stream_1
Br73_13transport	Br73_12packing consumer	Br73_10mixer liquid
	Br73_13transport	Br73_11Liq sterilization
		Br73_12packing consumer
		Br73_13transport

	packaging size	yearly volume Metric Ton/year	cost price peso/kg	GHG emission CO_{2-eq}/kg	CO_{2-eq}/kg*
Broccoli cut leaves cool fresh	500 gram	401	6.9	0.26	0.22
Broccoli dry leaf flour	200 gram	74	32	2.4	1.7
Broccoli leaf soup	1 litre	802	4.5	0.15	0.13

*GHG emmision inclusive savings

Note: The assumed GHG emissions savings through replacing an existing product in the market (like broccoli or soup) are very conservative estimates. The used (literature derived) GHG emissions intensity of farmed broccoli is considered low.

3.5.4. Comparison of the applications

Broccoli cubes produced from the stems, chilled with a shelf life of approximately 1 week, or longer till one year for the frozen cubes have the lowest cost price (3.1 resp. 3.3 peso/kg). Drawback of these products is that they require cold or frozen storage.

The broccoli powder from stems seems less interesting, at a cost price of 32 peso/kg and GHG emissions 2.4 kg CO2-equivalents/kg), but the relatively high price and high GHG emissions are caused by the volume reduction during drying. In dry matter equivalent the cost price of powder is only 18% higher than the frozen cubes, but then shelf stable at ambient temperatures. With respect to GHG emissions, the chilled and frozen cubes will require refrigerated/frozen storage in the distribution chain and at the consumer (these activities are outside scope of this study because they may vary amongst market channels), which will induce additional GHG emissions.

Comparison of the results for the broccoli leaves with the broccoli stems shows some remarkable differences. The chilled fresh cut leaves cost price is more than two times higher than of the broccoli cubes. Details from the calculations can explain the difference:

- The stems are released for free in the factory, where the leaves have to be collected and transported separately to the factory.
- The low bulk density of the cut leaves requires a much larger packaging than the broccoli cubes. The expected costs for the packaging of 400MT cut leaves are foreseen at 0.70 million peso/year compared to 0.34 million for the broccoli cubes. The higher GHG-emission is also explained by the higher amount of packaging material.

In contrast, the broccoli powder production from leaves is cheaper than if it would be made from the stems. For this product, the initial moisture content of the starting material is critical. It determines not only how much water must be evaporated but also how much starting material is required per unit dry end-product. The lower cost price and GHG-emissions of powder from leaves compared to from stems is explained by the fact that less than half the amount of raw material is required per unit product. Note hereby that the dry weight of the leaves found in the literature varies a lot, 19% (Liu 2018) and 13% (Prade 2021). Both higher than the 8% for the stems, but assuming the lower end value of the dry weight (13%) the cost price increases from 32 to 45 peso/kg. This makes verifying the actual dry weight of the available leaves important, if it is decided that the broccoli powder would be an interesting product.
All the calculated prices are not based on tolling cost but as if the factories must be newly built. The *Procestimator* however offers the opportunity to select tolling fees for a specific process step. When selecting

this opportunity, a fixed cost per kg product is taken into account for calculating the cost price. This estimation, however, is assuming that only one process step will be outsourced and not all of the different processes. The total costs will therefore not reflect the actual costs for the tolling in this case if this option is chosen for all the processes without manual corrections. On forehand, the required corrections are difficult to make. As a next step it is recommended to get quotations from local processors in order to obtain better cost estimates than those provided by the tool.
The GHG-emissions per kg of product is not affected by outsourcing. The energy, additives and packaging used to by the tolling factory is still taken into account.

3.6. Summary

In this chapter a methodology was presented oriented on identification of added-value applications of food losses and residue streams and on preliminary process design and estimating economic feasibility and sustainability impact including effects of situational conditions (like volumes, connection to market and local prices). The decision tree method for identification of valorisation options links to various databases from which opportunities for various materials can be derived. Consequently, this method can be applied by engineers who have generic knowledge of agro-food processes and products.
For practical assessment of apparent valorisation options, we propose to outline a logistic and processing chain that links the residue/loss stream to marketable products. Based on that outline, a techno-economic analysis and sustainability impact assessment can be done. In this study the *Procestimator* was used for that purpose which is equipped with predefined process template models. Inevitably, still specific expertise is required in order to assemble a complete process line model. Hence, this task requires food process engineering knowledge.

The approaches have been applied in two case studies: for rejected bananas from export chains and for broccoli stems and leaves (from farmers and processors/packaging stations) to food products and ingredients. Direct use as food products, like broccoli stems as food, can be straightforward implemented by BAMX (for instance as a fresh vegetable product). Pathways that involve more processing have been studied in this chapter.

For rejected bananas diverse ideas for processing to relatively high-value applications were identified (like gluten-free flour). Of these, the following options for food production were considered most adequate: banana puree, banana chips and banana flour. Cost price estimates as well as an environmental sustainability impact (GHG emissions) were analysed for these products. Results show that the cost prices depend strongly on situational condition (like annual volume, collection distance and expected price of the residue stream for current destination). A product like banana flour, for which the global market strongly grows, seems quite competitive in the market in terms of cost price and GHG emissions compared to other gluten-free flours. This application, however, serves a specific market, likely beyond BAMX scope. Since reference market prices lie in the range of estimated cost prices it is recommended to further assess the local situation in order to increase the accuracy of cost price estimates.
A quantitative estimate of GHG emissions was presented for banana flour (replacing other gluten-free flours). For 30,176 ton bananas / 7,318 ton banana flour the total GHG emissions reduction is estimated at 9,300 ton CO_2-eq. The other applications were not quantitatively analysed, but also considered to result in GHG emissions reduction.
Note: It is expected that processed banana products like chips and flour are already derived from B-quality bananas. The benefit (economic and in terms of GHG emissions) from local production would then come from short transport distances, with downside of less economies of scale. The net effect depends on specific choices made in processing and local arrangements. Other options (like lowering of the rejection rate, feed application or using it in non-food/energy applications with no restriction on the market demand) may make more sense in this case.

For residue streams from broccoli diverse ideas were explored. Especially for parts of the crop that are commonly considered a residue stream, the stem and leaves, large volumes of under-exploited material were identified as interesting resource for food. Structural valorisation pathways for processed products were analysed; especially products derived from broccoli stems (varying from fresh cubes to dry powder) are promising in terms of volume, cost price and climate impact. The actual volume potential is huge: when assuming half of the volume of ‘Cauliflowers and broccoli’ (annual production in Mexico around 700,000 according to FAOSTAT) and with the conservative assumption that 30% extra food can be obtained from the stem, the extra volume of food is estimated at 100,000 ton per year.

4. Main focus points for Postharvest Handling

4.1. Introduction

Postharvest practices are aimed at preserving the product quality as it is at the moment of harvest as much as possible with the aim of prolonging the products shelf life. This may be necessary to enable long transit times (export) or mid- and long-term storage (e.g. to keep raw material available for an extended period to enable processing industry to continue processing).
Primary producers and midstream (traders and processors), and undoubtedly also foodbanks, all have a significant interest in optimising these practices to prevent, or at the very least, minimize losses and maintain quality as effectively as possible. This means that knowledge on postharvest handling can contribute to reduced FLW in supply chains.

There are reasons why fresh food is wasted in primary production and midstream, that are beyond optimised postharvest handling. This may for example be due to:

- Market disruptions, leading to a sudden reduced demand, leaving produce unsold, either in the field or in midstream.
- Production planning issues, resulting in an increased production of a crop from one season to the next without the market being able to absorb it. Or a concentrated production during several weeks due to weather or field production issues.
- Marketing planning issues, leading to a higher purchase than sales possibility as result of for example a price drop of a competing fruit or vegetable, or at a competitor.
- Quality issues, making a product not suitable for processing after a certain period (e.g. potatoes from storage at the end of the storage season). Or making it not suitable for marketing due to size, malformation, colour, etc.

Whenever this is the case, the products become interesting for foodbanks because the product quality may still be good or at least reasonable. Produce just cannot be sold at a certain moment.

Postharvest handling by foodbanks should therefore be looked at from another angle. Not to preserve the product quality as long as possible, but rather to use the foodbanks infrastructure (cold rooms) in an optimum way. This can be done by a combination of:

- Optimized logistics focussed on optimising the planning between receiving and dispatching goods. Either to client directly or between foodbanks to assure goods stay in cold-rooms not longer than strictly needed,
- Careful handling,
- Rejecting as much as possible, or sorting out, spoiled products,
- Hygiene,
- Correct storage conditions focussing mainly on conditioning temperature and relative humidity (RH) as well as on ethylene production and sensitivity but also on avoiding condense on products,
- In case of the availability of just 1 cold room, choosing the conditions that fit best to a wide range of products. (E.g. 10°C and 85% RH will suit broccoli and lettuce (not optimally) as well as tropical fruits like banana, mango or tomato).

An online training has been provided to BAMX and associated farmers (as well as a second training for students) on best practices for post-harvest management, with the goal of reducing food loss and improving the quality of their products. This training focussed on general aspects that are important for farmers, as well as on practical aspects for BAMX to handle its produce. The PowerPoint presentation that was used as a basis for this training is included in Annex 2.

4.2. Post-Harvest Practices

Primary production and midstream

The main issues that influence maintaining quality and extending shelf life are following. Although these are not focus points of the foodbank itself, it is important for the foodbanks to understand the general mechanisms of extending shelf life.

- Ripeness stage at harvest
- Temperature management/ Cooling
- RH management
- Careful handling.
- Hygiene
- Packing

Ripeness stage at harvest

Different types of fruit require a different postharvest approach:

Some products **ripen after being picked;** they are called climacteric fruits. These products must be harvested in a mature state, but not ripe, as they continue to develop colour and flavour after being harvested (e.g. avocado, tomato, melon, banana). Depending on transit times to the destination market, a ripeness stage is determined for the harvest moment.

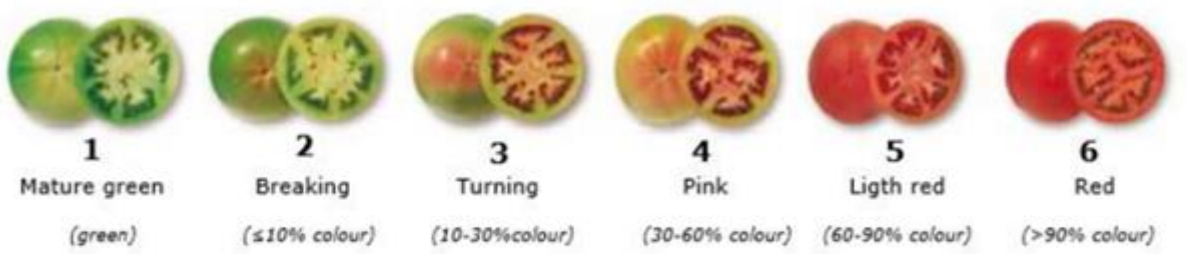


Figure 15 Ripeness stages for tomato (source: UDSA)

Other produce does **not ripen after harvest**, these are called non-climacteric fruits. These must be harvested when almost fully ripe, as they do not ripen further after being picked. Examples include strawberries, currents, grapes, citrus, etc. Harvesting these types of fruits in a too early ripeness stage, results in insufficient taste. Because of this, these fruits also need to be cooled rapidly after harvest.

Broccoli is considered climacteric as it continues to produce flowers after being harvested, which should be avoided by fast cooling.

Temperature management/ Cooling

In general, the faster a product temperature is brought to the optimum conditioning temperature, the more its shelf-life will increase. This effect is strongest at products that need to be stored at lower temperatures. The temperature needs to be measured at the core of a fruit. If for example an iceberg lettuce of 25°C is placed in a cold-room at 1°C temperature, It may take up to 48 hours before the core of the lettuce reaches the desired 1°C (orange line in the figure below). If pre-cooling is being applied, vacuum cooling in the case of lettuce, the cooling down time can be reduced to 20 minutes, resulting in a substantial extension of shelf life.

There are several methods of pre-cooling, their suitability being product dependent. Examples of pre-cooling methods are

- Forced air (forcing cold air to move through the product)
- Vacuum cooling (cooling through evaporation)
- Hydrocooling (inundating in cold water or showering with cold water)

In some cases, pre-cooling is not required. This may be the case if a product is consumed within a short period after its harvest, thus no long shelf life is required. In case, due to long transit times to markets, long shelf-life is required, pre-cooling within a limited time after harvest, has a significant effect on the ability to reach markets at further distance.

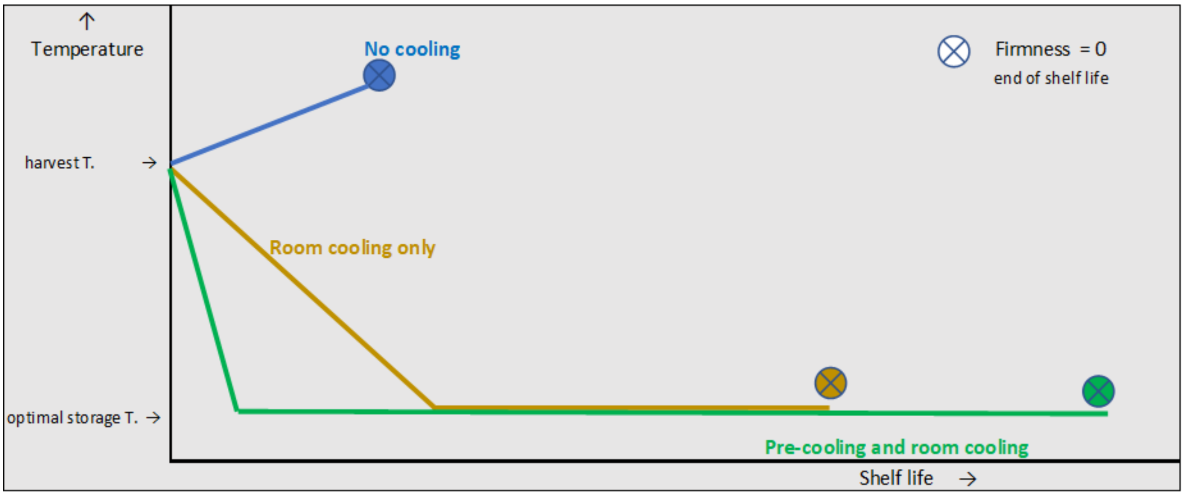


Figure 16 General effect of (pre-)cooling on shelf-life of perishables (source: R.J.A. Oostewechel)

The optimal postharvest handling practices are very product and market specific. Some produce needs cooling very fast after harvest because they need to be harvested almost fully ripe as indicated above and need to be stored close to 0°C (e.g. strawberry). Other fruits can be handled at ambient temperatures if it concerns local wholesale market but must be cooled when exported (e.g. mango, banana, tomato). The requirements per product group and market combination are indicated in the figure below. This fact influences the location of cold storage infrastructure and its size and sourcing area. For example, strawberries require small size cooling facilities (with pre-cooler) close to the production site whereas bananas may be transported to a central facility at longer distance because their cooling can start later.

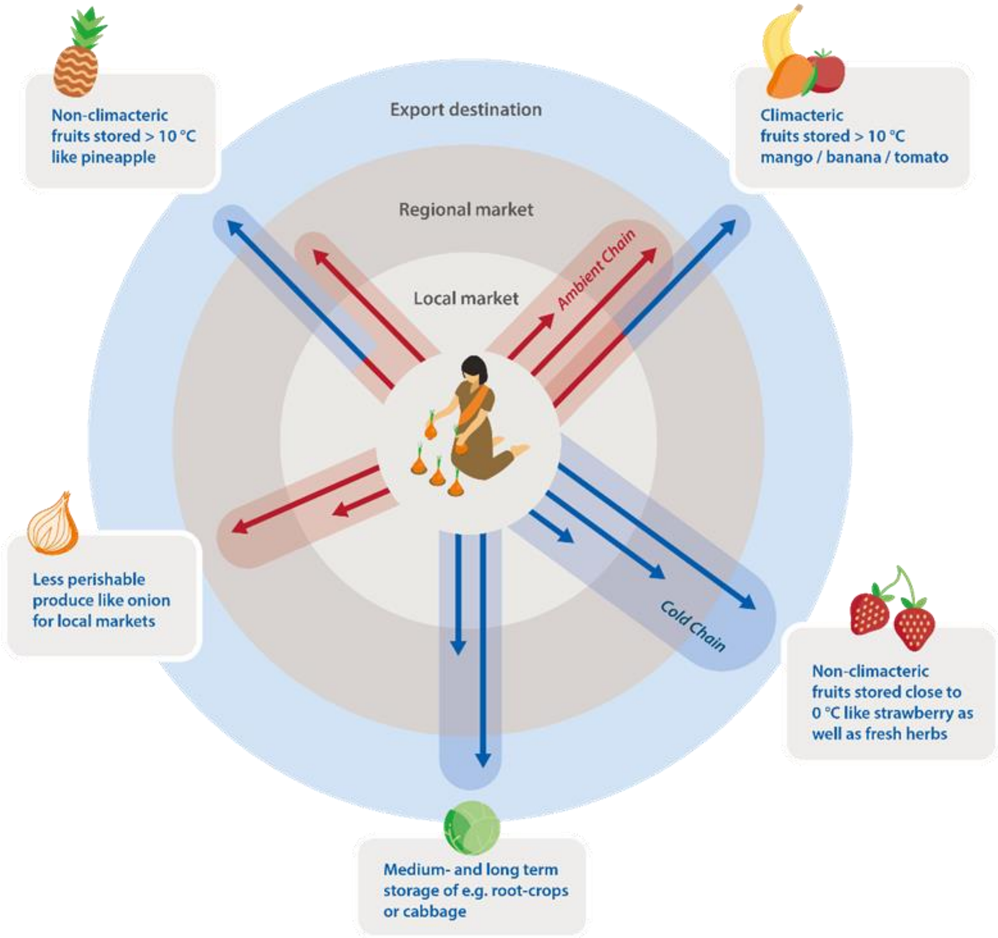


Figure 17 ***Ambient- and cold chain application for different product- market combinations (source: Postharvest assessment Methodology, 2022 WFBR)***

Relative Humidity (RH) and condense management

A low relative humidity causes products to wrinkle and lose weight. Most products optimally require a RH of 90 to 95% during storage. Ambient RH is often substantially lower. Some relatively simple measures are possible to increase RH levels. Putting product in the shade, covering stacks of crates with a plastic sheet to create a high-RH microclimate and wetting the cold storage floor are examples.
Where a high RH of the air is good, direct contact with water should be avoided as wet products are prone to infections. The same applies for condense. This mainly is caused by fluctuating temperatures and should be avoided.

The figure below shows the effect of RH on bell peppers stored for 24 hours at 5 different temperatures. One set in open crates, the second in plastic-covered crates that created a microclimate with higher RH.

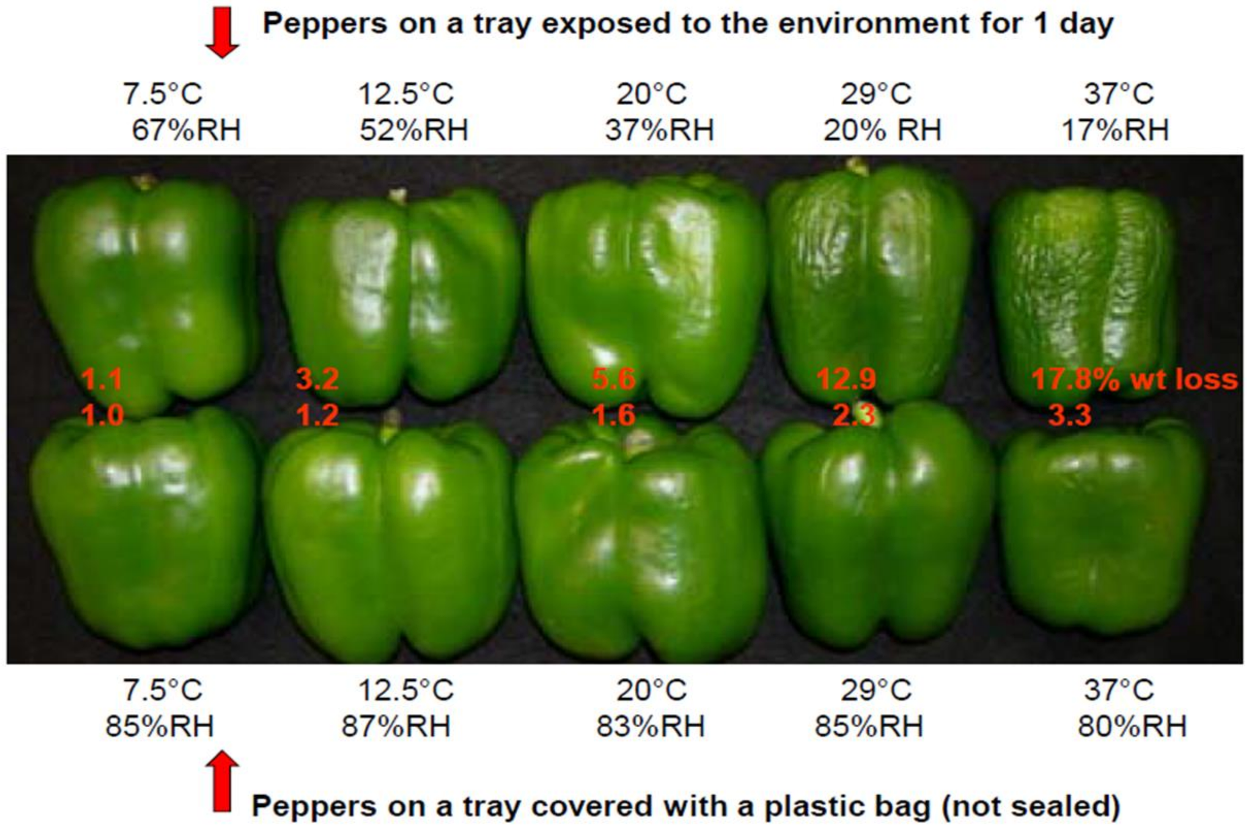


Figure 18 Impact of ambient RH on shelf life (shivering) (Cantwell, 2015)

Careful handling

Direct damage of produce occurs due to rough handling, like throwing, abrasive damage from harvesting, packing and transporting fruits in bags. Also produce shifting in cartons, pressure damage due to over stacking or puncture damage by nails, jewellery or field crates that are broken, are causes of product damage. Apart from this direct damage, fruit injuries and bruises form entry spots for diseases, cause water loss, bad appearance, and ethylene production (faster ripening). It is therefore of utmost importance to handle product with care.

Figure 19 Pressure damage in eggplant and careful harvesting of blueberry (photo: R.J.A. Oostewechel)

Hygiene at farm level

A clean environment helps to avoid cross contamination with pathogens and spoilage organisms. Special attention is required for avoiding contact with soil and fruit rests by washing field crates and placing crates on a pallet or plastic sheet. Also, personal hygiene of workers and availability of toilets and hand washing facilities need attention.

Figure 20 Stacking field crates on pallets and use clean crates (Photo: R.J.A. Oostewechel)

Packing

Packing is meant to transport produce but also to protect products from damage but sometimes causes it. This can be the case if pallets break, or cartons are not tightly secured on pallets by using edge protectors. Inferior quality cartons may become moist and lose their strength and whole pallets may collapse this way, damaging products before they reach their destination.

Liners are plastic microperforated bags that are sometimes used for transport (e.g. bananas or pomegranate) to limit dehydration during transit.

Figure 21 Liners used for banana and blueberry packing (photo: R.J.A. Oostewechel)

Consumer packing is done for convenience, presentation and labelling and often protects produce from dehydration.

Figure 23 ***Consumer packing in bags, PE-wrap, top-seal, flow-pack and clamshell (photo: R.J.A. Oostewechel)***

Foodbanks

Temperature and RH management

For food banks, the postharvest handling must be considered from a different angle. The foodbank has no influence on product handling in the so-called first mile, the time between harvest and conditioning the fruits and vegetables by placing them in cooled conditions. Foodbanks receive their products mostly at a later stage. The product starting quality at that moment is a fact and must be maintained as much as possible by the food bank. Food banks must take their existing infrastructure as a starting point and put a focus on the quality of produce they receive.

Table 29 ***Fruits and vegetables grouped according to 4 different storage temperatures (Queensland Department of Agriculture and Fisheries, 2017)***

	Fresh produce	Recommended Temperature	Storing life
Group 1: Chilling temperature (around 0 °C)			
Fruit	Cherry	0	2 - 3 weeks
	Nectarine	0	2 - 3 weeks
	Pear	0	2 - 6 months
	Plum	0	1 - 4 weeks
	Table grape	0	3 - 6 months
	Blueberry	0	1 - 2 weeks
	Kiwi	0	2 - 3 months
	Strawberry	0	5 - 7 days
Vegetables	Garlic	-1	> 9 months
	Artichoke	0	2 - 3 weeks
	Broccoli	0	3 - 4 weeks
	Cabbage	0	Up to 6 months
	Carrot	0	Up to 9 months
	Cauliflower	0	3 weeks
	Celery	0	5 - 7 weeks
	Chives	0	2 - 3 weeks
	Lettuce	0	Up to 4 weeks
	Onion	0	Up to 9 months
	Peas	0	1 - 2 weeks
	Radish	0	3 - 4 weeks
	Spinach	0	Up to 2 weeks
	Mushroom	0 - 1	7 - 9 days
	Sweet corn	0 - 1.5	7 days
	Asparagus	0 - 2	2 - 3 weeks
Group 2: Low temperature (2 to 6°C)			
Fruits	Apple	4	1 - 12 months
	Avocado	5 - 7	< 6 weeks
	Cantaloupe	3 - 5	12 - 15 days
	Longan	4 - 6	2 - 3 weeks
	Lychee	2 - 5	3 - 5 weeks

	Fresh produce	Recommended Temperature (°C)	Storing life
Group 2: Low temperature (2 to 6°C)			
Fruits	Orange	3-8	Up to 3 months
	Pomegranate	5-7	Up to 8 weeks
	Mandarin	5-8	2 - 6 weeks
	Passionfruit	7	2 - 4 weeks
Group 3: Mild temperature (7 to 11°C)			
Fruits	Honeydew	7 - 10	1 - 2 weeks
	Pineapple ripe	7 - 10	7 - 10 days
	Pineapple partially rip	10 - 13	14 - 20 days
	Papaya	7 - 13	1 - 3 weeks
	Lime	9 - 10	9 -8 weeks
Vegetables	Potato	4 - 14	5 - 8 months
	Beans	5 - 7.5	7 - 10 days
	Zucchini	5 - 10	2 weeks
	Capsicum	7.5	3 - 5 weeks
	Chilli	7.5	3 - 5 weeks
	Cucumber	10 - 12	Up to 2 weeks
	Eggplant	10 - 12	Up to 2 weeks
	Pumpkin	10 - 13	2 - 3 months
Group 4: Relative high temperature (12 to 15°C)			
Fruits	Water melon	10 - 15	2 - 3 weeks
	Mango	10-13	2 - 4 weeks
	Grapefruit	12 - 14	Up to 8 weeks
	Banana	13 - 14	2 - 3 weeks
	Lemon	14 - 15	4 - 6 months
Vegetables	Basil	12	3 weeks
	Ginger	12 - 14	6 months
	Tomato mature green	12.5 - 15	> 2 weeks
	Tomato light red	10 - 12.5	2 weeks
	Tomato ripe	7 - 10	3 - 5 days
	Sweet potato	13 - 15	4 - 6 months

In case a food bank has four or more cold storages, these can be used according to temperature requirements of the products given in

Table 29. However, in many locations, this is not the case. It is recommended in the case a foodbank has two cold storages, to dedicate them to two groups of fruits/vegetables. One with setting at 6°C for group one and two. The second chamber at 11°C for group three and four. These temperature settings may be sub-optimal but will not harm the products and are the best workable solution under the circumstances. It is further advised to focus logistical management of the foodbank on fast throughput by supply and dispatch planning.

In both cold rooms the RH should be measured and if low, corrected to levels of 80% or more. Although, even higher RH levels are recommended, 80% is easier to achieve and therefore more workable. It is also high enough if products stay in storage for a limited time.

Ethylene
Some products produce ethylene. Others are (very) sensitive to ethylene as its initiates and speeds up ripening. Several sensitive products should not ripen at all (e.g. beans, broccoli, berries, leafy vegetables) as this spoils them for consumption. Other product should only ripen upon arrival at consumers (e.g. banana, mango).
Storing ethylene producing products in the same rooms as sensitive products should be avoided if possible or limited in time if not possible.

Hygiene of foodbank premises and rejected produce
In addition to standard hygienic measures like hand washing, pest control, and premises cleaning procedures, it is crucial for food banks to prioritize the quality of the products they receive. While it does not necessarily need to be top quality, it must be consumable. Batches containing significant amounts of produce unsuitable for consumption require extensive sorting efforts. This process demands space, labour, and incurs costs. Moreover, such batches pose potential sources of contamination and risk infecting other products.
A clear procedure should be established for handling rejected and sorted-out products. Regardless, they should be clearly marked as such and removed from the premises daily.

4.2. Conclusions

Awareness about storing conditions of fruits and vegetables will be helpful for foodbanks to manage the produce. As postharvest handling is about maintaining quality, it is important to:

- Limit throughput time (by logistical planning and management),
- Avoid unconsumable produce as much as possible (e.g. by avoiding Wholesale market produce),
- Respect handling requirements regarding temperature, relative humidity, ethylene and hygiene.

Apart from measures to limit waste at the Foodbanks during handling, there is also sourcing to look into to assure that in general better quality produce is to be supplied to the Foodbank in the first place. Suggestions are:

- Harvesting fields of unsold produce may be difficult to organise and costly. But can be looked in to.
- Exporters may be interesting partners as they may sometimes end up with produce that is already packed but which they are unable to sell due to quality issues or market disruptions.
- Fruit and vegetable processors, particularly those dealing with potatoes, often encounter quality challenges with their raw materials. This is because the products they process and market as end products must maintain consistent quality standards. However, the raw materials stored or supplied to them may not always meet these standards, jeopardizing the quality of their final output. In such cases, the produce may either be returned to the supplier or disposed of, with food banks being a potential option for disposal.
- The local wholesale market typically manages to sell fruit of any quality, with only the lowest quality, comprising a high percentage of unfit produce, being designated for donation to the food bank. This makes such partnerships with the food bank potentially less appealing compared to other types.

Cooperation and coordination between foodbanks remain an important issue, both, in receiving produce as well as in distributing these to their clients. This coordination should also include storability of products and available space in cold rooms to avoid too much pressure on individual foodbanks without availability of suitable cold storage.

Established procedures must be in place for premises cleaning, disposal of rejected produce, pest control, and personal hygiene. Additionally, there should be a structured product handling procedure emphasizing proper placement in cold storage (temperature and relative humidity), with a visible list of products assigned to each cold room.

5. Discussion and suggested next steps

BAMX has to operate in a dynamic environment, very much depending on donors and therefore a very unpredictable day to day business. In this document tools are provided to on the one hand reduce uncertainty and on the other hand identify new residual flows with food potential to feed the poor.

In this report 3 directions for improving access to food losses were addressed: (1) improve predictability of volumes per supplier, (2) exploring alternative options for (feasible and sustainable) valorisation of residues to food and food ingredients, and (3) improve post-harvest handling.

5.1. Improving predictability of volumes per supplier

In order to improve predictability of supply in general the advice is to professionalize by investing in quantitative analysis of available volumes:

- To carry out a number of measurements in the main broccoli supplying regions, and be able to get good insight in the residual flows that can be expected, based on the BAMX collected farmer data in combination with farmer characteristics.
- Apply this to other vegetables and fruits categories (preferably build a database and expand your network with farmers and their characteristics).
- In the measurements not only the products that are commonly considered food products should be considered, but also other residue streams that potentially may be used for food application.
- To evaluate costs of collection and distribution internally (what is wasted from the incoming donation, how much is the total recovery fee) in such a way that every donation can be checked on financial feasibility, and learn from that when making decisions.
- Acquire relevant infrastructural data from all BAMX locations to improve decision making.

5.2. Exploring alternative options for valorisation of residues

For broccoli interesting residue streams were identified that are promising for food: florets, stems and leaves. The volume of florets that actually was not valorised was relatively small in the limited acquired data. Substantially larger volume products can be obtained as stems and leaves. These products can be obtained and may be donated as-is or minimally processed as vegetable food products (like packaged fresh leaves, fresh stems or cubes), processed to food products (like broccoli soup) or to food ingredients (like broccoli powder).
For exploitation of such products, it is recommended to first consider collection from processors only, since collection from farmers requires additional effort.
For processing to food ingredients techno-economic and GHG emissions analyses were presented in this report. It was concluded that the stems are a more promising source than the leaves. Based on a very conservative estimate, the total annually available volume of broccoli stems in Mexico is estimated at 100,000 ton. Per ton of this stream that would be utilised, and would replace dedicated broccoli production (with an assumed – conservative estimate – GHG emission intensity of 0.048 kg CO2-eq. per kg harvested crop) 48 million CO2-eq. GHG emissions is prevented.
We recommend BAMX to consider (1) collecting broccoli stems from processors and offer them either fresh or use them in sauces and/or soups for the poor, and (2) assessing interests of entrepreneurs in developing processing pathways for this material to food ingredients. Optionally, logistics for both pathways can be combined.

For bananas, data from measurements have been obtained from only one actor involved in export chains (because of unsafety situation in the region). The percentage of reject bananas turned out very substantial. Reject bananas can be processed to products like paste, snacks or flour. From techno-economic and GHG

emissions analyses for these applications it was concluded that the business case of such processing pathway can be attractive, depending on volume and market access. Furthermore, banana flour derived from reject bananas (considered as a gluten-free flour) has substantially lower GHG emission impacts than most other gluten-free flour product types in the market.
From the responses obtained from the banana company it was concluded that in the current practice most reject bananas are already collected by a processing company; therefore for the company who responded to the measurements this stream is not considered promising.

5.3. Improving post-harvest handling

In general, improving postharvest handling practices at the farmer level may result in a higher proportion of produce being sold commercially rather than being made available to foodbanks, even if the quality improves.
A relevant discussion revolves around optimizing the initial quality of products received by food banks. The goal must be to prevent unfit produce from being supplied to food banks because that requires sorting and waste removal, which occupies space, requires labour, and poses contamination risks to healthy products.

Efforts to reduce losses at the foodbank level start by ensuring a reasonable quality of produce is initially supplied. This discussion primarily centres on identifying the most suitable sectors to supply the food bank and how to enhance cooperation with these sectors. It also involves identifying companies that should be avoided.
Most suitable seem companies that are sometimes stuck with consumable products that cannot be sold commercially due to market disruptions, irregular shape and appearance, inadequate consistency (and therewith suitability) as raw material ingredients for processed products.

Optimal use of foodbank logistics has been addressed in chapter 4, taking into account the limitations of individual banks in cold storage infrastructure which can be solved by grouping produce as well as by limiting its stay in cold storage.

6. Literature

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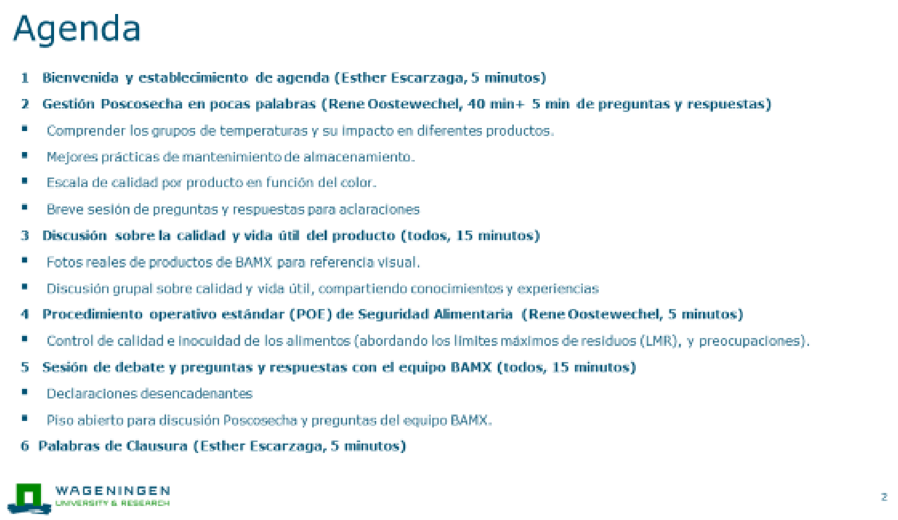
Annex 1 Broccoli farmer questionnaire

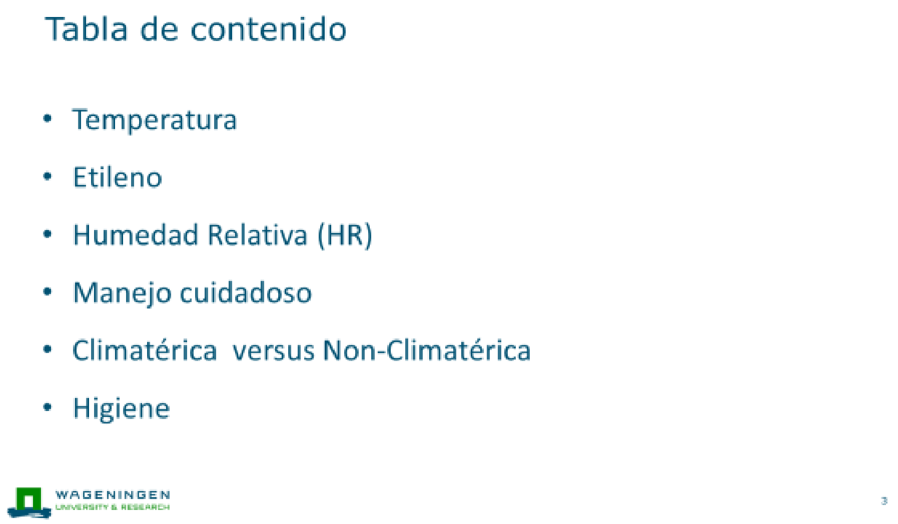
Questions to a broccoli farmer (example from Guanajuato)		
	Name company:	anonymous
	City/village:	-
	Date:	-
1	How much ha is he growing broccoli?	350 ha
2	What is the distance between the rows of planted broccoli (in cm)?	90
3	How does he decide when to harvest?	90 days, diameter 6-12 inches without bloom
4	How often is he harvesting (on average)?	August- September plantations, harvests February-March
5	How does he decide how much to harvest? Is this varying a lot or not, and can he estimate the average weight?	18 tons per ha
6	What type of clients is he selling to? (trader, wholesaler, processor, …)	Process plant, national and international customers.
7	Is he working contract based? If yes, oral or on paper?	Frozen by contract and fresh free market
8	Is he harvesting manually?	Yes
9	What is the average floret/head size when harvested? (cm or inch)	6-12 inches
10	What is the average stem size when harvested? (cm or inch)	3 inches ('Four fingers')
11	Is there a belief or do they have knowledge that the stem size relates to the shelf life, and that's why they keep the stem with the crown?	The cut part is oxidized, less stems more oxidation.
12	Are certain broccolis left on the field? (E.g., too small, damaged, …)	Yes, small crowns or yellowish crowns, plague damage.
13	If yes, can he estimate how much % of the total harvest that would be?	10%
14	Are there any activities taking place on the farm after harvest? Like sorting, grading, cutting, washing, packaging, floreting? (If yes, please take pictures or make video if allowed).	Everything is sent to process, sometimes cut the foil in field, depends on the capacity of the process plant.
15	Does he store broccoli. If yes, how long and under what conditions?	It is sent direct to customer, selection in field, fresh market with ice.
16	If there are leftovers from these activities in the previous question, what happens with them? (E.g., animal feed, composting, …)	It is returned to the ground
17	Does he cut stems from the broccoli? If yes, what happens with them? (E.g., waste, ploughed in the land again)	No
18	What happens with the part of the broccoli that is not harvested and stays in the soil? E.g., the leaves? (Please take picture of some broccoli remainders in the soil if possible)	It is returned to the ground
19	Is the broccoli harvested in crates, backpacks, …?	Backpacks
20	How much is the labour cost (per day, per full crate or per hour, …)?	Per day in band \$300. If they work with a backpack, each piece will cost \$7.50. Each backpack weighs 18 kg, and a person can harvest 50 backpacks per day.
21	Anything the farmer would like to add in the context of the above?	They have the ability to process the stem in the plant, it is not done for lack of market, currently there is no market.

Annex 2 Banana farmer questionnaire

Questions to a banana farmer (example from Chiapas)		
	Name company:	Anonymous
	City/village:	Anonymous
	Date:	Anonymous
1	How much land is he growing banana/ or how many trees?	11,068 Ha with banana export quality, 5,000 Ha with plantain
2	How many tons of bananas he produces per year?	250,000.00
3	How does he decide when to harvest? (please be specific about e.g. maturity level; how does he know the maturity level?)	From the age of the fruit they are 10 weeks, which are identified with a ribbon color weekly from the date of bagging the cluster.
4	How often is he harvesting (on average)?	It depends on the area sown and the registered bag inventory.
5	How does he decide how much to harvest? Is this varying a lot or not, and can he estimate the average weight?	It is decided according to the inventory of tapes by age of the fruit and a count is made for the previous harvest, varying the amount according to the yield of each cluster. The average weight of a cluster is 14 kg
6	What type of clients is he selling to? (trader, wholesaler, processor, …)	We have customers of commercial chains in the United States, domestic distribution customers throughout the Mexican Republic, local customers for local markets.
7	Do these sellers have requirements? (E.g., minimum/maximum number of fingers, maturity level, size, …)	If all customers give us the specifications of the fruit they require and all have minimum and maximum fingers, maturity, and length. 2,5-4 cm diameter 9-10 inches long, numbers of fingers depends on the weight
8	Is he working contract based? If yes, oral or on paper?	We work under long term contracts, agreements are in writing
9	Is he harvesting manually? Please explain how they do that. Are the bunches falling on the ground?	The bunches are manually cut using machetes. One person gathers the bunch and attaches it to the cable for transportation from the plantation to the packing facility. There, the bunch is manually disassembled and immersed in a chlorine solution for cleaning and fruit destarching. Subsequently, it goes through a selection process and is placed in plastic trays before being packed into 18.5 kg cardboard boxes each. Finally, the boxes are placed on pallets for assembly
10	Are certain bananas left on the tree? (E.g., too small, too mature, …)	No, we harvest every bunch, one per plant. Those that do not meet the required characteristics are packed as second quality and sold in the domestic market. The bunches that do not qualify for second quality are referred to as 'loose fingers' and are used for local and regional ripening. The remaining ones are used as livestock feed.
11	If yes, can he estimate how much % of the total harvest that would be?	There is no estimate because it varies depending on the area of the farm and the use they make.
12	Are there any activities taking place on the farm after harvest? Like sorting, grading, cutting, washing, packaging, removing latex, desinfecting? (If yes, please take pictures or make video if allowed).	Yes, as I described in point 9.
13	Does he store and/or ripen bananas. If yes, how long and under what conditions?	It cannot be stored, but there are ripeners in the area that are dedicated to ripening for sale in local markets.
14	If there are leftovers from these activities in the previous 2 questions, can he estimate that amount in some way (e.g. % per activity) and what happens with them? (E.g., animal feed, composting, …)	There is no estimate
15	Are the bananas harvested in crates or otherwise?	They are packed in cardboard boxes, in plastic or wooden bars and in sacks.
16	How are the bananas transported from the trees to the collection point on the farm?	Through a cable system that runs throughout the plantation, reaching all the way to the packing facility.
17	How much is the labour cost (per day, per full crate or per hour, …)?	Depending on the activity the packaging is by box, the excesses are by labour, the transport is by labour, and the palletizing is by labour.
18	Anything the farmer would like to add in the context of the above?	No

Annex 3 PowerPoint presentation postharvest training





TEMPERATURA (y tiempo)

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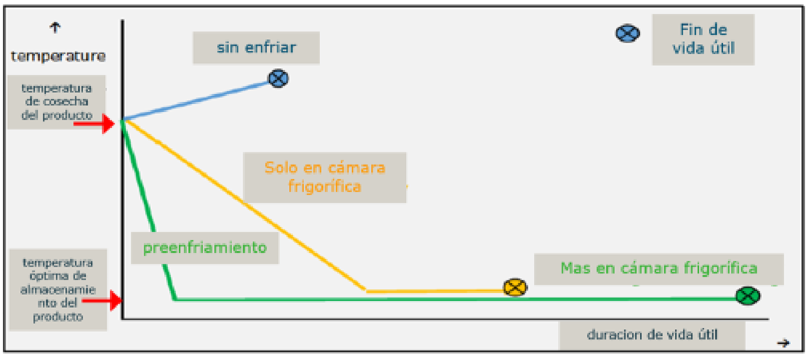
Gestión de temperatura/ enfriamiento y vida útil

efecto del enfriamiento y preenfriamiento en la vida útil



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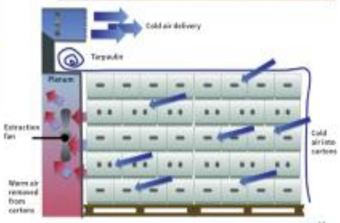
Ejemplos preenfriamiento (aire forzado)

Photograph 50: Mobile forced-air cooler
Source: Heuch Fresh, cold chain solutions



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Temperatura de enfriamiento correcta

		Temperatura de almacenamiento
Grupo 1	fría	alrededor 0 °C
Grupo 2	baja	2 a 6 °C
Grupo 3	leve	7 a 12 °C
Grupo 4	relativamente alta	alrededor 13 °C

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Grupo 1	fría	alrededor 0 °C	duración del almacenamiento
Frutas	cereza		2-3 semanas
	nectarina		2-3 semanas
	pera		2 - 6 meses
	uva de mesa		3 - 6 meses
	arándano		1 - 2 semanas
	kiwi		2 - 3 meses
	fresa		5 7 días
Verduras	ajo		> 9 meses
	alcachofa		2 - 3 semanas
	brócoli		3 -4 semanas
	remolacha		2 semanas
	escarola	2	4 semanas
	repollo		temprana: 3- 6 semanas (typo almacenage hasta 6 meses)
	zanahoria		manojo: 10 - 14 días / maduro: 7 - 9 meses
	coliflor		< 3 semanas
	apio		5 - 7 semanas
	lechuga		< 4 semanas
	cebolla		verde: 3 - 4 semanas, seca: 6 -9 meses
	hinojo		8 semanas
	guisantes		1 - 2 semanas
	rábanito		3 - 4 semanas
	espinaca		< 2 semanas
	champiñón		7 - 9 días
	puerro		8 semanas
	maiz dulce	0 - 2	< 7 days
	espárragos	0 - 2	2 - 3 semanas

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Te daré esta información para que puedas leerla tú mismo

Grupo 2	baja	alrededor 2 - 6°C	duración del almacenamiento
Frutas	manzana	1 a 4	1 - 12 meses
	aguacates	5 a 7	< 6 semanas
	cantalupo	3 a 5	12 - 15 días
	lychee	2 a 5	3- - 5 semanas
	naranga	3 a 8	< 3 meses
	granada	5 a 7	2 meses
	mandarina	5 a 8	2 - 6 semanas
	guava	5	3 semanas
	maracuja	7	2 -4 semanas

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Grupo 3	leve	alrededor 7 - 12 °C	duración del almacenamiento
Frutas	melon	7 a 10	1 a 2 semanas
	piña	7 a 10 maduro 10 a 13 semi maduro	7 a 10 dias (maduro) 2 a 3 semanas (semi maduro)
	papaya	7 a 13	1 a 3 semanas
	lima	9 a 10	6 a 8 semanas
	aguacates (hass)	7	< 6 semanaas
	mango maduro	10	2 a 4 semanas

Verduras	patata / papa	semilla 4 a 5 consumo fresca: 7 a 10 industria (friar) 10 a 15	5 a 8 meses
	frijoles / judias	5 a 8	7 a 10 dias
	calabacín	5 a 10	2 semanas
	pimienta dulce	7 a 8	3 semanas
	pimiento picante	6 a 7	3 semanas
	pepino	10 a 12	< 2 semanas
	berenjena	10 a 12	< 2 semanas
	tomate medio madura	10 a 12	< 2 semanas
	tomate madura (roja)	7 a 10	3 a 5 dias

Figure 5: Classification example of ripeness stage of tomatoes
Source: USDA

Grupo 4	relativamente alta	alrededor 13°C	duración del almacenamiento
Frutas	sandia	10 a 15	2 a 3 semanas
	mango semi-maduro	13	< 2 semanas
	pomelo	12 a 14	6 a 8 semanas
	banana	13 a 14	2 a 4 semanas
	limon	14 a 15	4 a 6 meses
	limon	7 a 14	< 4 weeks
	jackfruit (yaca)	13	4 semanas
	cherimoya	13	4 semanas

Verduras	tomate verde	13 a 15	2 semanas
	batata	13 a 15	4 a 6 meses
	jengibre	12 a 14	6 meses

Disponibilidad de cámaras frigoríficas

En caso de que no haya cámaras frigoríficas separados disponibles, use 3 o 2, agrupando producto por temperatura

Consejo:
Coloca en la puerta de la cámara frigorífica, una lista de frutas y verduras (con su temperatura óptima) que se van a almacenar en ella

Etileno

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Almacenaje y etileno

- Las frutas que producen mucho etileno no deben almacenarse con productos sensibles al etileno
- Por ejemplo, si se almacenan espinacas, brócoli o frijoles (judías) en la misma camera que frutas climatéricas maduras como el tomate, esas verduras se pondrán amarillas y comenzarán a pudrirse en tan solo un par de días.
- La fruta dañada, magullada o perforada producirá más etileno, lo que hará que las demás maduren, se ablanden y se echen a perder más rápido.

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Productora de etileno	
manzana	muy alta
platano (banana)	moderada
cherimoya	muy alta
lichi	moderada
mango	moderada
melon	moderada
maracuja	muy alta
tamarillo	alta
tomate	moderada

sensible al etileno	
asparago	si
platano (banana)	si (verde)
judías verdes / frijoles	si
mora	si
frambuesa	si
fresa	si
brócoli	si
repollo	si
zanahoria	si
coliflor	si
pepino	si
jengibre	si
verduras de hoja verde	si
puerro	si
lechuga	si
guisantes	si
pimiento	si
espinaca	si
calabacin	si
batata	si
sandia	si

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Humedad Relativa (HR)

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Una Humedad Relativa baja

- Medir la humedad relativa (del aire)

- causa arrugas
- Medidas sencillas: muévase rápido a la planta de envasado
- Use un paño húmedo para cubrir
- Mojar el suelo de una cámara frigorífica
- Empaque o cubra los productos agrícolas
- Use PAD pare mojar el aire
- Evite las gotas, mantenga productos seca

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Temperatura, HR y cubierta

pimientos en una bandeja, expuestos al ambiente durante 24 horas

7.5°C 67%RH	12.5°C 52%RH	20°C 37%RH	29°C 20% RH	37°C 17%RH

7.5°C 85%RH	12.5°C 87%RH	20°C 83%RH	29°C 85%RH	37°C 80%RH

pimientos en una bandeja, cubiertos con lámina plástica durante 24 horas

Source: UC Davis

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La lámina de plástico crea un microclima con alta humedad relativa

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Manejo cuidadoso

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Manejo cuidadoso

- El resultado de un manejo duro, sólo se hace visible después de varios días.
- Las lesiones y los hematomas son puntos de entrada de enfermedades, provocan pérdida de agua, mal aspecto y producción de etileno (maduración más rápida).
- ¡Crea conciencia con los manipuladores!
- Uñas cortas y guantes
- No tirar
- Sin bordes afilados en las cajas
- Sin sobrecarga de cajas apiladas

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Manejo cuidadoso

Daños por presión debido a un manejo brusco o apilamiento por encima del nivel de la caja

un pequeño pinchazo apenas visible se ve feo después de una semana

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Apilamiento cuidadoso

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Daño del producto

Piense en ocasiones en las que el producto pueda dañarse durante la manipulación.

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Climatérica vs. Non-Climatérica

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2 tipos de frutas con características diferentes

- Los diferentes tipos de fruta requieren un enfoque poscosecha diferente:
    - Frutos climatéricos aquellos que **pueden madurar después de ser recolectados**. ¡Estos deben estar crecida, pero no maduros! Todavía colorean y adquieren buen sabor después de la cosecha.
    - Non climatérico (**no madura tras la cosecha**). Deben cosecharse apenas maduros.!

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Frutos climatéricos ejemplos

- Aguacate
- Tomate
- Melón
- Banana (plátano)
- Chirimoya
- Frutas de hueso (como melocotón)
- Manzana
- Kiwis
- Mango
- Higos

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Frutos climatéricos. Características

- Las frutas climatéricas maduran rápidamente y desarrollarán sabor y aroma.
- Coseche los frutos climatéricos temprano, mientras aún estén verdes.
- Dejar varios días a temperatura ambiente para que maduran mientras se dirige al mercado
- O inyectar gas etileno en las cámaras de maduración en destino para llegar a la fase de maduración deseada, antes de venderlo al consumidor.

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Frutos Non-climatéricos ejemplos

- Cítricos
- Frambuesa, fresa, arándano
- Cereza
- Uva
- Piña
- Granada
- Sandia
- Pitahaya

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Frutos Non-climatéricos, Características

- Sólo madura mientras está adherido a la planta
- No maduran después de la cosecha
- Una cosecha demasiado temprana da como resultado un sabor insuficiente

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Ejemplo Tomate

- Climatérico
- Se puede cosechar en etapa temprana
- Pero el almacenamiento o el tránsito a < 7 °C pueden influir en la maduración

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Ejemplo fresa

- Non-Climatérico
- Debe cosecharse casi en su madurez para garantizar el buen sabor
- Debe enfriarse con aire forzado inmediatamente después de la cosecha a 0-1 °C para preservar la calidad (en media hora después la cosecha)
- Hay que cerrar la cadena de frío (del campo hasta consumidor)

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Higiene

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Higiene

- Sin tocar el suelo (cajas, ni producto)
- Utilice cajas de plástico limpias
- Coloque las cajas de campo sobre paletas o láminas de plástico.

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Procedimiento: Higiene Personal y Manejo de productos rechazados

2. Procedimiento: Higiene persona

- Los manipuladores deben tener las uñas recortadas para evitar dañar el producto fresco.
- Lavado de manos antes de ingresar al área de producción.
- El uso de guantes es obligatorio.
- Cámbiese periódicamente a guantes nuevos y limpios.
- No use joyas puntiagudas.
- No se permiten productos alimenticios en el área de producción

2. Procedimiento: Manipulación de productos rechazado

- Las cajas que contienen productos rechazados están claramente marcadas como "Rechazado" y se retiran a un área separada.
- Cualquier producto podrido deberá retirarse de la planta el mismo día. El producto con otros problemas debe retirarse de la planta de envasado a más tardar en un plazo de 24 horas.
- Limpiar diariamente el área donde se almacenaron los productos rechazados.

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Procedimiento: Estructura de la instalación

- Las **paredes** deben tener acabados para evitar la acumulación de suciedad, reducir la condensación y facilitar la limpieza
- Los **pisos** deben tener una caída adecuada para asegurar que el agua fluya hacia un drenaje adecuado. No deben ser resbaladizos. Los desagües deben contar con rejillas tanto internas como externas para evitar la entrada de plagas
- Los **techos** y los gastos generales (por ejemplo, cables) deben diseñarse para evitar la acumulación de suciedad o condensación
- **Ventanas** Siempre que sea posible, se deben evitar las ventanas de vidrio. Las ventanas que se abren directamente al área de embalaje deben ser de seguridad, vidrio templado o metacrilato. También deben incorporar algún tipo de protección contra plagas. Cualquier vidrio debe estar protegido con laminado. Debe existir una política documentada sobre vidrio/plástico duro
- La **iluminación** debe tener la intensidad suficiente para la zona de procesamiento. Todas las luces deben estar protegidas contra roturas
- Las **instalaciones de los trabajadores** deben estar separadas del espacio de producción. Los baños no podrán abrir directamente a las áreas de producción. Se deben proporcionar suficientes instalaciones para el lavado de manos.

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Procedimiento: Limpieza de instalaciones

Todos los equipos utilizados deben estar fabricados con materiales no peligrosos, preferiblemente acero inoxidable y plásticos

- **Programa de limpieza:**
  - El cronograma de limpieza incluye todas las áreas de la instalación, la frecuencia y el método de limpieza.
  - La limpieza de la nave de producción se realizará todos los días inmediatamente después de finalizar el turno de producción.
  - La limpieza de las cámaras frigoríficas se realizará una vez por semana (en seco).
  - Limpieza de los sanitarios diariamente.
  - Las áreas de pelado, procesamiento y despacho se limpian diariamente de acuerdo con un procedimiento operativo estándar (POE).
- **Procedimientos de limpieza:**
  - Primero se deben eliminar los residuos sólidos (cáscaras) mediante un cepillo o escoba.
  - Posteriormente, se deben enjuagar los equipos y pisos con agua a baja presión.
- **Productos químicos aprobados:**
  - Los productos químicos de limpieza o jabones que se utilizan son aptos para los alimentos y se registran las diluciones y concentraciones.
- **Limpiando materiales:**
  - Los materiales de limpieza están claramente identificados para evitar la contaminación cruzada (por ejemplo, cepillos con mango rojo para los baños, verde para el producto y niveladores azules para los pisos).
  - Los materiales de limpieza utilizados en áreas o superficies donde se colocarán alimentos no deben usarse para limpiar pisos o baños.
- **Almacenamiento de productos químicos (de limpieza):**
  - Todos los productos químicos no asociados con los alimentos, como agentes de limpieza, gasolina, pesticidas, aceite, etc., deben almacenarse en un armario fuera del área de producción.

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Procedimiento: Control de plagas

Plagas	Medidas preventivas	Medidas de protección
Insectos (moscas)	• Limpieza diaria del local • Eliminación diaria de residuos • Mosquiteras para ventanas y puertas • Matamoscas eléctricos con luz azul correctamente ubicados	• Trampa para moscas eléctrica (luz azul)
Pájaros excrementos de aves	• ¡NO SE PERMITE EL DENTRO! • Puertas/ventanas cerradas	
Roedoras	• Limpieza diaria • Eliminación diaria de residuos • Los desagües deben estar equipados con rejillas y trampas para evitar la entrada de roedores. • Mantenga el pasto corto	• Trampas • Inspección visual al menos semanalmente.
Perros/gatos callejeros	• puertas cerradas	

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Procedimiento operativo estándar (POE) de Seguridad Alimentaria

Control de calidad e inocuidad de los alimentos (abordando los límites máximos de residuos (LMR), y preocupaciones).

- Normalmente los LMR se controlan mediante el registro del uso de productos químicos en la finca. (GlobalGap)
- Sugerencia de realizar pruebas de laboratorio al azar (por ejemplo, fresa, lechuga, brócoli) para expresar su responsabilidad en este campo.
- O registre empresas certificadas que suministran productos

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Preguntas desencadenantes

1. ¿Qué fue lo más relevante que aprendiste hoy?
2. ¿Cómo se pueden aplicar las mejores prácticas sugeridas?

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Gracias!

rene.oostewechel@wur.nl

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To explore the potential of nature to improve the quality of life

Wageningen Food & Biobased Research
Bornse Weilanden 9
6708 WG Wageningen
The Netherlands
E info.wfbr@wur.nl
wur.eu/wfbr

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The mission of Wageningen University & Research is “To explore the potential of nature to improve the quality of life”. Under the banner Wageningen University & Research, Wageningen University and the specialised research institutes of the Wageningen Research Foundation have joined forces in contributing to finding solutions to important questions in the domain of healthy food and living environment. With its roughly 30 branches, 7,700 employees (7,000 fte), 2,500 PhD and EngD candidates, 13,100 students and over 150,000 participants to WUR’s Life Long Learning, Wageningen University & Research is one of the leading organisations in its domain. The unique Wageningen approach lies in its integrated approach to issues and the collaboration between different disciplines.