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Designing a packaging solution for Ghanaian farmers

Master thesis by Anna Koper

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Preface

After a lot of hard work, I am very excited to share my master thesis report with you. As in all other design projects over the years, this project made me experience things I did not expect. For example, going to Ghana for 5 weeks on my own, picking up dozens of banana leaves all over the Netherlands and then boiling them in the kitchen or cycling around for 3 hours on a cargo bike with a crate of 40 kilos of tomatoes. Throughout all of this I had the support of a wonderful set of people. So before you dive into the report I want first to thank some people.

First I would like to thank my graduation committee for guiding and supporting me throughout the project. Wilfred, thank you for paying attention to the details I overlooked and thinking along with the project at all times. Eliza, thank you for asking critical questions that helped me look at my project from a different perspective. I also want to express my gratitude to my 3 client mentors Charlotte, Esther and Lindsey for giving me the opportunity to play a part in this amazing project. Thank you for your enthusiasm and involvement and for always being available online or offline to discuss the project.

Secondly I am deeply thankful to all the lovely people Ghana that were so open in sharing their experiences and knowledge with me. Thank you to the amazing people at Kwadaso Agricultural College, Holland Greentech and all the farmers who I could rely on for guidance in Ghana and even in the Netherlands. A special thanks goes out to Joy for going out of her way to produce the solution in Ghana as a test. Furthermore, I would like to express my huge appreciation towards Mr. Samuel Darbah, Mrs. Josephine Darbah, Emanuela, Erica and Josephine for providing me with a home in Ghana, the good care and the delicious food.

Without banana leaves I could not have completed this project, therefore I also want to thank all institutions that were so kind to let me come by and pick them up whenever I needed them. A much appreciated thank you to TU Delft Hortus Botanicus, Utrecht University Botanic Gardens, Nederbanaan and Avifauna.

Lastly, I want to thank my dear friends, housemates, parents and girlfriend for simply cheering me up with your presence during the whole process and making me laugh. I'm so thankful for the all the ways you offered help from participating in creative sessions to reading my report and from simply giving me a hug to making me dinner.

Thanks a million and, dear reader, I hope you will enjoy this report!

Anna

Summary

Post-harvest losses of vegetables in Ghana can raise up to 50% (Saavedra et al., 2014) depending on the crop. Combatting these losses is crucial for ensuring financial security among commercial smallholder farmers. Amongst other reasons, lack of effective packaging practices is a major contributor to this issue. This thesis therefore focusses on the design of a packaging solution for fresh vegetables for Ghanaian commercial smallholder farmers to reduce post-harvest losses. The challenge lies in designing a simple, cheap and accessible solution that is buildable in the local context.

Extensive literature, desk & field research is conducted to get a broad understanding of the fresh vegetable chain in Ghana and its stakeholders. Part of the research phase takes place in Ghana where stakeholder interviews and field observations are conducted. Visits are made to local farms, markets and supermarkets and interviews are conducted with farmers farmers, market women, consumers, horticulture company and agricultural college. From this opportunities, challenges and barriers within the chain are identified to choose a focus for where to introduce a solution.

With all insights from the research, the focus with the most potential for making impact is chosen together with local stakeholders. The focus of the project with the most potential is: Using banana leaves as transport packaging to local market for tomatoes in crates. The first reason for this is that banana leaves are a cheap material widely available in Ghana that has the potential to be used for packaging purposes. Secondly, inadequate transport packaging is one of the biggest reasons for post-harvest loss. Lastly, tomato is the most grown, eaten and lost vegetable in Ghana. Current packaging in crates offers insufficient protection, but introducing a solution to add to these crates could have a great impact on fighting post-harvest loss without the need for farmers to invest in new crates.

Material tests are performed with banana leaves to discover material boundaries and possibilities of the leaves with which ideas can be evaluated on feasibility. Through rapid prototyping of ideas, iterations are brought to life and evaluated at a fast pace to check their potential. This process eventually leads to the design that has the most potential to reduce post-harvest losses in combination with being cheap and simple to produce without needing many additional resources or tools. This is the leafpad.

The leafpad is a transport protection sheet for transporting tomatoes in crates that can be produced by Ghanaian farmers themselves and is placed in between layers of tomatoes when being transported in wooden crates. The leafpads consist of 3 layers of banana leaves placed over each other and glued with the veins perpendicular to each other. This increases the strength of the sheets. During drying of the sheets, the leaves shrink slightly, creating air pockets that give the sheets thickness that functions as padding. The leafpad absorbs shock and vibration during transport as a result of bad road conditions and function as a layer between the fruits so they don't directly touch each other. For the production some simple tools are used that can be created at home by the farmers themselves with the help of an instructions guide. Materials are widely available in Ghana and production is cheap.

The design is validated through a transport simulation test and validation with stakeholders in Ghana. For future development scaling up the production process and turning it into a business is recommended so that farmers and other target groups can buy the sheets readily made, eliminating the need for taking time to produce the leafpads at home.

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Introduction

This chapter introduces the project by lining out the nature of the project, the stakeholders and the target group. Furthermore, it explains the design challenge and the approach to tackle this challenge as well as the research questions that are answered and the approach to this.

1.1 The ACHI project

In 2020 Delft University of Technology (TU Delft) joined forces with Kwadaso Agricultural College[1] (KAC) in Kumasi and Holland Greentech Ghana[2] (HGT) under the ACHI program with the motto 'Horticulture in Ghana for a brighter future'[3]. ACHI stands for Agricultural Colleges for Horticulture Innovation. The main objective of this bigger programme initiated and funded by the European Union, was to boost employment opportunities and increase professional skills for Ghanaian youth in the horticulture sector. To do this the regular curriculum at KAC was improved and a separate 4-month training programme was developed and introduced called 'Farming as a business'. This separate programme is offered to young, motivated people outside of KAC wanting to become active in the horticulture sector and runs in growing batches of about 30 to 60 participants. Within this programme, practical climate-smart horticulture training and resources are provided by Holland Greentech's agronomists and businesses & entrepreneurship education is provided with support of the Delft Centre for Entrepreneurship.

Ultimately the ACHI programme aims to establish a new generation of farmers that will implement modern and climate-smart practices to produce maximum yields with minimum negative impact on the environment.

Figure 1 - Commercial smallholder farm visit, farm owned by ACHI alumnus

[1] *https://kac.edu.gh/*
[2] *https://hollandgreentechghana.com/*
[3] *https://www.tudelft.nl/global/research/education-entrepreneurship/horticulture-in-ghana-for-a-brighter-future*

The improved farming practices as a result of the ACHI programme have had a significant impact over the last years. The alumni (figure 1) clearly demonstrate this through their increased yield and improved income. The impact is also demonstrated by the network of lead farmers connected to the project. The 20 selected lead farmers in and around Kumasi are provided with the right training, knowledge and resources by HGT to ensure better yields and business. They organize regular farm field days where students and other farmers in the region are welcome to receive knowledge on climate-smart and green practices. Throughout the last years, this ensured an outreach to more than 1200 farmers in the region, the creation of more than 200 jobs and the increase of HGT customers from about 180 to more than 1800.

This graduation project is part of a 4-year continuation of the ACHI project as a result of the success at KAC. Within the next years the collaboration and implementation of the training programme will expand to schools in 4 other regions in Ghana, visible in figure 1. When looking at the already achieved outreach and planned expansion of the programme there is great potential for making impact in the Ghanaian horticulture sector through this project.

KWADASO AGRICULTURAL COLLEGE

Holland Greentech

TU Delft

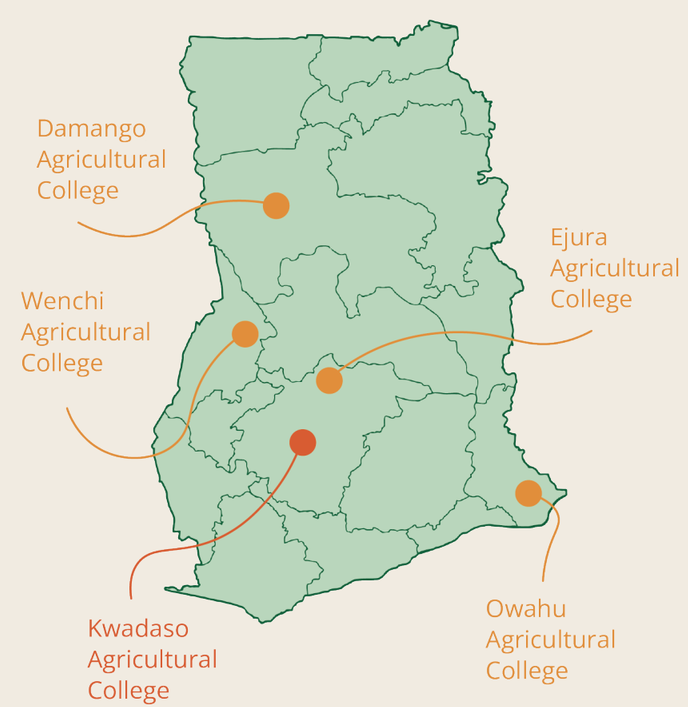


Figure 2 – Expansion of ACHI to remaining agricultural colleges in Ghana

1.2 Design challenge

Ghana's horticulture sector has seen major improvements in the past years and holds the potential to create jobs as well as address food security and safety. However, a significant challenge remains: post-harvest losses of vegetables in Ghana can be as high as 50% (Saavedra et al., 2014) depending on the crop. Combatting these losses is crucial for ensuring financial security among commercial smallholder farmers. Limited adoption of effective packaging (figure 3 & 4) among Ghanaian farmers is a major contribution to this issue and combined with the climate and lack of good storage space products have a short shelf life (Sugri et al., 2021). There the opportunity arises to improve education on this topic for KAC.

The challenge lies in designing a packaging solution that serves as an example for horticulture students, stressing the benefits of packaging such as extending shelf life, maintaining product quality and saving precious resources. The term packaging stands here for any material that is used to contain or protect products during on-farm handling, storage, transport and retail.

Through the resources and services of Holland Greentech, KAC students and the lead farmers with their network of commercial smallholder farmers are able to produce higher quality vegetables as compared to the average Ghanaian farmer. For these higher-quality vegetables, a packaging solution can maintain quality, help gain recognition for the farmer's hard work and reduce post-harvest losses. Additionally, the solution can ignite a sense of creativity and entrepreneurship among farmers and students in reducing losses by posing the opportunity to showcase the quality of the products of their farm.

Figure 3 - Lettuce packaged at a farm after harvesting

Ultimately, packaging produce motivates more sustainable, future-proof farming practices. When losing produce post-harvest, hard work and time put into farming as well as resources such as water, fertiliser, pesticides and nutrients are wasted. Minimizing this loss while stimulating entrepreneurship will get the most out of their hard work and used resources which will increase the total value of the harvest and the profit of the farmer. Given the context, the packaging solution should be buildable in the local context with locally obtainable materials and should explore options for sustainable forms of packaging while being financially feasible for local farmers.

Within the scope of this project, the focus will be on the education and adoption of packaging practices for KAC students, lead farmers and their network of commercial smallholder farmers in the Kumasi region. However, the higher goal is to reduce post-harvest losses on a more national level through education within the ACHI project that will expand to all agricultural colleges in Ghana. This means that the solution needs to be reproducible for others and include a guide with instructions.

Figure 4 - Bags of carrots unloaded from a truck

1.3 Core project players

In this chapter the stakeholders and their relationships with the ACHI project are explained. Next to the main stakeholders in the ACHI project, there are players in the local context who are involved and affected by this project. These will also be addressed. Lastly, the target group of this project is described. An overview of the most important stakeholders is visible in figure 5.

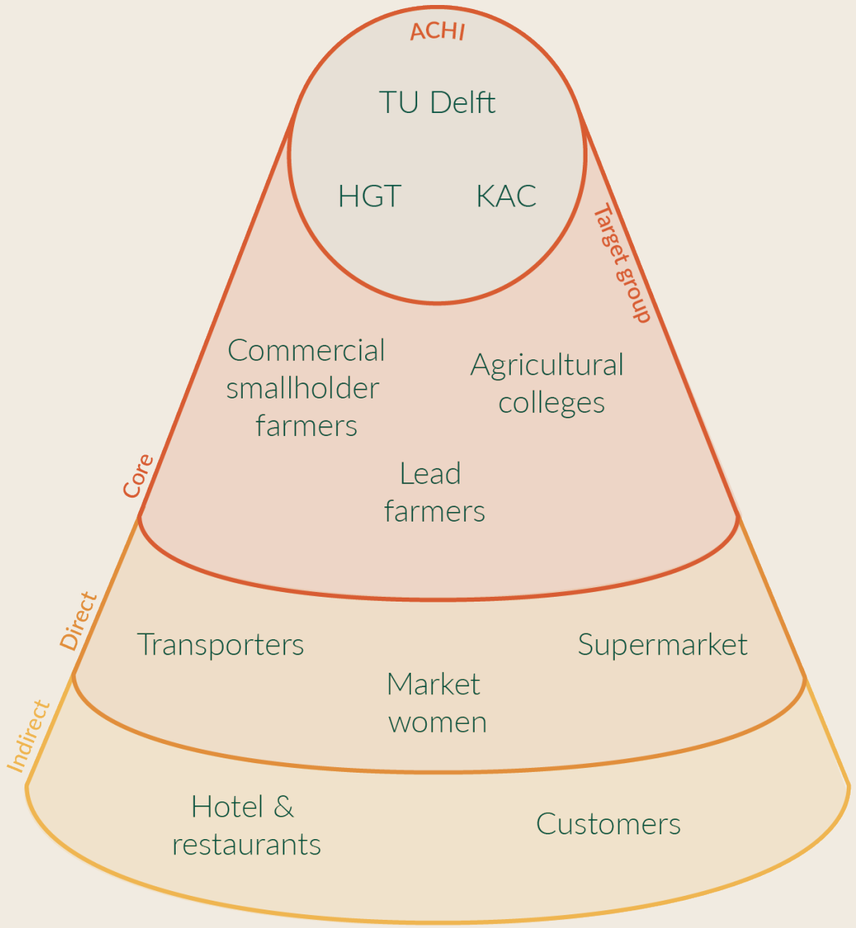


Figure 5 - Stakeholder relations

1.3.1 ACHI stakeholders

Kwadaso Agricultural College located in Kumasi (figure 6), is the oldest and leading agricultural institution in Ghana. KAC aims at teaching its students the practical and theoretical skills of farming through two types of education. The regular KAC students study the standard curriculum full-time and the ACHI program is aimed at professionals with an interest in the horticulture sector, also often without prior experience in farming and students who wish to know more about entrepreneurship. Within the ACHI project partnerships with several stakeholders under which Holland Greentech, TU Delft, lead farmers and the other 4 agricultural colleges in Ghana are maintained.

Holland Greentech is a Dutch organization providing horticulture products and services. It has branches in 12 African countries including Ghana where it supports farmers with their approach of ‘seeds and services’. They partner with local communities to provide horticulture knowledge and skills and help them acquire resources and technology to expand productivity. Knowledge is shared within the communities as well as between the different branches of Holland Greentech in other countries.

Holland Greentech is the distributor and representative of a variety of Dutch suppliers offering seeds, irrigation equipment, soil and fertilizer services, pest and disease control, business support and training. Their model is to sell high-quality inputs as well as train farmers in good agricultural practices and build a network of farmers, students and entrepreneurs. The type of farmers that partner with HGT are usually young, well-motivated farmers with a good education who are able to follow training and do bookkeeping. These are the people who really seek knowledge and see their farm as a profit-making business to invest in (Director of horticulture company in the Netherlands, 2024: appendix 1.1).

TU Delft has a mission to share its knowledge and expertise for global sustainable development. For the ACHI project, it does this through the Delft Centre for Entrepreneurship by sharing didactical and entrepreneurial experiences with teachers at Kwadaso Agricultural College. Together, TU Delft and KAC work on the improvement of several courses in the KAC curriculum and the integration of entrepreneurship in horticulture education to establish farming as a business.

Figure 6 - Classroom at Kwadaso Agricultural College

Figure 7 - Farm employee carrying a bag of harvested spring onions

1.3.2 Local stakeholders

The goal of the project is the design of a packaging solution for Ghanaian farmers, but other players in the local value chain are also affected by the solution. This could be anyone involved in the handling, storage, transport and retail of fresh vegetables. The players within the chain include farmers, farm employees (figure 7), market women (figure 8), transporters, supermarket chains, supermarket employees, restaurant owners, hotel owners and customers. It is important that the design is not only a good solution for the Ghanaian commercial smallholder farmer but fits within the chain and its players as well. Other stakeholders are people involved in the manufacturing and processing of packaging materials and tools.

1.3.3 Target group

The main stakeholder and the organization for which this graduation project is conducted is Kwadaso Agricultural College. The designed solution will serve as an example at the school to convey the importance and the benefits packaging can have on for example shelf life, product quality and revenue. To accurately serve this purpose the solution will be targeted towards the people that will benefit from the solution: KAC students, ACHI students and lead farmers with their network of commercial smallholder farmers that are connected to Holland Greentech. This target group is co-determined with the project client (appendix 1.3).

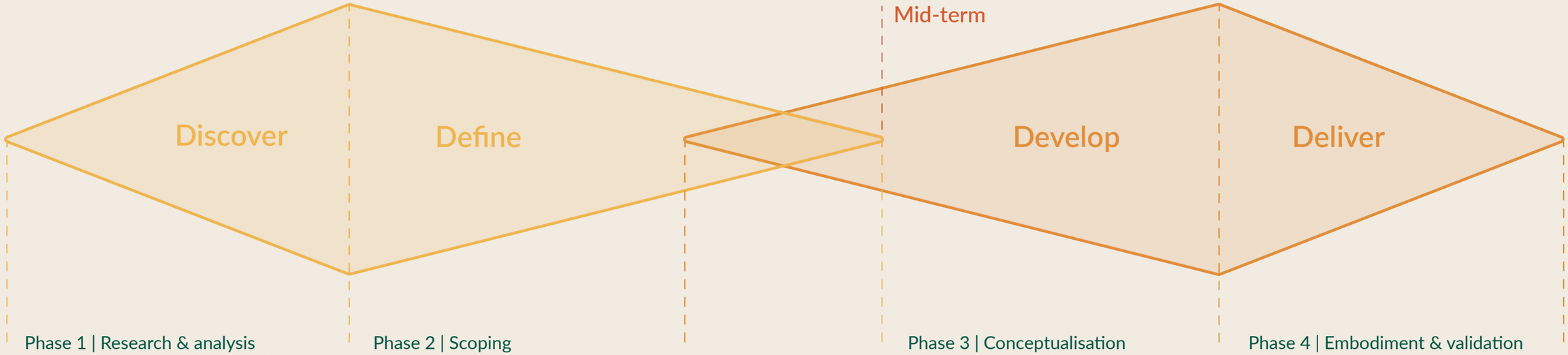
In this case, commercial smallholder farmers are the group of farmers who are willing to invest in and adopt new technologies that envision farming as a serious business. The farmers that are connected to Holland Greentech have access to higher quality inputs than the average Ghanaian farmer which means they can produce higher quality vegetables that have a longer shelf life and can therefore make more profit (Director of horticulture company in Ghana, 2024: appendix 1.2). Since the quality of these vegetables is high packaging them can be an additional benefit for maintaining quality and increasing revenue.

Figure 8 - A market woman at a local market

1.4 Structuring the project

To structure the project a slightly adapted double diamond method (Design Council, 2003) is used. The project consists of 4 phases: the research & analysis phase, the scoping phase, the conceptualisation phase and the embodiment & validation phase. The method is slightly adapted in a way that the beginning of the second diamond, the conceptualisation phase, overlaps with the scoping phase of the first diamond. This is to make optimal use of the time spent doing field research in Ghana during the research and scoping phase. During the scoping phase, a focus for the project is defined stemming from the research. Some parts of the research are more important and relevant for this focus than others. For this reason, more attention is given to these parts of the research in the following chapters. Overall, during the process, values of design for the base of the pyramid are taken into account given the nature of the project context. These values include affordability, accessibility, availability, reliability, sustainability and acceptability.

The overview of the approach to the project process is visible in figure 9.



Phase 1 | Research & analysis
In this phase, literature & field research is conducted to get a broad understanding of the context and its stakeholders. In the first weeks, literature research and expert interviews are conducted in the Netherlands. The second part of the research phase takes place in Ghana where stakeholder interviews and field observations are conducted. Visits are made to local farms, markets and supermarkets and interviews are conducted with farmers, vendors, consumers, KAC and HGT.

Phase 2 | Scoping
In this phase, the focus of the design challenge is formed together with local stakeholders such as Kwadaso Agricultural College, Holland Greentech and local farmers. All research is combined to define a promising design direction that has potential to make impact in the context accompanied by a set of requirements that ensures a suitable packaging solution for the context and target group.

Phase 3 | Conceptualisation
This phase consists of ideation and conceptualization of the packaging solution. Through rapid prototyping, iterations are brought to life and evaluated at a fast pace to check for feasibility. Making prototypes enables the improvement of concepts in a faster and richer way by being able to experience them directly.

Phase 4 | Embodiment & validation
In this phase, the packaging solution is detailed, realized and validated. The expected effect of the solution and explanation of all its parts are layed out. Final conclusions and recommendations are drawn and the guide with instructions accompanying the solution for KAC will be finalized.

Figure 9 – The project process

1.5 Research approach

In order to understand the context of the project desk and field research is conducted. Below, the questions that are answered and the approach to answering them are mentioned.

1.5.1 Research questions

In order to design a fitting solution a proper understanding of the context, current situation and stakeholders is crucial. The overarching research questions to understand this are stated below and the sub-questions can be found in appendix 2.

- What does farming in Ghana look like for commercial smallholder farmers?
- What does the fresh vegetable value chain look like from farm to consumer?
- What do post-harvest losses look like in Ghana?
- What is the best practice vegetable handling for extending shelf-life?
- What are packaging practices for fresh vegetables?
- Where in the process between harvesting and retail is it best to introduce a packaging solution in Ghana?

Figure 10 - Okra in baskets at local market

1.5.2 Research setup

For the research phase of this project literature, desk and field research were conducted in the Netherlands and Ghana. Literature research is conducted about farming and post-harvest losses in Ghana as well as vegetable handling, packaging and banana leaves. Next to this, several interviews with experts in the field of packaging and vegetable handling were conducted.

For five and a half weeks field research was conducted in Kumasi and Accra in Ghana by doing interviews and observations with the previously mentioned stakeholders: farmers, ACHI alumni, market women, supermarket chains, restaurant owners, customers, KAC staff and HGT employees. The people who participated in the research were selected by reaching out to the network of KAC staff and HGT employees as well as paying random visits to local markets (figure 10 & 11), supermarkets and hospitality establishments.

During all interviews and observations, a KAC staff member or HGT employee was present to assist where necessary and to translate if a language barrier was present. On the right the details of the interviews and observations are visible in tables 1 and 2.

Stakeholder	Details of interview participants	Amount
Farmer	Farmers at local farmers meetings. These are meetings where farmers of a certain district come together to discuss any problems on their farm and how to solve them.	6
	Farmers who are ACHI alumni & Holland Greentech Ghana customers	3
Entrepreneur	ACHI alumnus with own business in crop processing	1
Supermarket staff	Employees of the vegetable department	2
Market women	Market women at huge market where a wide variety of food and non-food products are sold	4
	Market women at market specifically for fruits and vegetables.	5
Customers	Customers at local fruits and vegetable market	2
	Medium-sized restaurant	1
	Roadside restaurant	1
	Hotel	1
KAC & ACHI staff	Crop science department	1
	Home science department (processing & packaging)	1
	Post-harvest technology department	2
	ACHI project coordinator	1
HGT staff	Manager Holland Greentech Ghana	1
	Director Holland Greentech Netherlands	1
Packaging expert	Packaging expert sustainable packaging KIDV	1

Table 1 – Details of interviews

Location	Details of observation location	Amount
Farm	Farms of ACHI alumni & Holland Greentech Ghana customers, one supplying the local market & the other the supermarket	2
Supermarket	3 biggest supermarket chains in Kumasi: Shoprite, Melcom & Palace	3
Local market	A huge market for food and non-food products & a market for fruits and vegetables specifically	2
Restaurants	One small roadside restaurant and one medium-sized restaurant	2

Table 2 – Details of observations

1.5.3 Data gathering

Interview and observation guides (appendix 3.1 & 3.2) have been prepared for different stakeholder groups with the aim of providing a base for semi-structured interviews and observations. The guides are structured by different topics to gain an understanding of on-farm processes, post-harvest losses, the road from farm to consumer and packaging practices. A semi-structured method is applied to acquire both quantitative and qualitative data. It allows for comparability between interviewees as well as flexibility per participant to gain richer, more nuanced insights. During all interviews and observations notes and photos have been taken. Interviews have been recorded and transcribed, apart from when the background noise level was too high. By doing so the full attention can be on the conversation and detail and nuances can be preserved.

Figure 11 - Vegetables displayed at local market

Take-aways from chapter 1

- The ACHI project boosts the horticulture sector in Ghana by providing climate-smart training by Holland Greentech and entrepreneurship education by TU Delft at Kwadaso Agricultural College. The project has been proven to be successful at KAC and will expand to the rest of Ghana's agricultural colleges, setting the standard for a new generation of farmers.

- The design challenge is to develop a packaging solution for Ghanaian farmers to reduce post-harvest losses and educate students on the importance and benefits of packaging. The solution needs to be affordable for local farmers, reproducible and can be realized locally.

- The target group consists of KAC students, ACHI students and lead farmers with their network of commercial smallholder farmers that are connected to Holland Greentech. They see farming as a serious business and treat it as such by being willing to invest in their farm and adopt new technologies to increase yields and revenue.

- Qualitative and quantitative data about the project context are obtained by visiting Ghana and conducting interviews and observations with a wide variety of stakeholders: farmers, ACHI alumni, market women, supermarket chains, restaurant owners, customers, KAC staff and HGT employees.

02.

Context

The following chapter paints a picture of the context of the fresh vegetable industry in Ghana. It explains farming in Ghana and specifically the Kumasi region followed by the numbers and reasons for post-harvest losses. Additionally, a depiction of the different farm-to-consumer situations is captured including current packaging practices.

2.1 Farming in Ghana

In Ghana, about 20% of the GDP can be linked to agriculture (Statista, 2024) and about 40% of the total working force in Ghana is employed in the Agriculture sector (Trading Economics, 2024).

The principle vegetable crops grown in Ghana include tomato, onion, bell pepper, chillies, cabbage, eggplant, lettuce (figure 12) and okra (MoFa, 2022) of which tomatoes hold the largest share (Mordor Intelligence, 2024b).

In Ghana, six distinct agroecological zones can be identified. Each has its own humidity, temperature, rainfall, natural vegetation and soil conditions (Global Yield Gap Atlas, n.d.). This means that different crops grow optimally in the different regions in Ghana and that the production of crops and their transport is for a part regionally dependent.

Figure 12 - Freshly picked lettuce

2.1.1 Farming in the Kumasi region

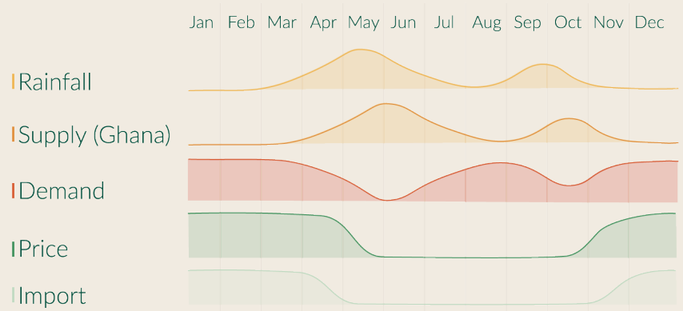
In the Kumasi region, vegetables that are often grown are cabbage, lettuce and a variety of onions (figure 13) since the soil and climate are best for these crops. Next to this different farmers cultivate crops such as tomatoes, chillies, cucumbers, eggplants, okra and bell peppers (local farmer, 2024: appendix 4.1).

Kumasi lies in a semi-deciduous forest zone (Mahallati, 2020). This means it is characterized by a bimodal rainfall pattern which means it has two wet and dry seasons and a generally high temperature throughout the year (WorldData 2024).

For farmers around Kumasi, crop cultivation can be challenging. Most rely on rainfall for crop growth and income, as they cannot afford irrigation. Kumasi has two growing seasons aligned with rainfall (graph 1). During and after these wet periods, vegetable harvests are high, but demand drops, leading to lower prices (local farmer, 2024: appendix 4.1). In the dry season, crop quality depends heavily on irrigation. Growing becomes more difficult, and higher demand is met by importing vegetables from countries like Togo and Burkina Faso, driving prices up (market woman, 2024: appendix 5.1).

The mean annual temperature in Kumasi is about 27 °C with a variation ranging from 35°C during the day to 20°C at night throughout the year and the relative humidity ranges from about 65% to 85% throughout the year (WorldData, 2024). The high humidity level year-round means diseases and pests have the ability to thrive. This makes it harder to grow vegetables of high quality than in other regions with lower humidity levels (ACHI project manager Ghana, 2024: appendix 1.4). For this reason, vegetable demand is also met by the supply of vegetables from other regions in Ghana. The vegetables travel long distances over poor-quality roads in overloaded trucks which unfortunately means they arrive damaged at the markets in Kumasi (market woman, 2024: appendix 5.1).

Figure 13 - Farm employee packaging spring onions at the farm after harvesting



Graph 1 - Rainfall, supply from Ghana, demand, price and import of vegetables throughout the year

2.2 Post-harvest losses

The definition of post-harvest loss is the qualitative and quantitative loss of food from the moment of harvest until the moment it is consumed (De Lucia & Assennato, 1994). This excludes any losses occurring before harvesting when the produce is still growing on the plant. Qualitative loss measures visible changes in appearance such as bruises, punctures or rot and quantitative loss looks at weight reduction (Wongnaa et al., 2023). This chapter lines out the numbers for major vegetable crops in Ghana and the causes of these losses.

2.2.1 Numbers

A certain percentage of post-harvest loss is unavoidable. To illustrate, post-harvest loss for fruits and vegetables in Europe and North America lies between 4% to 7% (Fabi et al., 2021). On the contrary, losses in low and middle-income countries can reach up to 40% to 50% (FAO et al., 2011). In Sub-Saharan Africa specifically, the typical loss of horticultural crops is estimated to be between 20% and 35% depending on the country and climate (Mutungi & Affognon, 2013). An overall number of post-harvest losses of vegetables in Ghana specifically is hard to find. The numbers that are found in literature for the major vegetable crops in Ghana can be found in table 3 and are numbers for quantitative loss. Since the numbers are sometimes only for a specific region and the sources might be slightly outdated it is best to conclude that vegetable losses of major crops in Ghana roughly lie between 20% and 40%. Overall research finds that tomatoes experience the most losses (Wongaa et al., 2023). Since price, supply and demand differ in the major and minor seasons, losses usually also differ per season. In the major season, demand is lower and supply is higher, resulting in more losses while demand in the minor season is high and supply lower, resulting in a higher portion of the harvest being sold. The difference in quantitative post-harvest loss between the seasons can lie around 20% (Wongnaa et al., 2023). The difference in qualitative loss between the seasons is unknown.

Vegetable	Post-harvest loss percentage in Ghana		
Tomato	27.1%	Upper East region	(Sugri et al., 2021)
	37.5%		(Ridolfi et al., 2018)
	30%		(Krampah, 2016)
	33%		(Wongnaa et al., 2023)
	20%	during transport	(Bani et al., 2006)
Cabbage	60%		(Baral & Hoffmann, 2018)
Bell pepper	36.6%	Upper East region	(Sugri et al., 2021)
Eggplant	30%		(Wahaga & Arimeyaw, 2021)
Onion	27.3%	Upper East region	(Sugri et al., 2021)
	23.9%		(Falola et al., 2023)
Okra	20-30%		(Vowotor et al., 2012)
Lettuce	20%	5 days after harvest	(Dovlo et al., 2021)
Chilli pepper	16.3%		(Osei-Kwarteng et al., 2018)
Cucumber	-		

Table 3 – Post-harvest losses for major vegetable crops in Ghana

Figure 14- Cabbage imported from Burkina Faso, damaged as a result of transport

2.2.2 Causes

Post-harvest losses along the value chain in Ghana and the rest of Sub-Saharan Africa have a variety of reasons which are visible on the next page. Some causes can be more easily influenced while others will take extensive time and effort. In a large study in Southeast Asia and Sub-Saharan Africa, a variety of approaches have been assessed and from this, solutions around packaging are estimated to have the most potential in the short term given that they are usually relatively simple solutions that can be implemented easily without requiring significant investments (Kitinoja & AlHassan, 2012; Sarán, Roy, & Kitinoja, 2012). Next to this, they can help face challenges that take more time and organization to tackle like a poor road network and energy infrastructure. Implementing packaging at the farm level can have a positive influence on reducing losses during several stages such as storage, transport and retail (Tapsoba et al., 2022).

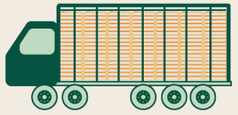
The following causes are a combination of all factors found in the following papers. (Kitinoja & AlHassan, 2012; Sugri et al., 2021; Wongnaa et al., 2023, Kansanga, Mohammed, Batung, Saaka, & Luginaah, 2023; Dovlo, Kunu, & Rudin, 2021; Kiaya, 2014, Director of horticulture company in Ghana, 2024: appendix 1.2; local farmers, 2024: appendix 4.1; market women, 2024: appendix 5.1; supermarket chains, 2024: appendix 5.3-5.5):

Post-harvest handling
Rough handling of vegetables causes bruises, scratching and punctures, leaving them more vulnerable to diseases and deterioration.

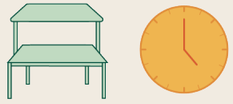
Temperature
Lack of shade and high temperature during harvest, handling, storage, transport and marketing contribute to high pulp temperatures & water loss.

Market availability
There are several problems with market availability, reliability and accessibility. The demand can be unreliable which leaves farmers with a harvest they are unable to sell, resulting in losses.

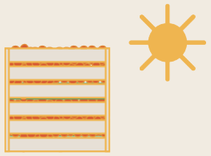
Poor sanitation
The lack of washing or pre-sorting of vegetables to remove decayed products before transport or storage increases the chances of fungal and bacterial diseases or insect pests.



Transportation issues
The access people have to the road network can be poor as well as the quality of the road. Trucks drive at least partly on unpaved roads with potholes, causing produce to get damaged or squashed more easily because of vibrations and movement (figure 14).



Time to market
It can vary widely how much time it takes for produce to reach the market. The longer it takes the more damage the vegetables suffer and the higher chances there are for rot, pests and diseases.



Poor storage
Many farmers lack a storage facility and there is virtually no temperature-controlled supply chain, meaning the shelf-life of products drastically decreases during storage. Sometimes there are sheds or canopies to provide shade during storage, but exposure to sunlight is not unusual. Next to this items are stored unshielded from microorganisms.

Poor packaging
During harvest, handling, storage and especially during transport and marketing underperforming containers are used causing damage such as bruises, punctures and compression damage. The containers do not ventilate well, resulting in higher temperatures. At the market vegetables are often displayed without protection.

2.3 Farmer & consumer

Within the vegetable value chain, there are several important players. The section of the chain that this project looks at is the part in the value chain from where the farmer is cultivating crops up until the moment it is purchased by the consumer. in this chapter these two stakeholders who form the end and the beginning of the chain will be highlighted. After that the different ways the vegetables reach the consumer and the challenges therein are highlighted.

2.3.1 Commercial smallholder farmers

The focus of this project is on the Ghanaian commercial smallholder farmers connected to the ACHI project. These are farmers cultivating crops on 20,000 m2 or less, producing food predominantly for the local market but also for their households and sometimes domestic supermarkets (Jaro et al., 2018). They envision farming as a business and are willing to invest in it. About 70% of the farmers in Ghana can be defined as commercial smallholder farmers, for the larger part engaging in rudimentary agriculture (Alidu et al., 2022). The remaining farmers cultivate crops on medium (24,000 – 76,000 m2) and larger scale (80,000 m2 or more). These farmers mostly supply the domestic supermarkets as well as the export market in some cases (Jaro et al., 2018). Many commercial smallholder farmers depend on the weather for the yield of their crops. During the wet season(s) production is abundant while in the dry season, most farmers are dependent on rainfall since few have irrigation systems (figure 15) (local farmer, 2024: appendix 4.1).

Farmers usually grow a variety of crops of which are vegetables and part other crops. Most of Ghana's vegetable farming is done in more urban areas (Quansah et al., 2020) and the remaining part is farmed in rural areas.

Figure 15 - Irrigation on the field at KAC

Figure 16 - Local small commercial farm in Kumasi.

The interviewed farmers grow around 2–4 different vegetable crops and have their farms in urban to semi-urban areas. They indicate that the choice for growing a specific crop is based largely on the demand for the crop as well as how appropriate the soil and climate are for growing the crops (local farmer, 2024: appendix 4.1) They dedicate their days to farming and sometimes have additional staff helping at the farm depending on the size of the farm and the activities.
Ghanaian farms differ from the typical farms known in Western countries. They consist of a piece of land with a small shed for tools, but other than that no structures that can be used for storage or processing (figure 16). Multiple of these lots lay next to each other, owned by different farmers. Since the farm is not always adjacent to the home of the farmer, they often have to commute to their piece of land (local farmer, 2024: appendix 4.2).

Making good profits as a farmer in the Ghanaian horticulture sector is difficult and requires personal motivation and investment. There is little to no overall regulation and organization which means farmers need to set up their own connections (figure 17) and organize their own chain if they want to avoid getting low prices for their vegetables (director of horticulture company in the Netherlands, 2024: appendix 1.1). The easy option for most farmers is selling their vegetables to middle women who will transport them to the market and sell it to market women at local markets. In this case, farmers usually get low prices for their produce since each stakeholder adds their individual profit margin and a large amount of post-harvest loss occurs, meaning produce is sold for little at the market. For these farmers getting as much money for the least amount of effort is a big driver (local farmer, 2024: appendix 4.2).

"If the farmers want to sell their produce to the supermarket, they need to meet the demand. And you know, they don't want to go through the stress of packaging and cleaning and sorting and grading and all that."

(farmer supplying the supermarket, 2024: appendix 4.3)

If farmers want to get a better price for their vegetables they need to take matters into their own hands. An example of this is Susan, an ACHI alumnus and HGT partner. Originally she was a farmer and in order to get a better price she decided to take the step to sell her vegetables to the supermarket. To meet the demands of the supermarket she now buys and transports vegetables from other farmers to her own farm. On top of this, she sorts, cleans and packages the vegetables in plastic bags by hand and then she has to transport the vegetables to the supermarket as well. Most farmers are not able to take this step of organization because they do not have the money and resources available. The solution therefore needs to easy and cheap to be accessible. There are also other ways of setting up collaborations to get better prices. For example, when transporting produce to the local market it is cheaper if you can guarantee to fill a full truckload. Many smallholder farmers lack sufficient yield individually, but by collaborating with others, they can meet truckload demands and reduce transport costs. Collaboration and initiative are therefore crucial for farmers to thrive.

"So you see her job has long since gone beyond just growing vegetables. She actually has to organise the whole chain. And, if you don't do that, so if you don't organise your chain and you don't manage to set up those collaborations you actually get such a low price for your vegetables that you can barely make a profit."

(director of horticulture company in the Netherlands, 2024: appendix 1.1)

Figure 17 - Farmers meeting for farmers of the same district in Kumasi

2.3.2 Consumers

Typical meals in Ghana consist mostly of starchy staples like cassava, yam, plantain, cocoyam, maize or rice with smaller portions of food containing higher nutrients (Aberman et al., 2022). Vegetables are not always included in meals in abundance but are more seen as a side dish. Some families even do not include vegetables at all because of the price and the lack of awareness about their nutritional value (director of horticulture company in Ghana, 2024: appendix 1.2).

However, the amount of middle-class families is steadily rising and with that the number of consumers wanting to buy quality vegetables. The estimation is that the domestic vegetable market will grow at about 10% per year (Mordor Intelligence, 2024a). Therefore the coming years will be crucial in fighting post-harvest losses to meet the demands.

"There's still a little bit of...not much awareness on the healthiness of vegetables and why people should choose quality vegetables rather than the others. First of all, a lot of people are not even eating vegetables in their homes."

(director of horticulture company in Ghana, 2024: appendix 1.2)

Figure 18 - Crops grown for home consumption

For the Ghanaians that do consume vegetables, many of them grow at least some vegetable crops for home consumption (figure 18 & 19) and sell the remaining amount when sufficiently is produced for the family (Aberman et al., 2022). Next to producing at home, the consumer buys vegetables either at the local market or the supermarket. About three-quarters of consumers purchase only from the traditional local market and the remaining quarter also goes to the supermarket (Wordey, 2019).

About 12.8% of total household food expenditure was spent on vegetables of which tomatoes make up about one-third which is the highest share (Van Asselt et al., 2018). Next to vegetables for home consumption, vegetables for the hospitality industry in Ghana are also often bought at the local market (appendix 6). Local market is therefore by far the biggest sales market for vegetables.

Figure 19 - Palm oil production at home

Figure 20 - Packaged vegetables at the supermarket

When buying vegetables the Ghanaian consumer pays attention to a variety of things. The following factors are considered, listed from most important to least important: weight, health benefit, safety, affordability, bargain, shelf life, appearance, taste, bulkiness, naturalness, price (cheap), origin and value for money (Antwi & Matsui, 2018). Local market women in Kumasi say customers mainly pay attention to a combination of perceived quality, size and price (appendix 5.1). If produce is bought for home consumption perceived quality and size are usually more important than price (entrepreneur in crop processing, 2024: appendix 5.2). This means that maintaining good quality of vegetables is an excellent way to maximize revenue for farmers and market women. The perceived quality is assessed based on how the vegetables look, so how much scratches, bruises and other damages are visible (consumer, 2024: appendix 5.1). This is also tied to another important factor for the consumer which is the perceived health benefit with regard to nutrients and contamination risks (ACHI coordinator in Ghana, 2024: appendix 1.5). Market women indicate that vegetables that usually get sold first are the undamaged, big-sized vegetables (market woman, 2024: appendix 5.1). The damaged vegetables, which are about 4 times cheaper, are usually bought by people who prepare food on the side of the road.

Customers usually perceive packaged vegetables (figure 20) as higher quality, more healthy vegetables because it shows that they went through several processes to get cleaned and sorted before packaging (ACHI coordinator in Ghana, 2024: appendix 1.5). Next to this, the products are usually traceable because of contact details, this allows for a check and also means farmers are prepared to meet vegetable quality standards if checks are performed (ACHI coordinator in Ghana, 2024: appendix 1.5).

2.4 Farm-to-consumer situations

There are several ways in which a vegetable grown by a commercial smallholder farmer can reach the consumer. In this section, three different situations applicable to Kumasi are explained: farm to local market, farm to supermarket and farm to consumer. These three situations are derived from the interviews and observations conducted in the local context. An overview of these situations is visible in figure 21. The processes and corresponding challenges are highlighted to get a good overview of where there is room for improvement and where the most impact can be made. Because of the design focus which is later explained in this report, the situation of farm to local market is highlighted in detail, while the other two situations are more generally discussed, their full explanation can be found in appendix 7.

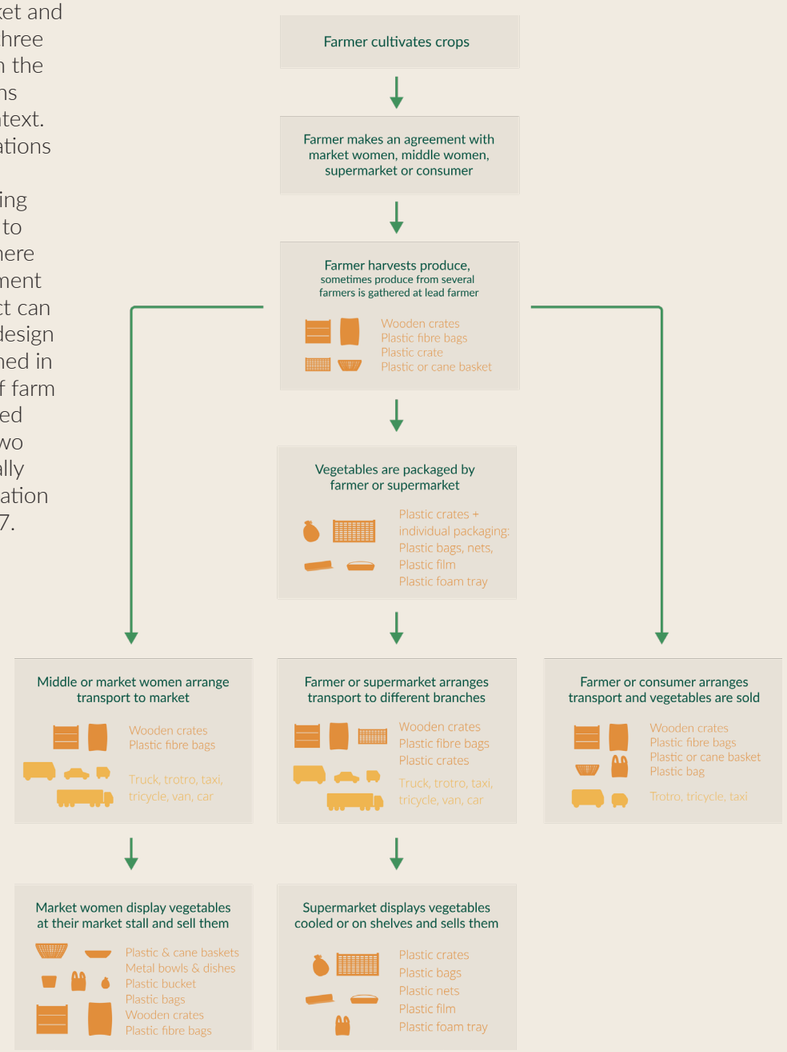


Figure 21 - Process from farm to consumer overview

2.4.1 Farm to local market

The first situation is by far the most common way for commercial smallholder farmers to sell their produce as well as for consumers to buy their produce. The reason for this is that it is the option that requires the least amount of effort, investment in resources and personal organization. The road from farm to local market is visible in figure 22.

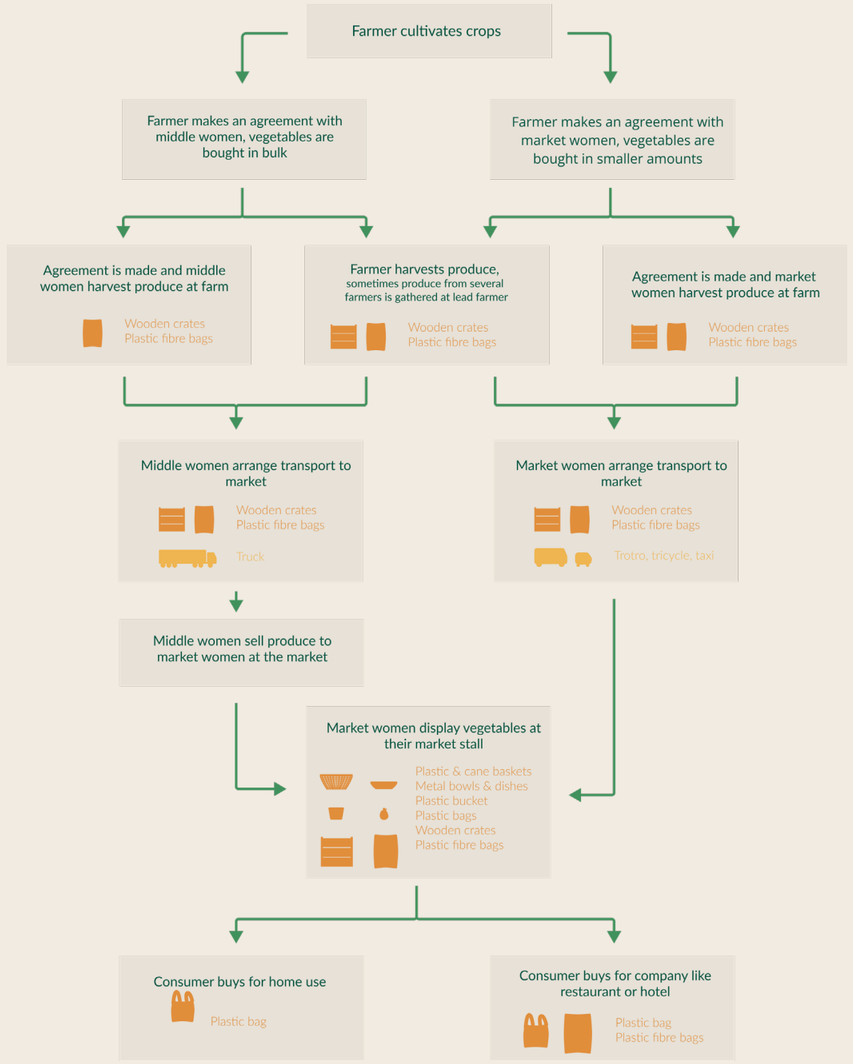


Figure 22 - Process from farm to local market

Figure 23 - Tomato crates carried from local market

Figure 24- Transport bag for green bell peppers with extension sown on

Agreement

The way it works is that the farmer will first make an agreement with either the market women or the middle women. In this case, market women are stall holders at the local market that sell vegetables to consumers. If they make an arrangement with the farmer it is usually about smaller quantities. Middle women are women who take on the role of traders. They buy vegetables in bulk from farmers and sell them at the market to market women. Depending on the agreement either the market women, middle women or farmers themself will take care of harvesting. Harvesting is preferably done in the morning or evening when it's dark and temperatures are lower to preserve them better (ACHI project manager Ghana, 2024: appendix 1.4). When the vegetables are harvested they are packaged in big plastic fibre bags of 150 by 75 cm or wooden crates of 70x70x70 cm for transport (figure 23, 24 & 25).

Figure 25 - Transport bag for carrots

Harvesting

Usually when smaller amounts of vegetables are sold, such as 1 to 5 bags or crates, market women will harvest it themselves since it does not take too much time (figure 26 & 27). The farmer and market women agree upon a price per bed that will be harvested and the farmer will receive the money the next time the market women come around to the farm after the produce is sold at the market. When vegetables are bought in larger amounts it is more common for the farmers to harvest the produce themselves and have it ready for pick up by the middle women/traders.

When farmers have enough produce to fill a truck they get a better price. Since many farmers cannot meet the numbers necessary to fill a whole truck on their own cooperation between farmers is crucial. In this case, smaller farmers bring their produce to a lead farmer with some storage space or a cooperation of smaller farmers brings their produce together for pickup (Director of horticulture company in the Netherlands, 2024: appendix 1.1). In these cases, a price is often paid per bag or crate. If farmers sort their produce prior to packaging it can increase their revenue. Bigger, better-looking vegetables can be sold for a higher price per bag than damaged vegetables (local farmer, 2024: appendix 4.1).

Sometimes it can also happen that market or middlewomen fail to come by the farm to pick up the produce for any reason. In case the farmer has already harvested, this means the produce usually deteriorates in quality very fast since many farmers don't have appropriate storage space available (local farmer, 2024: appendix 4.1).

Figure 26 - Farmer harvesting spring onions

Figure 27 - Market woman carrying harvested produce off the farm

Figure 28 - From left to right: taxi, trotro, tricycle

Figure 29 - Truck with empty tomato crates

Figure 30 - Bags of carrots being loaded from truck to tricycle

Transport

Transport is arranged by the market women and middle women based on the amount of produce and distance (market woman, 2024: appendix 5.1). The transport is done by private market players who are not involved in the farming or retail process with whom the market and middlewomen make arrangements. This means that for market women with smaller amounts, any transport that fits the load and is available is a good choice. Several forms of public transport such as a taxi, trotro or tricycle are used (figure 28). A trotro is a van in which many extra chairs are mounted that functions as a minibus and a tricycle is comparable to a tuktuk. If larger amounts need to be transported, transport goes by truck (figure 29).

The bags and crates are usually filled to the brim and the trucks are overloaded since transporting more produce means making more profit per drive (figure 30). The vegetables on the lower sections of the truck endure high amounts of pressure from the produce above and the poor condition of the road accounts for shocks and impact damage. Next to this, it is easy for heat to build up since there is little to no ventilation possible. When the trucks arrive at the market the market women will pick up the order they placed and take it to their stall. Some produce is also taken to stalls across the city by tricycle. Each market has a market queen that has the overview of a network of all stakeholders involved. She is the leader of the market who functions as a mediator and oversees prices and supply (Scheiterle & Birner, 2023).

Figure 31 - Market women at a local market

Figure 32 - Market stall in a large roofed market

Display at the market

Once the bags and crates are taken to the market stalls, produce will often be displayed on tables or transferred to other containers like sugar cane baskets, plastic baskets, metal bowls or plastic buckets (figure 31 & 32). First of all, this allows for more ventilation which maintains quality better and it also allows for better price determination per amount of vegetable. By dividing produce over smaller containers a price per unit can be determined in comparison to the whole bag, meaning the market woman can ensure she makes a profit in the end. Very occasionally you see plastic bags with vegetables displayed which are said to be organic. However, this is hard to check and market women say that often still pesticides are used. For market women, it is important to make an attractive display of their fruits and vegetables since high-quality appearance of vegetables is important for increasing sales.

Some women put lettuce in water to maintain freshness or display bananas on banana and palm leaves to minimize brown spots. Even though good efforts are made to maintain quality many vegetables show signs of damage from transport or being displayed in the open sun. Overall, tomatoes (figure 33), bell peppers and cabbages show the most damage.

Figure 33 - Damaged tomatoes at the local market

"When they see those bruises, they buy them at a lower price. But those fruits that have maintained its quality and everything, they buy at a higher price."

(local farmer, 2024: appendix 4.1)

Price

If a consumer wants to buy produce it is customary to first bargain over the price. Once a price is established the market woman will package the produce in a plastic bag and hand it over to the customer, as the orange one visible in figure 31. As mentioned before the price highly depends on the season and demand. When the vegetables are at their most expensive (April-June) they go for about double the price compared to the when they are the cheapest (July-November). Next to this, damaged vegetables sell for about ½ to ¼ of the price of a good-looking vegetable or are not sold at all and organic vegetables for 1.5 to 3 times the price of a normal vegetable.

Hospitality customers

Next to consumption for home use, restaurants and hotels also visit the local market for their supply of vegetables. To avoid spoilage and acquire high-quality vegetables the market is visited at the beginning of each day. This is a convenient way of supply for restaurants since is it cheap, there are always vegetables available which makes it reliable and you can buy the exact amount you need (Restaurant owner, 2024: appendix 6). In case restaurants buy larger amounts of vegetables they are packaged by market women in one of the plastic fibre bags used for transport. Next to this, people are selling homemade meals on the side of the road. These customers also buy vegetables at the market but more often go for the damaged vegetables. These are cheaper and since they process them into a meal it is less important how the vegetables look.

2.4.2 Farm to supermarket

Part of Ghana's vegetable retail happens in supermarkets. These are usually supermarket chains sourcing vegetables from medium to large-scale farms or from a network of small-scale farmers that can meet demands like supplying a wide variety of high-quality vegetables on a frequent basis (director of horticulture company in Ghana, 2024: appendix 1.2). This means that only commercial smallholder farmers who are organized can meet the demands of the supermarket. When supplying to a supermarket farmers have to take charge of a large part of the value chain. They harvest the produce, then take care of sorting, grading and cleaning and are often also asked to package the produce (figure 34). For the farmer this adds value since packaged vegetables can be sold for more money and it allows the farmer to establish a recognized brand, attracting more customers to the farm as well.

"So all we do is leave it on that balance. So when the season is in and you have it in abundance, it's an advantage for you. And when the season is on the low side, you have to balance it"

(farmer supplying the supermarket, 2024: appendix 4.3)

Packaging

When the vegetables are ready to leave the farm they are packaged in plastic fibre bags, wooden crates or more often plastic crates (figure 35) and transported to the supermarket firm by the farmer themselves. Since farmers do their own transport it pays to invest in plastic crates which would have the risk of getting lost or stolen when used for supplying the local market. They are expensive compared to wooden crates or bags but maintain the quality of vegetables way better (farmer in the Volta region, 2024: appendix 4.4).

Figure 34 - Packaged bell pepper by a farm employee

Figure 35 - Plastic crates used by a farmer supplying to the supermarket

Price

Farmers are paid monthly and receive a fixed price per kg of vegetable throughout the year. The farmer therefore needs to account for the varying prices as a result of demand and season themselves.

Overall, less damaged and more ripe vegetables have a higher price. Specific prices and packaging for the major vegetable crops in Ghana can be found in appendix 5.6. Supermarkets sell vegetables in packaged form to meet the needs of their target group. Customers visiting the supermarket often go for packaged vegetables rather than unpackaged ones. Supermarkets indicate that this is because packaged vegetables look more appealing and are perceived to be of higher quality (supermarket employee, 2024: appendix 5.4). All packaging observed in the supermarket was made of plastic. Most common are plastic bags and plastic film and also plastic foam trays and plastic nets are used (figure 36 & 37). All packaged vegetables look like they are of high quality. In some supermarkets domestic farmers are highlighted (figure 38).

Figure 36 - Differently packaged tomatoes at the supermarket in Kumasi

Figure 37 - Unpackaged vegetables at the supermarket in Kumasi

Figure 38 - Farmers highlighted at the supermarket

Figure 39 - Farm employee packaging green onions

Figure 40 - Transport by tricycle

2.4.3 Farm to consumer

Some farmers focus their business on selling directly to consumers. Often these are friends and family or a fixed customer base that is built up over the years. Such a direct link allows for farmers to receive a higher price than when selling to middle or market women but does ask for a little bit more effort in organizing sales.

Agreement & harvesting

When selling directly to consumers the farmer either calls their clients to see if they want to place an order or the client calls the farmer if they need something. When the agreement is made the farmer will harvest the produce and usually also sort and clean. After cleaning, the vegetables are packaged in plastic fibre bags (figure 39), wooden or plastic crates or plastic or sugar cane baskets.

Transport

To receive the vegetables the consumer either visits the farm or the farmer transports the produce to the consumer. If the consumer comes to the farm the farmer packages the order in a plastic bag. If the farmer has to take care of the transport the vegetables are either packaged in fibre bags, crates, baskets or small plastic bags depending on the order size. Transport is either done by car if the farmer has one or by public transport in the form of a taxi, trotro or tricycle (figure 40).

Take-aways from chapter 2

- The most grown vegetables in Ghana are tomatoes, onions, chillies, eggplants, bell peppers, cucumber, cabbage, lettuce and okra.
- Farmers in Ghana are usually dependent on rainfall for their yield. Vegetable prices and therefore income fluctuate over the year depending on the rainy and dry seasons. As a result of the difference in demand and supply because of the growing seasons, post-harvest loss also significantly differs per season.
- Post-harvest losses for major vegetable crops in Ghana roughly lie between 20% - 40%. With tomatoes experiencing the most losses.
- Post-harvest losses are caused by high temperatures, long time to reach the market, problems with market availability and poor handling, sanitation, packaging, transportation and storage. Packaging solutions have great potential in the short term since they are usually relatively simple solutions with low investment required.
- In Ghana 70% of the farmers are commercial smallholder farmers that supply to the local market.
- Consumers largely buy vegetables at the local market. They are looking for high-quality looking, big vegetables for a good price. These sell for a higher price, so maintaining quality of the vegetables increases revenue.
- The most customary way for farmers to sell their vegetables is to middlewomen (traders) or market women. They will arrange the transport to the local market in big bags or crates loaded on trucks or other vehicles resulting in high amounts of damage. When the vegetables are sold they are put in plastic bags.
- Farmers that sell their produce to the supermarket harvest the produce themselves, sort, grade and clean the produce. If requested by the supermarket produce is packaged in plastic bags. The farmer will then transport the produce to the supermarket. All packaging in the supermarket is made of plastic such as bags, films, nets and trays.
- Farmers who sell directly to consumers harvest, clean and sort the produce. They sell their produce in plastic bags.

03.

Packaging of vegetables

This chapter explains why fresh vegetables are packaged in general and what the options are for doing so. To explain the reason for packaging, first, the factors that are of influence on vegetable deterioration and the optimal conditions are lined out. Then the reasons to package and their corresponding benefits are described. After that different packaging practices for extending shelf life that are currently not adopted in Ghana are addressed accompanied by examples that show the potential of these practices. Lastly, the sustainability impact of packaging is taken into account.

3.1 Best-practice vegetable handling

Vegetables continue their living processes when they are harvested. The shelf-life they have after harvesting, therefore, depends on how fast they use up their food reserves and how much water they lose (FAO, n.d.). Vegetables are highly perishable and require good post-harvest handling to extend their shelf-life and maintain their quality. This includes measures to slow down physiological processes and minimise the risk of damage, microbial growth and contamination (Mahajan et al., 2014).

3.1.1 Vegetable deterioration

The processes that are of the highest influence on the quality deterioration and weight loss of vegetables are transpiration and respiration (Lufu et al., 2019). The transpiration rate of a vegetable is the extent to which it releases water and causes the vegetable to wilt, shrivel, lose crispness, firmness and succulence (Gast, 2001). Respiration is the process where oxygen and nutrients are used to produce energy, carbon dioxide and water (Horticulture Innovation Australia Limited, n.d.). These processes and therefore the quality deterioration of vegetables are influenced by temperature, humidity, airspeed, light, physical stress, the combination of gasses in the surrounding environment and the influence of microorganisms and plant enzymes (Adewoyin, 2023). The influence of these factors and what to take into account for best practice vegetable handling can be found on the right in figure 41 (Adewoyin, 2023; Deltatrak, n.d.; Gast, 2001; Horticulture Innovation Australia Limited, n.d.). The process of respiration itself also produces heat. This increases the temperature which further increases respiration and transpiration and with it quality deterioration (Horticulture Innovation Australia Limited, n.d.).

3.1.2 Optimal vegetable conditions

Each vegetable is different and therefore each vegetable has its optimum storing conditions (appendix 8). Overall, temperature and humidity, which are directly related to each other, are the storing conditions that are of the most influence. Most leafy greens such as cabbage and lettuce are stored optimally at around 0°C - 2°C with a relative humidity of 95% - 100%. For aubergines, chillies, cucumbers, okra, peppers and tomatoes a temperature of around 7°C - 12°C with a relative humidity of 90% - 95% is optimal for extended storage (Zainalabidin et al., 2019). For onions, an optimal temperature is 0°C - 2°C with a relative humidity of 65% - 70% (Tripathi & Lawande, 2019).

Temperature

Higher temperatures increase rates of transpiration & respiration immensely. E.g. A publication by the University of California states that for each increase of 10°C up to 30°C, respiration can increase 200% to 400%.

A well-cooled and ventilated environment reduces temperature.

Light

Different types of light and light intensities influence vegetable storage which is different for each vegetable. Overall sunlight causes increased water loss and sometimes sunburn.

Keep vegetables in a shaded area away from the sunlight.

Combination of gasses in the environment

Oxygen supports respiration and multiplication and living processes of microorganisms.

Oxygen can be controlled by O2 impermeable packaging such as wax coating & vacuum packaging, replacement of oxygen with nitrogen or packaging in tight plastic.

Physical stress

Damage and bruises as a results of impact and pressure increase transpiration and respiration rates, expending more energy and water. Damaged fruits are also more prone to contamination by microorganisms and mould.

Careful handling and sorting decrease the risk of damage. Minimizing compression and impact during all stages is of importance too.

Humidity

Most vegetables thrive at higher relative humidity since this decreases the rate of transpiration. E.g. In a room with 95% relative humidity leafy greens last 4 times longer than stored in a room with 80% relative humidity.

Using moisture barriers in packaging and storing and sprinkling water on vegetables.

Airspeed

A high air speed increases the rate of transpiration since water evaporates faster.

Keep the airspeed around stored vegetables low.

Microorganisms

Microorganisms can contaminate produce and feed off of stored energy. In unsanitary conditions chances of contamination increase.

Sanitary conditions, and sorting of decayed and damaged produce decrease risk of contamination. Also low temperature, low humidity and a combination of gasses can slow down the multiplication and living processes of microorganisms.

Plant enzymes

Enzymes accelerate physiological processes like ripening and respiration. Ethylene accumulation can cause rapid ripening in vegetables sensitive to it, though leafy vegetables are unaffected. Ethylene sensitivity is higher in some vegetables, especially tomatoes, and its production increases with maturity, physical stress, disease, and high temperatures.

Sorting damaged vegetables, maintaining a low temperature and ventilating well to avoid accumulation.

Figure 41 - Influence of factors on vegetable deterioration and what to take into account for best practice vegetable handling

3.2 Reasons for packaging

Packaging can have a range of functions that can help to determine whether or not to decide to use packaging and which packaging to use. The most important function of packaging fresh vegetables is to extend their shelf life (Packaging expert KIDV, 2024: appendix 1.6). How to do this adequately depends on the type of vegetable and many other factors. The optimal packaging solution is influenced by the produce in combination with the context and is therefore different for every situation (Packaging expert KIDV, 2024: appendix 1.6). For example, some vegetables can be packaged airtight while others rot faster because of condensation that can occur in closed packaging. Overall, the different functions of packaging can be (WUR, n.d.):

Maintaining product quality

Packaging can protect against factors that accelerate the deterioration of vegetables and therefore has the potential to extend their shelf life. Packaging can for example minimize moisture loss, protect against damage, divide pressure, provide a certain gas condition, block out light or enable ventilation.

Minimizing food-loss

Packaging can help minimize food losses by extending shelf life and maintaining product quality. Unfortunately, the packaging itself is not always sustainable. The impact on the environment strongly depends on the source of the material, the management after the use and the impact of the packaging versus food loss numbers.

Preventing contamination

Packaging can protect against the contamination of microorganisms. It can function as a barrier as well as slow down the living processes of microorganisms by providing certain gas conditions. It can also protect against other contaminations such as dirt or chemical substances.

Increasing sales

Packaging can function as a tool to generate more sales. Adding a logo, distinctive design or slogan can make a product more attractive and can help establish a recognizable brand.

Conveying information

Packaging can be a way of conveying information to the consumer such as name, origin, weight, price, expiry or packaging date, quality certification etc.

Facilitate convenience

Packaging offers products to consumers in an easy way. It bundles certain portions or contains produce that can be eaten straight away such as pre-cut vegetables.

3.3 Packaging practices for fresh vegetables

When looking at packaging practices for fresh vegetables several options can be of use for maintaining product quality and extending shelf life. Currently in Ghana, the most used ways of packaging are transport from farm to market in fibre sacks or wooden crates and packaging for the consumer in plastic bags, cling film or unpackaged. In this chapter several packaging opportunities are outlined to reduce post-harvest losses for vegetables that are not widely adopted in the Ghanaian fresh vegetable market at the moment. In appendix 9 a more thorough explanation can be found.

Packaging in plastic

To enhance shelf life optimizing the gas permeability of the packaging that is based on the oxygen transmission rate of the product inside can prevent spoilage. The packaging may contain tiny holes for more permeability or form a barrier that prevents permeability (Higgs, 2019). In a study, perforated and unperforated plastic and fabric packaging materials compared to no packaging for tomatoes were tested in a tropical climate. The longest shelf life was observed in perforated plastic (figure 42) packaging whereas the lowest, with a span of 7-8 days less, was observed when no packaging was used (Poudel et al., 2022).

Packaging in corrugated fibreboard or paper

Corrugated fibreboard (figure 43), also called cardboard, is a material often used in packaging for fresh vegetables. It has many benefits like its versatility, low cost and low weight. It is relatively strong but loses strength in high humidity. When moisture is absorbed it can lose strength by as much as 75% (TNAU, 2011). Therefore most corrugated fibreboard is treated with coatings to reduce this (Packaging expert KIDV, 2024: appendix 1.6).

Figure 42 - Eggplants packaged in perforated plastic, preventing condensation

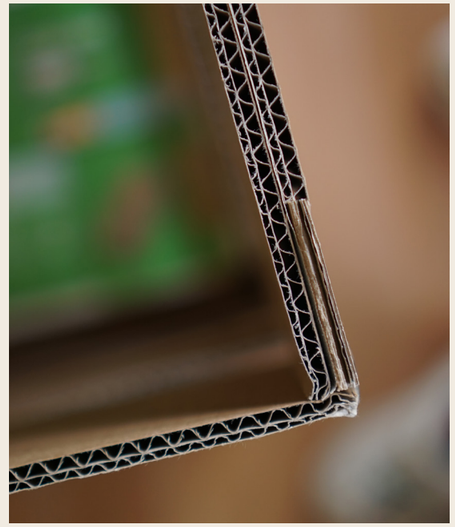


Figure 43 - Corrugated fibre board

Packaging with agricultural waste

An opportunity that has been tapped into more and more over the years is the use of agricultural waste, such as plant leaves to design bio-sourced packaging. An example of this is the company Banana Leaf Technology[4] which uses banana leaves to create biodegradable food containers (Banana Leaf Technology, 2024). Plant waste is used because of its biodegradability, low cost and abundance in some areas (figure 44). Some plant leaves can even have antimicrobial properties and the majority of leaves that are currently used to wrap foods (figure 45) have been proven to be non-toxic (Hounsou et al., 2022). In practice, there hasn't been any link observed between any health hazard and leaf-packaged foods (Vowotor et al., 2012). On top of that using locally grown materials as packaging can benefit the local supply chain and expertise and add revenue by reducing losses as well as using a raw material that is cheaper than synthetic material (Tapsoba et al., 2022).

Figure 44 - Plaintain trees next to the road

Figure 45 - Plaintain leaves used to wrap food in a Ghanaian household

[4] *https://bananaleaftechnology.com/*

Transport packaging solutions

Packaging liners are used to line a packaging container to prevent damage to the produce inside and can be made from a variety of materials (figure 46). Liners can function as protection against physical impact as well as form a moisture or microorganism barrier. A study conducted in Tamale, Ghana where liners made of several different materials for plastic and wooden tomato crates were field tested during transport shows that the use of any liner results in a reduced amount of damage compared to the control crates (Dari et al., 2017). A test performed in India with corrugated fibreboard liners for guava in plastic crates showed 12.5% fewer bruises in the fruits after transport (Kitinoja et al., 2012). Next to lining packaging containers, the material can also be added between layers of vegetables, creating separate layers with material for protection in between vegetables.

Figure 46 - Plastic packaging liner

Bundling in smaller quantities

Currently, vegetables in Ghana are transported in big sacks and crates where they suffer damage because of compression within the container as well as pressure as a result of stacking the containers. Bundling vegetables in smaller quantities (figure 47) can reduce compression or impact during transport. At KNUST in Ghana, half-sized sacks of the original sacks for cabbages were tested during transport. While the original sacks holding 70 kg of cabbage suffered 32% breakage and head-splitting, the smaller sacks containing 30 kg resulted in a reduced number of 23% (Kitinoja et al., 2012).

Figure 47 - Bundling spring onions in smaller bunches for consumers

3.4 Sustainability impact

The packaging of vegetables has sustainability benefits, but the packaging itself does have an impact on the environment. Given the state of the world and the more and more apparent consequences of climate change, it is important to weigh the positive and negative factors packaging has on the environment. Next to this, students at KAC are taught climate-smart agricultural practices so any education about packaging that is introduced should also consider the effects on the environment.

Overall, the resources put into growing vegetables are usually greater and have much higher inherent value than the resources used for their packaging. Therefore, post-harvest losses can sometimes pose a greater negative effect on the environment than when packaging is used to protect them (Manalili et al., 2014). Whether packaging is the more sustainable option or not is different for every situation since many factors need to be considered (Packaging expert KIDV, 2024: appendix 1.6). When assessing the sustainability of a product-packaging-context combination the whole lifecycle needs to be taken into account. Sourcing of the materials, the production, the distribution, the use-phase and the end-of-life need to be considerd. In general, packaging material usually has a short lifetime since it is used to contain other products after which it often loses its value. Therefore, it is extra important to take into account the sourcing and end-of-life phases. For material sourcing it is important to consider using recycled materials, bio-sourced materials and the amount of material used per weight of produce it contains (impact ratio) as well as the consequences of material choice on the production. For end-of-life, important factors are if it can be recycled, reused or if it is biodegradable. (KIDV, 2021).

Take-aways from chapter 3

- Vegetables continue their living processes after harvesting and are therefore highly perishable. Slowing down these living processes is the key to a longer shelf-life.
- Factors that influence living processes of vegetables and therefore the quality deterioration are temperature, humidity, airspeed, light, physical stress, the combination of gasses in the environment, microorganisms and plant enzymes.
- Temperature and humidity are the factors that are of the highest influence on shelf-life. Overall low temperature and high humidity are best for vegetables.
- The main reason for packaging is extending shelf-life next to maintaining product quality, minimizing food losses, preventing contamination, increasing sales, conveying information and facilitating convenience.
- There is a variety of current packaging practices that are not widely adopted in Ghana but could have potential. Options are:
  - Plastic packaging - Perforated plastic extends tomato shelf life by optimizing gas permeability.
  - Corrugated fibreboard - Cardboard is versatile but weakens in high humidity unless coated.
  - Agricultural waste packaging - Banana leaves and other plant waste offer biodegradable, cost-effective packaging with local benefits.
  - Transport packaging - Liners reduce produce damage during transport, showing fewer bruises.
  - Bundling - Smaller containers reduce vegetable damage compared to larger containers.

04.

Design direction

This chapter explains how the conducted research leads to the project direction and focus. It does so by listing the challenges with current packaging practices in Ghana and then outlining the opportunities and barriers. This leads to the choice of the most promising project focus and the list of requirements to come to a successful design solution.

4.1 Current packaging challenges in Ghana

From interviews with a wide variety of stakeholders, the challenges with current packaging practices in Ghana within the following three main themes are identified.

4.1.1 Transportation challenges

For the great majority of transport packaging big plastic fibre bags or wooden crates are used. The first challenge is the size. The bags and crates are large and contain way too many vegetables per container, causing compression damage. It is suggested that the produce per crate should not exceed a weight of 25 kg but tomato crates in Ghana contain at least more than twice as much (Naika et al., 2005). The most commonly used crates are;

- Large crate, 80x80x80 cm, 120kg of tomatoes
- Medium crate, 70x70x70 cm, 72 kg of tomatoes
- Small crate, 60x60x60 cm, 52 kg of tomatoes

On top of this transportation trucks are overloaded and because of stacking heights especially the vegetables in the bottom section of the trucks experience excessive compression (figure 48). Part of the roads are unpaved with many potholes and irregularities. As a result of this vegetables endure impact from shocks, vibrations and movement.

The bags and crates are not adapted to such transportation conditions. The inside of crates for example have sharp protrusions and a rough surface without padding or shock-absorbing material (figure 49).

During transport vegetables are also exposed to direct sunlight and dust sweeping up from the roads, increasing the risk of contamination. Lastly, the containers also do not allow for proper ventilation, causing heat to be trapped and preventing the aeration of gasses. Sun exposure, dust, trapped heat and insufficient ventilation are also problems during storage in plastic fibre bags and wooden crates.

Figure 48 - Truck in Ghana loaded with tomato crates (StatsGH, 2022)

Figure 49 - Crate with tomatoes & markings from owner of the crate

"So when the vegetables get to the market, they show bruises. It's not the same as when it's harvested on the farm. Depending on the type of vegetables, for garden eggs[5], pepper too."

(Local farmer, 2024: appendix 4.1)

Figure 50 - Vegetables packaged in plastic bags in the supermarket

4.1.2 Packaging material

Currently, packaging for individual or bunches of vegetables is done in plastic bags, films, nets or foam trays (figure 50, 51 & 52). In supermarkets, vegetables are prepackaged and completely sealed from the outside environment which is beneficial for preventing contamination, but also traps moisture and gasses as a result of respiration and transpiration of the vegetable, leading to condensation in the packaging and deterioration of the vegetables (supermarket employee, 2024: appendix 5.4). In local markets, vegetables are packaged in plastic bags when bought by the consumer. Most of this plastic unfortunately ends up on the ground.

Figure 51 - Bell peppers packaged individually in a supermarket

Figure 52 - Cucumbers packaged in plastic bags at local market

[5] *Type of eggplant grown in Africa*

Figure 53 - Packaging at a local market to determine a price per quantity

4.1.3 People & awareness

The majority of farmers in Ghana are unaware of the benefits proper packaging can have on vegetables for maintaining quality and extending shelf life. They see packaging as a hassle in which you have to invest time, money and effort while you can also sell vegetables if they are not packaged (Market woman, 2024: appendix 5.1). In cases where vegetables are properly packaged the reasons for choosing the specific packaging differ. Pre-packaging for retail such as in supermarkets is mainly done because it makes the vegetables more appealing and convenient to take. In this way, they can ask for more money for it and raise the value of the produce. In local markets pre-packaging is mostly done for organic vegetables to show they are of a higher value. In other cases, it is done to determine a value per unit to be sure to make a profit out of your supply (figure 53).

Another challenge is the price of proper packaging materials. Vegetables decay for example less fast in plastic crates since they contain smaller quantities and allow for better ventilation. Even though farmers might be aware of this they often do not have to capacity to invest in them. Additionally, the current system is not adapted to the use of plastic crates and they are harder to acquire, limiting their use to supermarket chains and personally organized farmers. The wooden crates and fibre bags however are cheap and widely available, which makes it a good choice for the majority of farmers.

"So it's more the people who are packaging do it more because their supplier kind of, when they want it. And not because it will keep the vegetables more fresh."

(Director of horticulture company in Ghana, 2024: appendix 1.2)

4.2 Opportunities for change

From a synthesis of the reasons for post-harvest loss, the current challenges around packaging in Ghana and optimal vegetable conditions several opportunities for change arise. Overall, some factors determine where introducing a packaging solution could make the most impact and would be most suitable in the current situation. From a combination of these factors and all conducted research, several feasible opportunities for the project are formulated.

Figure 54 - Damaged green bell peppers at the local market

4.2.1 Overall potential of packaging fresh vegetables in Ghana

When looking at the different vegetable crops that are grown and sold in Ghana there are a few that seem to experience more quality and quantity loss than others. Consistent with the online obtained post-harvest loss numbers tomatoes, bell peppers (figure 54) and cabbages show the most signs of damage. Both tomatoes and bell peppers easily lose water, making them highly perishable, the tomatoes even more than the bell peppers (Teacher post-harvest technology at KAC, 2024: appendix 1.7). They are both relatively fragile and deteriorate at even faster rates when the skin is punctured or bruised. A packaging solution for these vegetables could therefore have a greater impact than a solution for other vegetables. On top of this, these vegetables are priced higher per kilo compared to other vegetables (appendix 5.6). Making sure that these vegetables maintain their quality and sell for full price has therefore also the most impact on the profit made for them.

4.2.2 Potential for adoption

The potential for adoption of new packaging practices depends on several factors. The most important one is the target group. While non-organized farmers are not likely to take up new practices, the farmers who see farming as a business are on the other hand excited to see if new innovations can help them increase their revenue (Director of horticulture company in the Netherlands, 2024: appendix 1.1). These are the farmers that are partners of HGT as well as a new generation of farmers educated at KAC and other agricultural colleges connected to the ACHI project, which is also the target group of this project. Secondly, the adoption of a solution also depends on which solution would be introduced where. Solutions for retail packaging would be more suitable for supermarket supply while solutions for storage and transport could make more impact for local market supply (Teacher post-harvest technology at KAC, 2024: appendix 1.7).

Overall non-perishable objects in Ghana are used to their maximum extent during their life cycle since buying new objects costs money that people don't have. If an object breaks down it is often repaired or it is used for other purposes. You can see this all around, strings from plastic fibre bags are used to tie things together, packaging materials like meal boxes and egg containers are used at home for storing food (figure 55) and clothes are repaired rather than discarded. This means that the packaging solution could have a long lifespan if designed well and could serve other purposes apart from the intended one.

Figure 55 - Kitchen of a Ghanaian household with repurposed packaging materials

Figure 56 - A field at KAC, taken care of by students as part of the curriculum

4.2.3 Education at KAC

At Kwadaso Agricultural College a new generation of farmers are taught climate-smart modern practices through the regular curriculum and ACHI project (figure 56). The two departments mainly applicable to the topic of this project are the post-harvest technology department and the home science department. The post-harvest technology course is about the handling of vegetables pre and post-harvest to extend the shelf life and reduce post-harvest losses. It teaches when and how crops need to be harvested and which processes to go through after harvest such as cooling, sorting, grading, cleaning and packaging in bulk (Teachers post-harvest technology at KAC, 2024: appendix 1.7).

The home science department takes care of the education about options for processing crops into other food items and packaging. The processing of damaged crops into food products prevents post-harvest losses and can help increase profits. The current education about packaging revolves around packaging processed produce rather than fresh vegetables since this poses difficulties for shelf life with regards to moisture and ventilation (Teacher home science at KAC, 2024: appendix 1.7). They teach how to select a fitting packaging material that will extend the shelf life of the specific product inside. Next to this important information when labelling your food such as contact details, best before date and more is also addressed. The packaging solution of this project could therefore be an addition to further strengthen the KAC curriculum in both the post-harvest technology department and the home science department and would be a suitable example for a new generation of farmers.

4.3 Barriers and limitations

Several factors can have an influence on the effectiveness and introduction of a solution. Below the barriers and limitations deducted from the field research are lined out.

Responsibility in the chain

Responsibility for events happening in the chain can be a grey area in Ghana. A farmer can deliver their produce in a good state to the market women who will arrange transport after which it will arrive damaged at the market. Damages both to vegetables or crates are more seen as things that just happen rather than a responsibility. So the driver is not accountable for damages to vegetables during transport. In the end, the farmer will receive less revenue since damaged goods are sold for a lower price by the market women who pay the farmers.

Reaping the benefits of your own investment

Since the target group are farmers, they are the ones that will invest in the solution. They usually only get paid after market women have sold their produce. This means that while farmers make the investments that will maintain vegetable quality, they are dependent on the market women for how much revenue they make. This relationship is based on trust which can be a risk for the farmer. Will the farmer profit from the investment or the market women?

Investment vs. payout time

Whether people are willing to invest in a solution depends on the payout time, especially for farmers with a smaller budget. Actually, the smaller the budget the sooner they need to see the benefits since they don't have a buffer. Overall people do not have big amounts of money so the cheapest solutions with the fastest payout time have the most potential of getting adopted (figure 57). This will be further touched upon in chapter 7.4.

Figure 57 - Cut-open plastic fibre bags reused as packaging material for lettuce

Waste handling

In Ghanaian households, waste is separated into organic waste and non-organic waste. The organic waste is used as manure for growing crops for the household and the non-organic waste is burned next to the house. This also happens on the streets where for example waste is burned after a day of working. Next to this lots of plastic, mainly water containers, are discarded on the street and end up in the natural environment (figure 58). Ghana has been slow in adopting regulations to tackle plastic waste and the introduction of policies on the management of plastic waste will depend on the coordination between sector and government agencies (UNEP-LEAP, n.d.). Knowing that non-organic material will be burned or end up in nature at the end of the product's life, it is best for the environment that the packaging solution can be used many times before discarded or can be wasted organically.

Figure 58 - Ditch with waste at a farm

4.4 Focus of the project

From the problems around packaging, the opportunities for change and the barriers & limitations 4 promising focuses were derived and discussed with lecturers at KAC (appendix 10). Out of these directions, the people from the post-harvest technology department thought a transport solution would be the most promising since it can be a simple solution that fits directly in the current context and could have an impact on many people (Teacher post-harvest technology at KAC, 2024: appendix 1.7). Samuel, the project coordinator of ACHI in Ghana and lecturer in crop science at KAC, however, saw the most potential in the use of organic material or agricultural waste as a packaging material since it can sustainably fight post-harvest losses. Because both options have great potential for making an impact they were combined into using banana leaves as a packaging for tomatoes in Ghana. Initially, options for both retail and transport are explored but after transport solutions have proven to be more promising in effectiveness and potential for impact this direction is pursued. This in combination with the packaging practices in chapter 3.3, the packaging challenges in Ghana in chapter 4.1 and the opportunities for change in chapter 4.2 leads to the design focus of the project:

Using **banana leaves** as **transport packaging to local market** for **tomatoes in crates**

Figure 59 - Plantain plants next to a Ghanaian road

4.4.1 Banana leaves

Banana leaves are the leaves of the plant of the species Musa. Under this falls a variety of plants under which the banana and plantain plants. Plantains (Musa paradisiaca) are widely consumed in Ghana & in West-Africa Ghana is the biggest producer of plantain (Okoli, 2020). The plants grow in abundance in Ghana are therefore widely available (figure 59 & 60). Currently, Ghanaians are familiar with wrapping hot food in banana leaves but other use purposes are left unexplored. Given that the banana plant and leaf have been proven to be a versatile material for years in Asia this poses an untapped potential in Ghana. Few tests are done with banana leaves concerning transport packaging, but the ones that can be found pose promising results (Forero-Cabrera et al., 2017). Banana leaves can therefore be a cheap, biodegradable option to fight post-harvest losses.

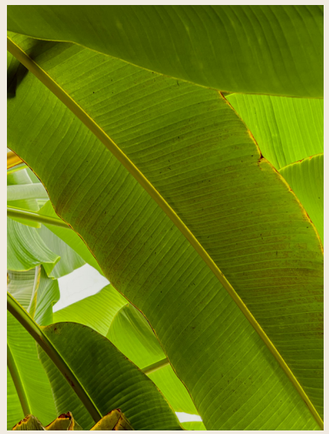


Figure 60 – Close-up of plantain leaves next to a Ghanaian road

Figure 61 - Transport truck in Ghana

4.4.2 Transport packaging to market

For commercial smallholder farmers selling vegetables through local markets is by far the most common way to sell vegetables, but it also has the biggest transport problem (figure 61). Post-harvest losses of tomatoes roughly lie around 35% and transport is one of the biggest causes of that, accounting for 20% of the loss (Bani et al., 2006). Because of the size of this problem, a solution can have a big impact. Next to this, it is a problem that people are motivated to tackle. Farmers and market women make more money for good-looking, undamaged vegetables and customers mostly look at appearance when buying them.

Since most of the farmers supplying the local markets have smaller budgets the solution needs to be cheap and simple in order to be feasible (Teacher post-harvest technology at KAC, 2024: appendix 1.7). A more simple, cheap solution that is easy to implement in the current system also has great potential because it can immediately mitigate the effects of bigger problems in the transport chain that take more time to solve such as the lack of good road infrastructure or cooled transport. Effective transport packaging can extend shelf life and maintain product quality by mitigating the effects of shocks, vibrations and movement.

4.4.3 Tomato in crates

A packaging solution for tomatoes likely has a greater impact than a solution for other vegetables. In Ghana tomato is the vegetable that is most grown (Mordor Intelligence, 2024b), the most eaten (Van Asselt et al., 2018) and experiences one of the highest post-harvest loss rates (Wongaa et al., 2023) (see table 3 in chapter 2.2). Tomatoes lose water easily (Teacher post-harvest technology at KAC, 2024: appendix 1.7) and are relatively fragile and soft, making them highly perishable (figure 62) and in higher need of adequate protection (Esguerra et al., 2018).

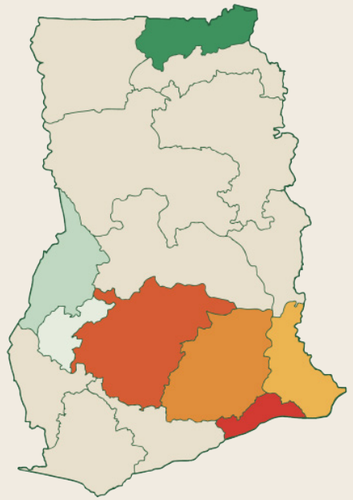
Current packaging for transport in large wooden crates does not protect the tomatoes well at all. The crates are packed to the brim causing the tomatoes at the bottom of the crates to be crushed because of the pressure of the produce above. The inside surface of the crates is rough, causing punctures and scratches and proper ventilation is not possible causing a build-up of heat. The reason these crates are used is because they are sturdy and cheap. Adding a solution to the existing crates allows farmers to fight post-harvest losses without the need for higher investment in new crates and having to discard the crates they already invested in.

Tomatoes are primarily grown in the central regions (figure 63) (Claussen et al., 2024), where about 11,728 farmers are involved in tomato production (Aklama, 2022). They are relatively hard to grow because of the humid climate, especially in the area just mentioned (Director of horticulture company in the Netherlands, 2024: appendix 1.1). This means that tomatoes sell for a high price per kilo compared to other vegetables (appendix 5.6). So, per tomato that maintains quality and is sold for full price a relatively higher impact on profits can be made.

4.4.4 Approach on the focus

To develop a suitable solution for the design focus, first a set of requirements is formulated, visible in the following chapter. It is then crucial to first explore the material boundaries of the leaves in order to asses what the possibilities are with the material and how to treat it. This is described in chapter 5. With the requirements and material boundaries, ideas and concepts can be created and evaluated. Through the process of rapid prototyping these ideas and concepts, design choices are made and functions of the design are further developed which is described in chapter 6. The final design that follows out of this process is described and evaluated in chapter 7.

Figure 62 - Tomatoes at local market



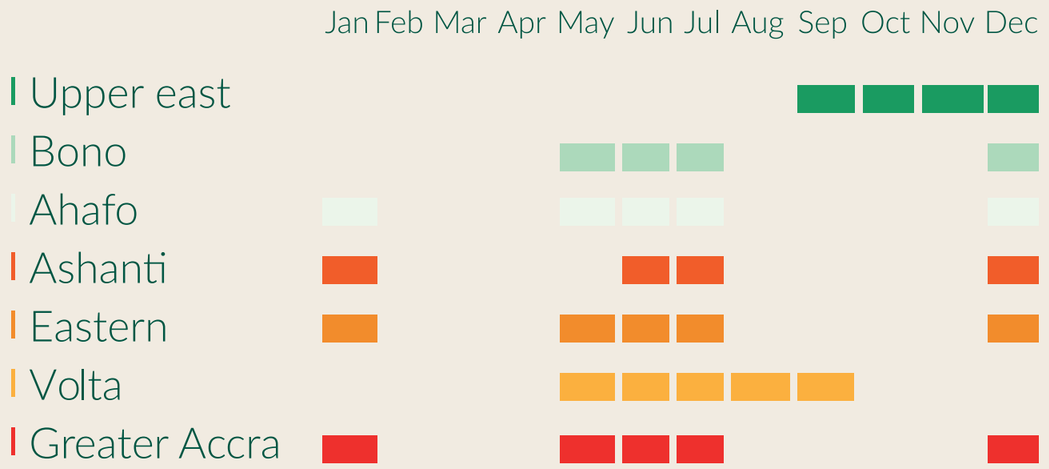


Figure 63 – Primary growing regions and seasons for tomato in Ghana (Claussen et al., 2024)

4.5 List of requirements

In order for the solution to be successful it needs to meet a set of demands. These demands are derived from field research in Ghana as well as online research included in chapters 2 and 3. Next to this, a set of wishes includes factors that can maximize the impact of the solution. For both the demands and wishes there are 3 categories. Functionality is about the effectiveness of the solution in reducing post-harvest losses. Acceptance focuses on the likeliness of the target group to implement and invest in the solution. Lastly, production makes sure that the packaging solution and tool can be produced locally, therefore being accessible to farmers. The reasoning behind the demands and wishes can be found in appendix 11.

Demands transport to local market

Functionality

1. The packaging solution reduces quantity loss (currently at 33%, (Wongnaa et al., 2023)) of tomatoes, measured in weight in kg, by 10%.
2. The packaging solution reduces quality loss (bruises, breakage of the skin, rotting, currently at 55% damage (Dari et al., 2017)) of tomatoes as a result of shock, vibration, compression, scratches and punctures by 15%.
3. The packaging solution allows for ventilation (it is not fully closed).
4. The packaging solution lasts at least 6 days in normal use conditions.
5. With the packaging solution the tomato crates used in Ghana for transport can contain a minimum of 90% of the amount of tomatoes compared to the current amount.

Acceptance

1. 75% of commercial smallholder farmers and market women in the Kumasi area accept the use of banana leaves as a packaging material for transport.
2. The packaging solution should be acceptable to use for 75% of commercial smallholder farmers in the Kumasi area.
3. The investment in the packaging solution and packaging tool pays out within 2 months.
4. Packaging should not take more than 3 minutes extra per medium-sized crate (70x70x70 cm).

Production

1. The farmer can use & produce the packaging solution themselves.
2. Building instructions for the packaging solution & packaging tool are available for farmers to enable reproduction.
3. The materials for the packaging solution & packaging tool can be obtained in Ghana.
4. The farmer can get the packaging tool produced locally.

Wishes transport to local market

Functionality

1. The packaging solution reduces quantity loss, measured in weight in kg, as much as possible.
2. The packaging solution reduces quality loss as a result of shock, vibration, compression, scratches and punctures as much as possible.
3. The packaging solution is applicable to as many people as possible.
4. The packaging solution reduces the temperature of the tomato during transport compared to the current situation.
5. The packaging solution protects the tomatoes from dust during transport.
6. The packaging solution protects the tomatoes against contamination with microorganisms.
7. The packaging solution lasts as long as possible.

Acceptance

1. The packaging solution pays out as fast as possible.
2. The packaging solution requires as little investment as possible.
3. Packaging should be as fast as possible.
4. Packaging should be as easy as possible.
5. The packaging solution is reusable for the same or other purposes.
6. All commercial smallholder farmers and market women in the Kumasi area accept the use of banana leaves as a packaging material for transport.

Production

1. The farmer can produce the packaging tool themselves.
2. The materials for the packaging solution & packaging tool are obtained within a radius of 10 km of Kumasi.
3. The solution is reproducible for farmers in other low or middle-income countries.

Transport truck in Ghana

Take aways from chapter 4

- Main challenges around current packaging practices in Ghana revolve around three themes:
    - Transport packaging practices are not effective in maintaining product quality and are not adapted to transport conditions, resulting in high amounts of damage.
    - Current packaging material is only partly effective in extending shelf-life and only plastic is used which usually ends up in the environment.
    - Most people are unaware of the benefits that effective packaging can have on extending shelf-life and maintaining product quality. Existing effective packaging solutions are usually also very expensive for the general farmer.

- Overall, the most fragile and most damaged vegetables are tomatoes and bell peppers. Since losses are higher more impact can be made here. Tomatoes and bell peppers are on the more expensive side compared to other vegetables, this means relatively more revenue can be increased if fewer vegetables are lost.

- The potential for adoption of a packaging solution is higher when the benefits of investment are seen as soon as possible. Next to this, organized farmers with some investment capacity are likely to adopt new innovations.

- Barriers to the adoption of packaging practices are lack of clarity around responsibility in the value chain, risks around who will benefit from the made investment, low investment capacity of farmers, and improper waste management of inorganic materials.

- The focus of the project with the most potential is: Using banana leaves as transport packaging to local market for tomatoes in crates. The first reason for this is that banana leaves are a cheap material widely available in Ghana that has the potential to be used for packaging purposes. Secondly, inadequate transport packaging is one of the biggest reasons for post-harvest loss. Farmers are motivated to tackle this but for the solution to be feasible it needs to be cheap and simple. Lastly, tomato is the most grown, eaten and lost vegetable in Ghana. Current packaging in crates offers insufficient protection, but introducing a solution to add to these crates could have a great impact on fighting post-harvest loss without the need for farmers to invest in new crates.

05.

Using leaves as packaging

Banana or plantain leaves aren’t a very familiar material to work with for many people. This chapter will therefore first give a brief introduction to the banana plant and leaves and their potential as a packaging material. After this, the perception of the banana leaf from the farmers’ and consumers’ point of view is discussed. The chapter closes with a guide on how to handle and process the banana leaf if it is used as a packaging material for tomatoes.

5.1 The banana plant

Bananas and plantains fall under the Musa species of which plantains are found the most in Ghana. In this report 'banana leaves' is used as an umbrella term for plantain and banana leaves. They are herbaceous plants growing in tropical climates that die after producing one flower cluster out of which the fruits grow (Okoli, 2020). It is hard to name the specific cultivars growing in Ghana since little information about this is available, but they fall under the Musa x paradisiaca L. species as most bananas and plantains do (Karikari & Abakah-Gyenin, 1976). In West Africa Ghana is the largest producer of plantain (Okoli, 2020). The plants are usually grown for their fruits and are cut down after harvesting since the plant only produces fruits once. In most African countries the stems and leaves are discarded as waste and either left on the ground or burned. When the material naturally decomposes it is beneficial for the soil and also produces greenhouse gases, just as when they are burned. It is estimated that approximately 4 tons of biomass is produced for every ton of fruit that is harvested (Okoli, 2020). Here lies an opportunity since processing this material into other products has existed for years and has been utilised in Asian countries for a long time.

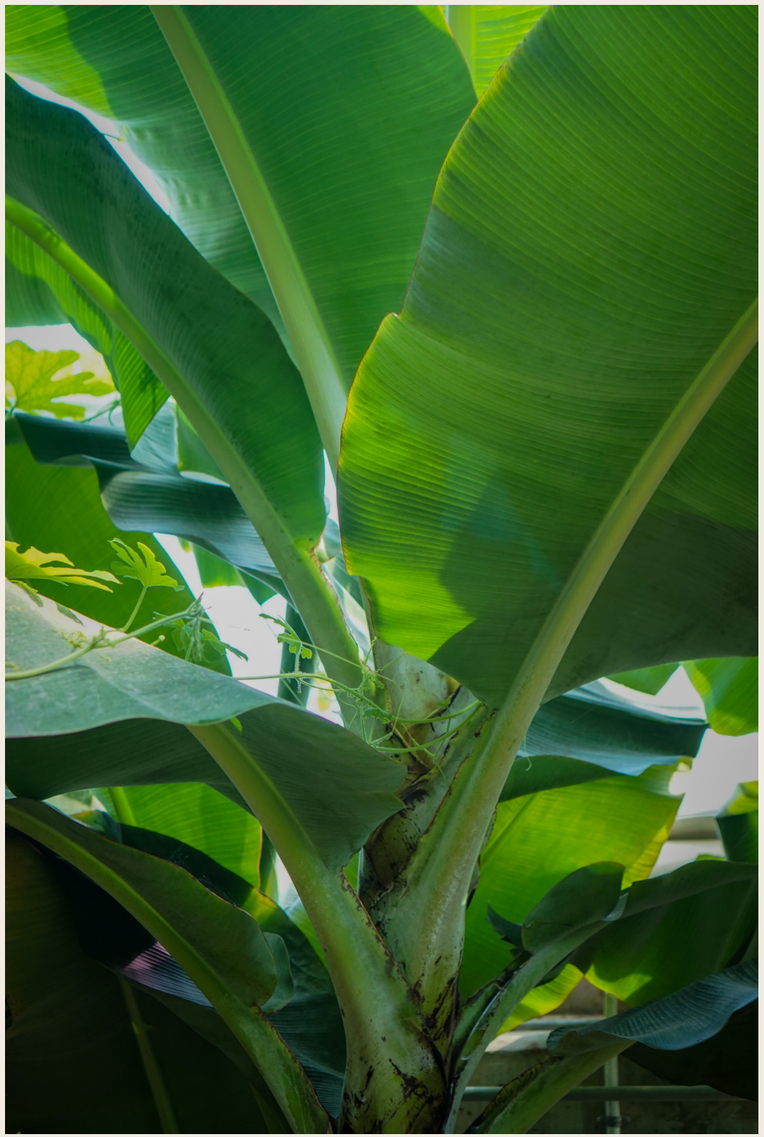
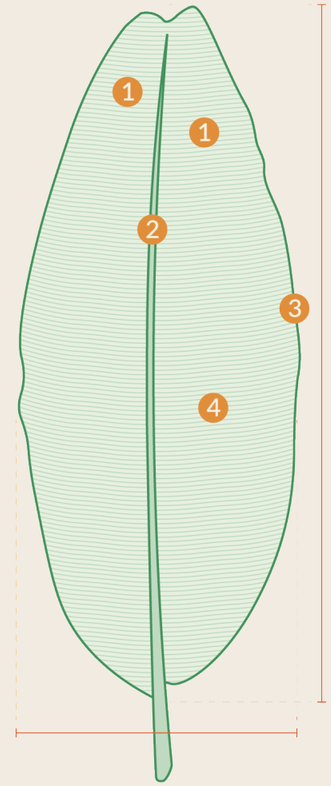


Figure 64 - Banana plant stem with leaves emerging from leaf sheaths.

Morphology

Banana plants grow quickly, reaching their full height of about 9 meters in only 9 months and mature and fruit somewhere from 12 to 18 months depending on the conditions (Valmayor & Wagih, 1996). After about 7 to 8 months the plant has approximately produced 30 leaves (FAO, n.d.-a) and keeps 10 to 15 functioning leaves (Karamura et al., 2011). About every 7-10 days a new leaf emerges from its leaf sheath (figure 64), this is influenced by the conditions where more leaves are produced in wet seasons than in the dry seasons (Karamura et al., 2011). The leaf consists of the leaf blade which is divided into two halves by the midrib (figure 65). The veins emerge from the midrib and run parallel to each other to the margin without branching, making the leaf easy to rip (Vézina, 2020). They are large oblong leaves ranging from 150 to 400 cm in length and 70 to 100 cm in width (Valmayor & Wagih, 1996). Since plantain plants have a slightly smaller leaf area (Karamura et al., 2011) the size of the plantain leaf ranges from about 150 to 275 cm in length and 70 to 85 cm in width.



1 Leaf blades
2 Midrib
3 Margin
4 Veins

Leaf length
Banana 150-400 cm
Plantain 150-275 cm

Leaf width
Banana 70-100 cm
Plantain 70-85 cm

Figure 65 – Morphology of the banana leaf

Banana leaves are relatively cheap, biodegradable, non-toxic and show antibacterial and antifungal activity (Mostafa, 2021). Meaning they are safe and can help preserve food for longer which is great for packaging applications. Banana leaves are known to be used for the handling and transport of bananas, where they protect the fruits against damage (Al-Dairi et al., 2023), but are not found to be used for other fruits or vegetables except for in one research paper. In this research, banana leaves were used to protect lulo fruits during a storage and mechanical damage test. Here the banana leaves proved to be effective in reducing damage as compared to no packaging (Forero-Cabrera et al., 2017).

5.2 Perception of banana leaves in Ghana

Banana leaves have been used for centuries in Ghana to wrap hot food (figure 66). It is, therefore, a familiar material to many Ghanaians, however, they are not familiar with the use of banana leaves as a packaging for other foods such as tomatoes. Therefore, it is important to consider the perception people in Ghana have of banana leaves in general and their use as a packaging material for fresh vegetables.

The perception of Ghanaians towards using banana leaves in traditional ways for ready-to-eat meals is positive. In a study conducted in Ghana, 87% of consumers rejected the idea of using a different packaging material for ready-to-eat cornmeals than the currently used banana leaves (Mensah et al., 2012). Additionally, Ghanaians seem to respond positively towards adopting reinvented versions of traditional packaging such as leaves since they consider them to be safe, harmless and less costly (Boateng et al., 2022).

" Banana leaves have been used to safely package 'fante kenkey' for centuries. It has potential to be used for other products too."

Figure 66 - Food wrapped in banana leaf at Ghanaian household

5.2.1 Questionnaire

To find out their general perception of the leaves (figure 67) and their use for packaging fresh vegetables a questionnaire is conducted amongst Ghanaian farmers and consumers.
First, questions are answered about the material in general and afterwards, a different set of questions is presented to farmers and consumers.
Overall, 12 people participated in the questionnaire of which 5 farmers and 7 consumers.
With this limited sample size considered when interpreting the results the most important results are highlighted in this chapter. The questions, results and discussion can be found in appendix 12.

5.2.2 Overall perception

Overall, both farmers and consumers perceive the banana leaf as a material that is healthy, of good quality and cheap. 40% of respondents rate banana leaves as a high-quality material and 90 % of respondents rate banana leaves as neutral or higher on quality of the material. Overall farmers rate the banana leaves slightly higher in perceived quality. They see the benefits it could have as a packaging material and recognize the use of it in their environment for other purposes. At the same time, some questions remain about the application of this material for packaging fresh vegetables.

5.2.3 Perception of farmers

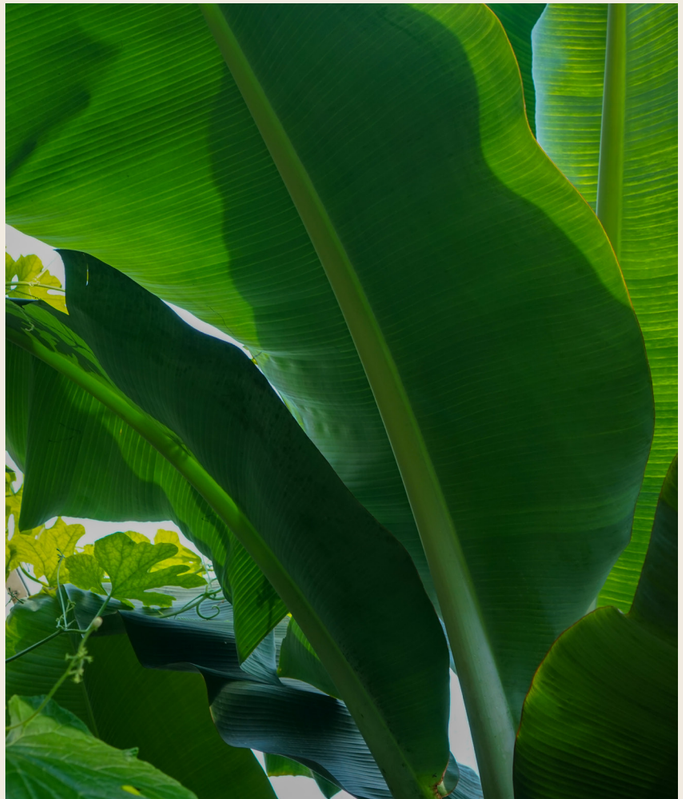
All farmers participating in the questionnaire stated they would use banana leaves as a packaging material if it helps to reduce damage to their produce. Of course their actual willingness to adopt would likely depend on additional factors such as the time, resources, and effort required, which need further evaluation in future designs. The reason that they would want to use the leaves is that they see it as a biodegradable, natural option that can help preserve the freshness of vegetables and could even be medicinal.

The reason that it is currently not happening is the fact that the farmers currently do not know any innovative solutions and do not know how to process the leaves to use them as packaging material. If they would use them 60% of the farmers would get the leaves from their own farm and the other would get it locally from other farms for free or at a very low cost.

" I think banana leaves are organic and if used as a packaging material would help protect the environment from the pollution of plastic wastes."

"(I would use the leaves) Due to their antioxidant and antimicrobial activities, which help preserve freshness and protect against spoilage microorganisms."

Figure 67 - Banana leaf with midrib



"I have little knowledge on how to process the leave as a packaging materials."

5.2.4 Perception of consumers

All consumers get at least a part of their vegetables at the local market, and 40% also gets their vegetables from other places such as the supermarket or directly from a farm. When buying vegetables the following factors, stated in order of most importance are:

"Because banana leaves are organic and biodegradable which will intend protect the environment but the banana package should be made well to prevent the spill off of vegetables due to tear."

1. Appearance (damages)
2. Health benefits (nutrients)
3. Safety (pesticide use, contamination)
4. Price
5. Size & weight

This is in line with the fact that undamaged vegetables are usually sold first and also are worth the most. Additionally, freshness, storage/display and the source are also paid attention to. 85% of the consumers say they would buy vegetables packaged in banana leaves. Mainly because it will minimize plastic waste, is environmentally friendly and could have health benefits. Again the willingness to buy vegetables in reality would also depend on the specific design of the packaging.

"It's safer to consume and it's environmentally friendly."

Figure 68 - Banana plant in a greenhouse in the Netherlands

5.3 Handling the banana leaf

Online using the banana leaf is mainly discussed for medicinal purposes and wrapping or preparing hot food. Research and information on working with the leaves for other purposes are hard to find. Therefore, to get familiar with the leaf as a material in general, a series of material exploration tests are performed which can be found in appendix 13. The banana leaves are obtained from several organisations in the Netherlands (figure 68): TU Delft Hortus Botanicus, Utrecht University Botanic Gardens, Neder Banaan and Avifauna.

5.3.1 Leaf veins

The first feature of the banana leaf that is crucial to consider is the veins (figure 69). The veins do not branch, making the leaf easy to rip along the vein direction (figure 70) whether dried or fresh but hard to rip when tearing the leaf perpendicular to the veins. Similarly, when stretching the leaf parallel to the veins it is very strong and when stretching perpendicular to the veins the leaf rips easily (appendix 13.4). Dried leaves seem to have greater tensile strength than fresh leaves in both directions. Folding the leaf has different results for dried or fresh leaves. While both fresh and dried leaves remain intact when folded along the veins, the dried leaves break when folded perpendicular to the veins as opposed to the fresh leaf (figure 71) (appendix 13.4).

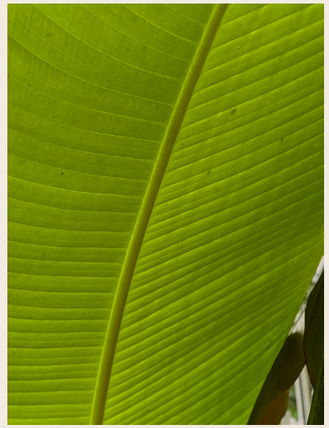


Figure 69 - Veins on the bottom of the banana leaf

Figure 70 - Ripped, unbranched vein in banana leaf

Figure 71 - Folding crease in fresh banana leaf

Figure 72 - Shrinkage in leaf after drying

5.3.2 Applying heat

When the leaf is heated it becomes more flexible, making it easier to work with and less prone to breaking and tearing, also after drying (appendix 13.3). Next to this, heating the leaf sterilizes the material before use. Therefore, leaves always need to undergo a form of heat treatment before use. There are multiple ways of effectively heating the leaves such as holding the leaf over an open flame for 30 seconds, placing the leaf in an 80°C oven for 3 minutes or boiling the leaf for about a minute. Out of these three options heating the leaf in the oven is the most effective, however, not all Ghanaians have access to an oven. Both holding the leaf over a flame and boiling are feasible for the majority of the people in Ghana, however, boiling will give nicer results since discolouration can occur with the flame.

5.3.3 Shrinking during drying

While fresh leaves are flexible, dried leaves become more rigid. During drying the leaf shrinks, mostly in the direction perpendicular to the veins (figure 72) (appendix 13.6). Varying the ways of drying gives different outcomes and can have an influence on the shrinkage (appendix 13.7). If you just leave the leaf out to dry on its own some form of crumpling occurs, however drying under a flat weight or using forced drying can make the leaf dry fully flat. In the last two cases there must be a way for moisture to escape, otherwise drying can take a long time.

5.3.4 Storing the leaves

Ideally, it is best to use the leaves directly after harvesting, but if necessary, the leaves can be stored before use. By far the best way to store them is in the fridge, rolled up in a kitchen towel or something else that absorbs moisture and put in a plastic bag. Best is to do this before applying the pre-treatment described below but do quickly clean the leaves with a weg cloth to remove dirt. This keeps the leaves good for at least 6 weeks. Since not all Ghanaians have a fridge other options for storing are placing the leaves in room temperature water or storing them in an airtight environment for up to a week.

5.3.5 Pre-treatment of the leaf

Before using the leaf it needs a pre-treatment. The pre-treatment used in the project for all the leaves for prototyping is highlighted here in figure 73 and stems from the conclusions of the material tests. This treatment is deemed most suitable for the farmers in Ghana since the tools and resources that are necessary are available in the average Ghanaian households and do not require high investments or efforts.

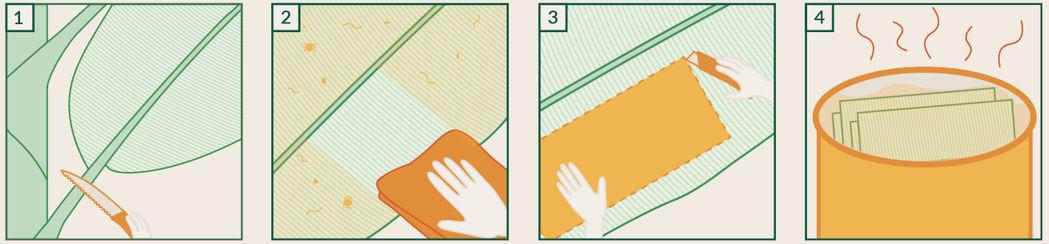


Figure 73 – Pre-treatment of the leaves

5.3.6 Duration

Depending on the size of the crate a certain amount of leaves are necessary. On the right an estimation is made for the time it will take to apply pre-treatment to leaves necessary to produce the solution for 10 medium-sized crates (table 4). For 10 crates 80 sheets are necessary, made of approximately 160 leaves. For the same amount of sheets, it will either take slightly more or less time depending on the crate size. Additionally, the more leaves are prepared at once the faster the process goes.

Activity	Duration
Harvesting the leaves	60 minutes
Cleaning the leaf blades with a rag	80 minutes
Cutting the leaf blades in the right size	40 minutes
Boiling the leaf pieces	60 minutes
Total time pre-treatment for 80 sheets	4 hours
Total time pre-treatment for 1 sheet	3 minutes
Total time pre-treatment for 1 leaf	1.5 minutes

Table 4 – Duration to treat leaves.

Take-aways from chapter 5

- Bananas and plantains fall under the Musa species of which plantains are found the most in Ghana with the largest production in West Africa Ghana (Okoli, 2020). The plants are usually grown for their fruits and are cut down after harvesting since the plant only produces fruits once. Plants are either left to naturally decompose or are discarded and burned, both producing greenhouse gasses. Here lies an opprtunity to utilise this material.

- Banana & plantain plants reach their full height in about 9 months. When mature they produce a new leaf every 7-10 days. The plaintain leaf is about 150-275 cm long and 70-85 cm wide.

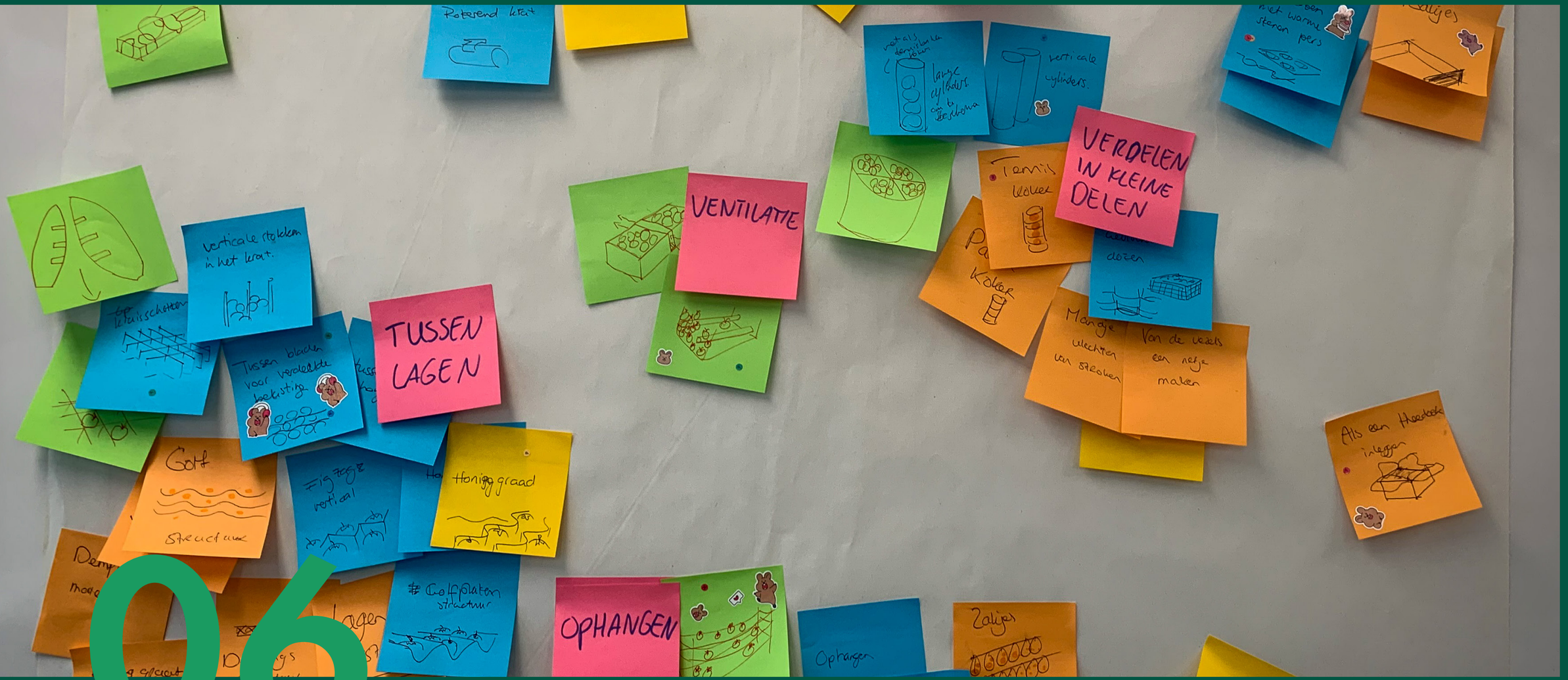
- Banana leaves are cheap, biodegradable, non-toxic and show antibacterial and antifungal activity, meaning they can help preserve food

- A questionnaire is conducted amongst Ghanaian farmers and consumers to find out the general perception of banana leaves and their use for packaging fresh vegetables. All respondents perceive the leaves as healthy, cheap and of good quality and see benefits it could have for the environment although some questions remain.

- All farmers state they would want to use the leaves if it reduces post-harvest loss because they see it as a biodegradable, natural option that can help preserve the freshness of vegetables and could even be medicinal. They are currently not doing it because they do not know any innovative solutions and do not know how to process the leaves to use them as packaging material.

- Research and information on working with banana leaves are hard to find. Therefore, a series of material exploration tests are performed. Important is that:
  - Due to the unbranched veins leaves are prone to ripping.
  - The veins also affect the tensile strength and ability to fold which is different for dried and fresh leaves.
  - To make it easier to work with the leaf heat is applied which also sterilizes the leaf. This is included in the pre-treatment necessary before using the leaf.

- The pre-treatment deemed most suitable for farmers includes cutting the leaf from the plant, cleaning the dirt and insects off with a rag, cutting the leaf to the desired size, boiling the leaf pieces for 1 minute and letting them dry. This treatment is most suitable because it requires minimal amount of cheap tools and resources which are available in an average Ghanaian household.



06.

Designing the solution

This chapter will explain the process and design choices by which the final design emerges. This process consists of four phases: the ideation phase, the iterate & explore phase, the concept optimization phase and the final design phase. First the process is described in general and then the design choices per phase are covered.

6.1 The process

The process of coming to the final design consists of several phases, visible in figure 74 and starts with the ideation phase. This phase, fueled by the literature and field research, is focused on creating ideas and evaluating their feasibility. Ideas that emerged during my own ideation and creative sessions with others are clustered and evaluated with the requirements and material boundaries. This results in 10 ideas that are iterated upon through rapid prototyping in the second phase. At the end of this phase all insights are brought together into 1 concept to continue with. The array of design choices that emerge from the all prototypes are reflected in the design concept. The third phase focuses on the optimization of the design concept. The concept is further developed on several factors which leads to the final design. The fourth phase consists detailing, explaining and validating the final design with stakeholders. The results of the validation are used to write recommendations and propose an implementation plan. The fourth phase is described in chapters 7 & 8.

After making the choice to focus on using banana leaves as a packaging material, initially, both retail in the supermarket and transport to local market were explored. For both a set of demands and wishes was developed to select and evaluate concepts with, these can be found in appendix 11. The list of requirements for transport to local market, under which the solution falls can be found in chapter 4.5.

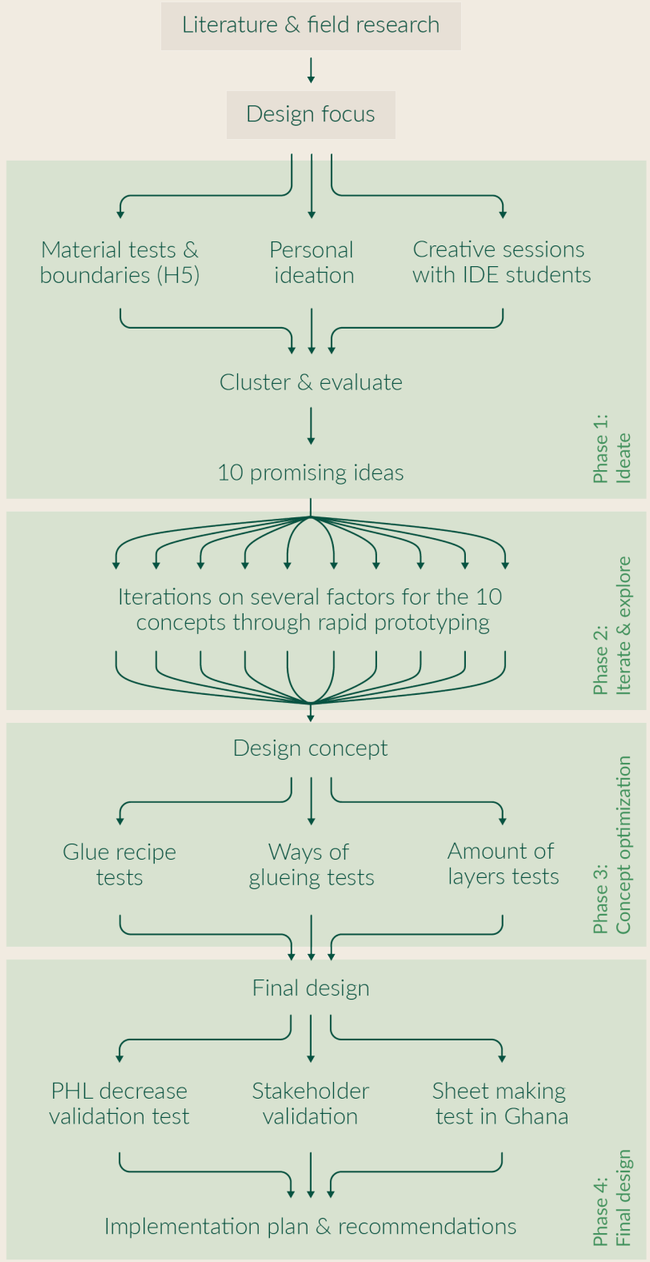


Figure 74 – Design process overview

6.2 Phase 1: Ideate

This phase describes the process of creating and selecting ideas to develop. First the method for the ideation and the several ideation rounds are explained. Then the clustering and selecting of ideas is covered.

6.2.1 Methods

Throughout the project, several rounds of ideation are completed. The first round consisted of ideas that were noted down during the literature and field research to not forget them later on in the process. In the second round, factors from the post-harvest loss cause in chapter 2.2 and the optimal vegetable conditions in chapter 3.1 were formulated as how-to's. The design has to comply with at least a part of these factors. The following factors were used (figure 75). How to:

- Avoid damage
- Ventilate
- Cool down
- Protect from compression
- Protect from impact
- Protect from contamination
- Protect from rough and sharp things
- Contain

The results of these how to's were used to create ideas with the material boundaries and requirements as a guide of what criteria to meet. The third round of ideation is done in the form of creative sessions with other IDE students, explained in the next paragraph. The fourth round of ideation was done by building further on the ideas that emerged from the creative session. The new look on the design problem inspired new and combined ideas.

Figure 75 – How to's

Figure 76 - Ideation in the first creative session

Figure 77 - Problem finding in the second creative session

Figure 78 - Prototyping in the first creative session

6.2.2 Creative sessions

Since I have been fully emerged in the project there might be options or ideas I haven't thought of or have already discarded. For this reason, two creative sessions were organized to get fresh, unbiased ideas (appendix 14.1). The sessions were conducted with IDE students since they are experienced in ideation and creativity techniques. One ideation group consisted of people who have no experience with the African context. The other group has experience with working in low to middle-income countries with one participant that did a project in Ghana specifically. Together the groups offer a wider view on the matter where different ideas emerged.

The session consisted of a diverging, reverging and converging phase. After presenting the problem, the participants explored the different aspects of the problem through flower associations and restated the problem in their own way (figure 76). Then ideation was done through how to's and brainwriting (figure 77). After this ideas were clustered and each participant could choose one of the most promising ideas. Each individual then made a quick prototype with a banana leaf, visible in figure 78, and presented this to each other.

6.2.3 Clustering

The next step was clustering the ideas from all rounds of ideation. All ideas from the ideation phase were collected on post-its. These were first divided into retail or transport solutions and then further categorised (figure 79). The retail solutions were categorised by their production manner:

- Bags
- Boxes with lids
- Weaving
- Wrapping
- Folding

The transport solutions were categorized by their packaging function for transport:

- Stimulating ventilation
- Bundling or separating
- Absorbing impact
- Dividing weight
- Fixating or limiting movement
- Protecting against sharp or rough surfaces

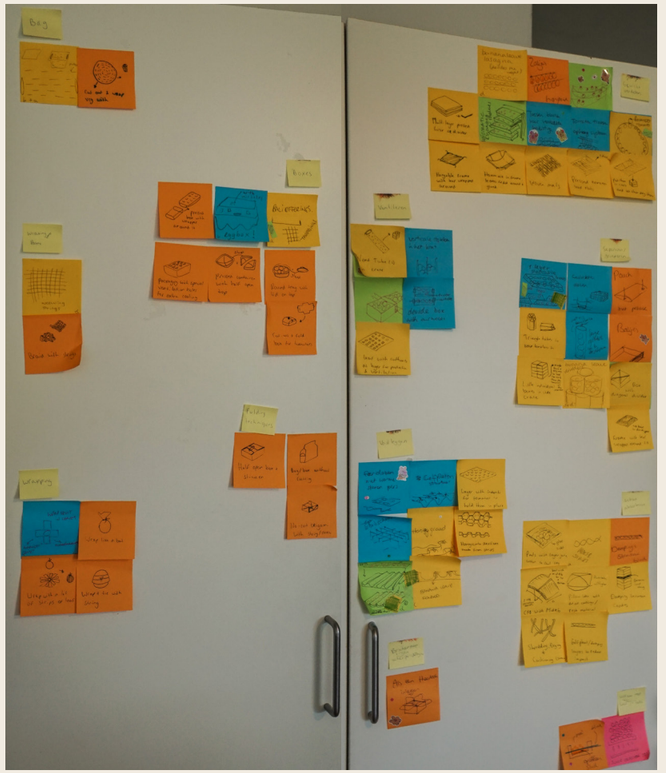


Figure 79 - Clustered ideas (left: retail, right: transport)

6.2.4 Selecting ideas

Once clustered, the ideas were assessed on feasibility. By holding them next to the conclusions of the material tests the ideas that were not possible to produce with the leaves were discarded. The remaining ideas were then held next to the demands and wishes to assess their potential to meet them. Out of this process the 10 best performing ideas were chosen to start prototyping with. The thought behind this is that trying out as many different ideas as possible through rapid prototyping will give insights into working with the material that otherwise might not be tested, risking the chance of missing crucial information that could be useful for the solution.

6.3 Phase 2: Iterate & explore

This phase covers the iteration of the 10 chosen ideas. First, the method of this phase is described and then the factors that are iterated upon which are important for the solution are discussed.

6.3.1 Method

For the iterate & explore phase, 3 weeks were taken in which the 10 ideas were iterated and conceptualized. After three weeks one concept was chosen in order to have enough time for developing the design concept and detailing the final design. For each prototype, the most suitable pre-treatment for the context and stakeholders was applied to the leaves (see chapter 5.3). The intention, method, results, and conclusions are documented for each prototype in appendix 15. After each prototype an evaluation was done to determine whether further iteration was needed or if the idea was ineffective. Following continuous exploration and iteration, the remaining concepts were assessed on meeting the demands and wishes, and one concept was selected for further development.

Figure 80 – Prototypes of different concepts

6.3.2 Factors

Throughout the rounds of iteration there are several factors on which the concepts are developed. These factors contribute to meeting the requirements and come back in different concepts. As a results of the development of these factors in the prototypes there are a variety of things that I have learned that are taken into account when bringing together everything in the final design. The most important factors and conclusions are described here. For each factor the connection is made to several prototypes in figure 80. They are referred to by their assigned number in the figure, which correspond with the appendix in which their prototypes are described.

Creating strength

A single layer of leaves is prone to ripping because of the unbranched vein structure of the leaf. A single layer can therefore not support weight and is undesired (prototype 15.2, 15.4, 15.8). Therefore, the material needs an increase in strength. By placing two or more layers of leaves over each other with the veins in perpendicular direction and attaching them, with for example glue, a stronger material is created that is less prone to ripping (prototype 15.5, 15.7, 15.10). Because of the vein structure the material is also more prone to ripping if cuts or holes are made, this should therefore also be avoided (prototype 15.5).

Glueing

To attach leaves to each other glue is used. In this case glue made from natural ingredients to make the solution biodegradable. These home-made natural glues are less strong than some synthetic glues, which brings some considerations along (prototype 15.7). If the area that is glued is too small object come apart more easily (prototype 15.6, 15.9). Next to this, it is moisture sensitive. If the object becomes wet the glue can liquify again after which it will also dry again. Therefore, if the glued area is too small it can come apart even more easily. Since vegetable chains are quite moisture sensitive it is an important factor.

Shape retention

In order to retain the shape of the leaf when it is made into an object a rigid mould is necessary (prototype 15.2, 15.3, 15.8). If leaf objects are dried without a mould they deform while drying as a result of shrinking (prototype 15.1). This directly means that the mould should accommodate the shrinking to prevent damaging the object (prototype 15.2, 15.4). Lastly it is important that the mould allows for ventilation, otherwise the drying time is significantly increased.

2D to 3D

In almost every prototype a 2D leaf is transformed into a 3D object. There are several ways of achieving this, but the most iterated upon is created thickness that can serve as padding. In this case, creating an object that can return to their original state after a load is applied is desired. This can be achieved through trapping leaf scraps in layers of leaves (prototype 15.6), letting layers of leaves naturally dry while they are attached with glue (prototype 15.7) and creating a corrugated fibre board structure (prototype 15.9).

Feasibility for at-home production

A very important factor to consider is the feasibility of the object to be produced at home. This mainly considers the difficulty of the production and the time it takes. If an object has too much parts to put together (prototype 15.10) or takes intricate tools and time to make it (prototype 15.9) is not feasible for a farmer to produce themselves.

6.4 Phase 3: Concept optimization

In phase 3 the chosen design concept is optimized on several factors. For each of the factors different tests are performed and combinations of factors are tested to come to a final design proposal. The design choices as a result of the tests are covered in this chapter.

The chosen design concept is a structure where layers of leaves are glued together and left to dry between a rack, creating air pockets that have a damping effect (appendix 15.7). This choice is made based on the fact that this concept has a great potential to reduce post-harvest losses in combination with being cheap and simple to produce without needing many additional resources or tools.

With the insights of material tests and the iterate & explore phase, the concept is iterated upon in several ways, testing out different combinations of factors that influence the effectiveness of the sheet (figure 81). The most significant factors that are improved upon are described in this chapter. The full tests can be found in appendix 13.9 & 15.7.

6.3.1 Glue recipe

Different recipes for natural glues were tested. The first series of tests, in appendix 13.8, are performed by mixing warm water from the faucet with each of the following ingredients:

- Corn starch
- Rice flour
- Agar (red seaweed)
- Gelatin
- Arabic gum

Out of these 5 recipes agar performed the least and Arabic gum worked the best although not sufficient. Therefore, a different recipe was tried involving placing the mixture over a heat source. For this recipe a first test was done by using water, flour, sugar, vinegar and baking soda. This proved to be very effective and works on both fresh and dried leaves. Since regular flour is hard to find in Ghana the recipe was tried with options that are available such as corn starch, cassava starch and cassava flour. Both the cassava flour and starch work the best, which is great since this is widely available in Ghana.

6.3.2 Ways of glueing

Chapter 6.3 the area that is glued is discussed. Here this is explored further to see the effect of the glued area on adhesion, the drying of the sheet and the pattern of air pockets. First different glue patterns are explored:

- Singular direction stripe pattern along the veins
- Singular direction stripe pattern perpendicular to the veins
- Singular direction stripe pattern diagonal to the veins
- Double direction stripe pattern along and perpendicular to the veins
- Double direction stripe pattern diagonal to the veins

Overall, all patterns show less adhesion and only the singular direction stripe pattern along the veins shows a desired pattern of air pockets that is similar to when glue is applied to the full area. Overall a pattern with bigger air pockets breaks more easily and one with more, smaller air pockets has a better damping effect since it returns to its original state after enduring a load. Since applying a glue pattern is quite a hassle and shows no advantage over applying glue to the full surface it is not desired.

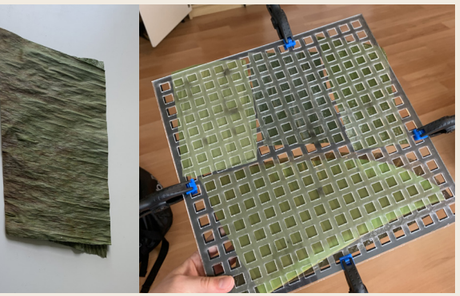
The amount of glue also influences the sheet. Using a thick layers of glue does result in better adhesion but it also results in less air pockets and slower drying. Therefore applying a thin, even layer is the best.

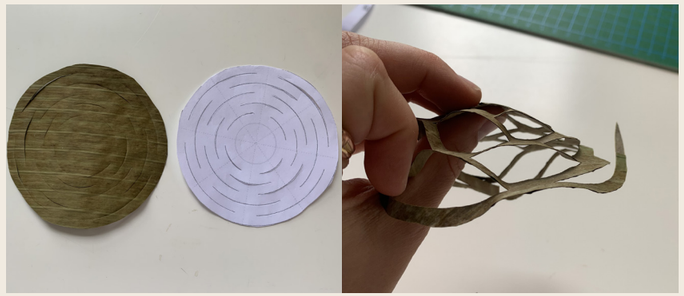
Lastly the option of natural spray glue is explored. This could be more convenient and fast during production. For this test the cassava glue is either mixed with rubbing alcohol (96%) or water with a ratio of ¼ glue to ¾ liquid. The mixture with alcohol gives the same result as spreading glue, however several types of alcohol can be toxic to the environment it is not desired right now. The mixture with water dries very slow and also show less air pockets which is also not desirable. For now spraying glue is therefore not feasible.

6.3.3 Amount of layers

As mentioned before a singular leaf easily rips and combining multiple layers results in a stronger material. For this reason tests are done with several layers of leaves ranging from 2 to 4 to find the sweet spot. When two layers are used you get a material that is strong and still quite flexible. When pressed upon it initially functions very well as padding but when repeatedly pressed upon it breaks more easily than with more layers. Using 4 layers creates a very strong sample that becomes very stiff and shows less air pockets which makes it have less damping effect. The best option is three layers. This stays together well and lasts longer than two layers. The sheet does have some stiffness but not too much and show the best air pocket pattern with more, smaller air pockets.

Figure 81 - Exploration and optimization of transport protection sheets





Take-aways from chapter 6

- Ideation is done through using factors from the post-harvest loss causes and the optimal vegetable conditions as how-to's. How to:
  - Avoid damage
  - Ventilate
  - Cool down
  - Protect from compression
  - Protect from impact
  - Protect from contamination
  - Protect from rough and sharp things
  - Contain

- In the iterate & explore phase the 10 chosen concepts were iterated upon through making prototypes. Throughout the rounds of iteration there are several factors that contribute to meeting the requirements on which the concepts are developed:
  - Shape retention - A rigid, ventilated mold is needed to prevent deformation and reduce drying time.
  - Strength - Leaves are layered with perpendicular veins and glued to increase strength, as single layers are prone to tearing.
  - 2D to 3D - 3D objects are made by trapping leaf scraps, drying layered leaves, or using a corrugated structure.
  - Glueing - Natural glue is moisture-sensitive and weaker, so large glued areas are needed to prevent separation.
  - At-home production - The design must be simple and quick for farmers to produce at home without complex tools.

- After several rounds of iterations the concepts that were deemed feasible were scored on the requirements once more and one concept is chosen to develop further. The chosen design concept is a structure where layers of leaves are glued together and left to dry between a rack, creating air pockets that have a damping effect. This concept was chosen for its strong potential to reduce post-harvest losses while being affordable and easy to produce, requiring minimal resources and tools.

- In phase 3 the chosen design is optimized by performing tests of different combinations of 3 factors:
  - Glue recipe - A heated mixture of water, flour, sugar, vinegar, and baking soda worked best, with cassava flour and starch proving ideal for Ghana.
  - Ways of glueing - A thin, even glue layer is the best option for quickly achieving desired air pockets. Spray glue wasn't feasible.
  - Amount of layers - Three layers provided the best balance of strength, flexibility, and air pockets, outperforming two or four layers.

07.

The leafpad

This chapter fully explains the design and production process of the leafpad. First, the solution is generally explained and after that, the details are discussed. The effectiveness, costs, payout time, production and implementation are touched upon and the design is validated and improved upon with stakeholders.

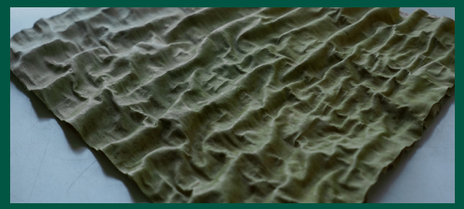
leafpad

Benefits

- Absorbs shock and vibration
- Prevents tomatoes from bumping into each other
- Divides weight, minimizing pressure points
- Hinders the spread of microorganisms between layers
- Allows for ventilation
- Is fully biodegradable
- Simple and cheap independent reproduction

10% reduced quantitative loss

20% reduced qualitative loss



10% increased revenue at wholesale level

26% increased revenue at market level

5.25 minutes to produce one leafpad

Payout time of 1.5 months without reuse and 0.5 month with reuse

7.1 Use & benefits

The leafpad is a transport protection sheet that can be produced by Ghanaian farmers themselves and is placed in between layers of tomatoes when being transported in wooden crates. Per crate about 8 of these sheets are used to reduce post-harvest losses. Layers of leaves are placed over each other and glued.

During drying of the sheets, the leaves shrink slightly, creating air pockets that give the sheets thickness that functions as padding (figure 83 & 84). For the production some simple tools are used that can be created by the farmers themselves, this and the production of the sheets are explained in chapter 7.2. The leafpad absorbs shock and vibration during transport as a result of bad road conditions and function as a layer between the fruits so they don't directly touch each other. The use scenario of the leafpad is visible in figure 82.

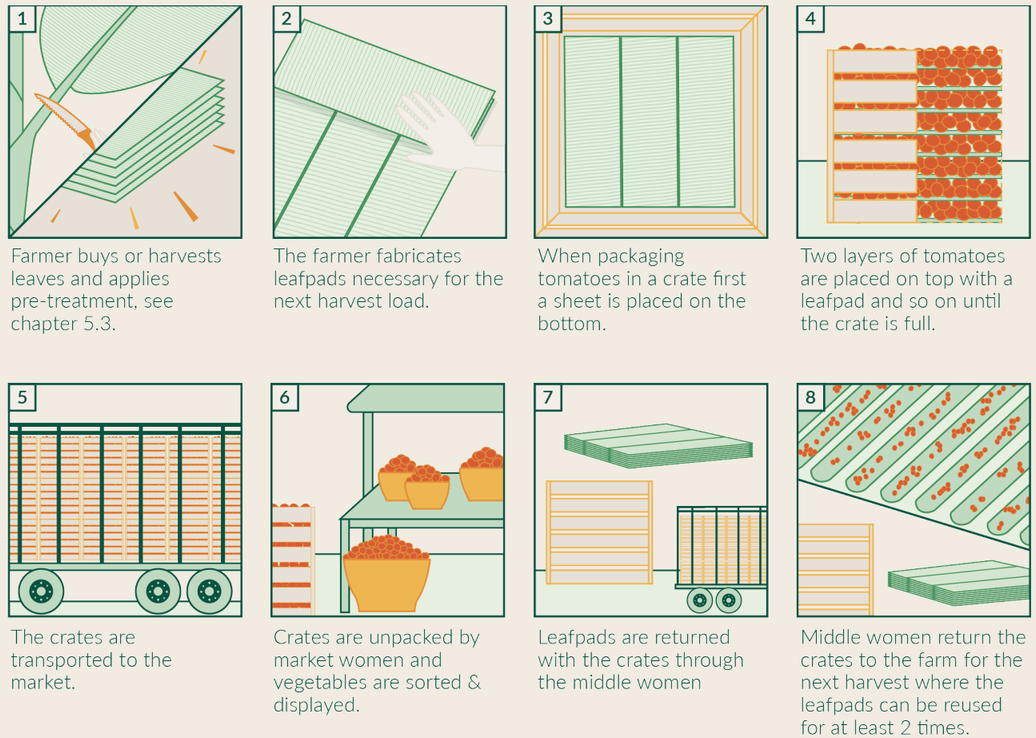


Figure 82 – Using the transport protection sheets

Figure 83 - Crumpling on transport protection sheets

7.1.1 Functionality

The air pockets in the leafpads give them shock and vibration absorbing abilities that can mitigate the damage to vegetables as a result of bad road conditions. They function as a layer between fruits to prevent the tomatoes from directly bumping into each other. The leafpad also divides weight from the layers of tomatoes above more evenly over the layers below, minimizing pressure points. Lastly, it also forms a barrier that hinders the spread of microorganisms between layers, preventing fruits from decaying as a result of other rotting fruits. Next to this, the leaves have antifungal and antimicrobial properties meaning they are safe and even beneficial to use as packaging. The choice is made to place the sheets between the layers and not on the sides lining the crate. Although this would protect the tomatoes from the rough surface of the crate, it would not allow for ventilation. In this case the choice is made for more ventilation since temperature is one of the most influential factors on decay of vegetables, as is described in chapter 3.1.

Structure

The leafpads consist of 3 layers of banana leaves placed over each other with the veins perpendicular to each other. This increases the strength of the sheet and prevents the sheet from ripping easily as would happen with one layer. The layers of leaves are held together by an easy-to-make glue made from natural ingredients. This also means that the sheets are fully biodegradable and do no harm to the environment.

7.1.2 Mitigating problems

Banana and plantain plants can be found in abundance in Ghana and almost every farmer has a least some of these plants growing on their farm. This makes the leafpad a cheap, easy, environmentally friendly solution that farmers can produce and use themselves to reduce losses and increase revenue. Because of the way the vegetable chain is currently put together, it is a challenge to drive back post-harvest losses during transport. There are many large problems that take a long time to mitigate such as low-quality roads, unrefrigerated transport, unorganised chain and market availability. The need for solutions in the meantime is high and calls for simple solutions that can mitigate problems while the large problems are being fixed. The leafpads can be easily made by farmers themselves with the help of instructions, meaning they can take matters into their own hands right away to increase gains. Given the fact that the group of people connected to this project (KAC students, ACHI students, HGT customers) is part of a new generation of farmers that are eager to take matters into their own hands this is a solution that fits the target group and could greatly benefit them.

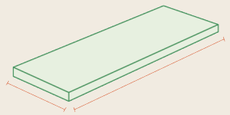
Figure 84 - Crumpling on transport protection sheets close up

7.2 Components & Production

The leafpad is designed in such a way that farmers can easily produce and use them themselves. To make the sheets a few tools are necessary such as wooden cutting stencils, drying racks and a paintbrush. For the leafpads themselves banana or plantain leaves and natural glue are required. The amounts mentioned in this chapter are necessary to transport 10 medium-sized crates, which creates 80 transport protection sheets. This is consistent with the output per load of a small farm in the tomato season (Director of horticulture company in Ghana, 2024: appendix 20.2).

7.2.1 Fixed equipment

This equipment needs to be built and invested in once. It is necessary to facilitate the production of the sheets. The equipment that is available in the average Ghanaian household is not included. This equipment includes a knife, a cloth, a pot for boiling water and a mixing tool.

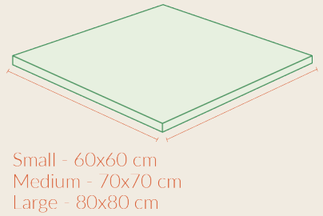


1x Small wooden cutting stencil

The small stencil is used to make cutting the leaves in the right size. The size is the size in which the leaf samples need to be cut for the crate size. With the average leaf size, the following stencil sizes are necessary:

- Small: 20x60 cm
- Medium: 23,5x70 cm
- Large: 20x80 cm

A wooden plate can be obtained from a hardware store or the local market. The wooden plate needs to be sawed into the right size. Both stencils can be cut out of the same wooden plate and together cost 20.80 (table 5).



1x Large wooden cutting stencil

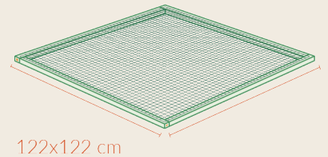
The large stencil is used to produce sheets in the right size for the crate. For standard crates this is:

- Small: 60x60 cm
- Medium: 70x70 cm
- Large: 80x80 cm

A wooden plate can be obtained from a hardware store or the local market and just needs to be sawed into the right size.

Material	Price GH₵	Amount	Cost GH₵	Cost €
Wooden plate, 120 by 214 cm	80.00	0.20	16.00	0.93
Wooden plate, 120 by 214 cm	80.00	0.06	4.80	0.28
Total cost cutting stencils			20.80	1.21

Table 5 – Costs for leaf-cutting stencils



6x Drying rack side

The drying rack is used to dry leafpads between so they dry flat and quick while allowing crumpling to form air pockets. The drying rack can be stacked. This means that several layers of wire mesh racks can be stacked on top of each other instead of making two racks for every layer of sheets drying. For example, 4 sheets can be dried between two racks, 8 can be dried between 3 racks, 12 can be dried between 4 racks and so on. If over the course of two weeks, 80 leafpads are produced, 6 sides of a drying rack are necessary. Then each week two cycles of 20 sheets can be dried in the rack. Material necessary for 1 side of a drying rack:

- 4x wooden slat of 117 cm
- 1x wire mesh piece of 120 by 120 cm
- 4x nails
- 16x wood staples

The wooden frame of the drying rack is 122 cm by 122 cm. The frame is assembled by nailing the slats in a square. After that, a piece of wire mesh of 120 by 120 cm is cut from the roll. The wire mesh is placed on top of the frame and hammered into place with the use of wood staples (figure 85).

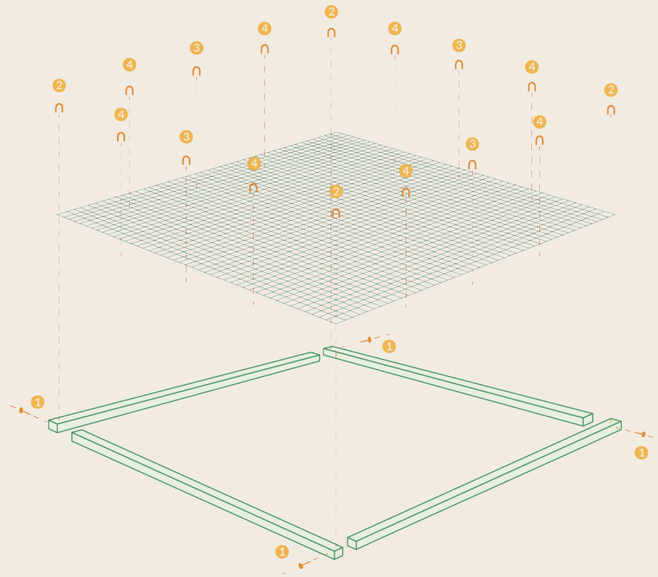


Figure 85 – Building instructions of the drying rack

Figure 86 - Prototype of the drying rack

Wood and wire mesh can be obtained from a hardware store (figure 87) and nails & wood staples from a hardware store (figure 87) or the local market. In total one drying rack side costs 103.5 cedi. The investment necessary for 6 sides is 621.14 cedi (table 6).

1x Paintbrush

The paintbrush can directly be used to spread glue over banana or plantain leaves. Preferably a large paintbrush so fewer strokes have to be made, saving time. It can be obtained at the local market for about 20 cedi.

Material	Price GH₵	Amount	Cost GH₵	Cost €
Wooden slat, 300 cm long, profile of 2.5 by 5 cm	25.00	2.00	50.00	2.90
Wire mesh roll, 120 cm by 914 cm	300.00	0.14	42.00	2.44
200 nails	100.00	0.02	2.00	0.12
350 wood staples	200.00	0.05	9.52	0.55
Total cost 1 side drying rack			103.52	6.00
Total cost 6 sides drying rack			621.14	36.03

Table 6 – Costs for drying rack

Figure 87 - Advertisement for hardware store next to a road

7.2.2 Variable components

The following components are directly necessary to produce the sheets and need to be acquired every time new sheets are made. The amounts are again for 10 medium-sized crates, which creates 80 leafpads.

Figure 87 - Glue made with cassava flour

4 Liter Glue

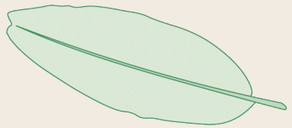
The glue is used to keep the leaves attached while drying, allowing air pockets to form. It is strong enough to hold but can also be taken apart if wished so. To make it you need:

- 4 liter water
- 800 gram cassava flour
- 1200 gram sugar
- 160 milliliter vinegar
- 120 gram baking soda
- Obtain materials at the supermarket or open market.

To make the glue mix the water and flour well in a pan and place it on a stove on medium heat. When the mixture starts to warm up the sugar is added. Throughout the whole process, you should keep stirring, if possible with a whisk. When the sugar is dissolved the vinegar is added and once this is stirred through the baking soda is added. The mixture will foam because of the reaction between the vinegar and baking soda. When the mixture starts thickening you can take it off the stove, stir until it is smooth and then let it cool. After that, you can use it as glue (figure 87). The cost of the glue is visible in table 7. If kept in the fridge, the glue lasts at least 3 weeks.

Material	Price GH₵	Amount	Cost GH₵	Cost €
Water, 1 liter	4.00	4.00	16.00	0.93
Cassava flour, 1 kilogram	10.00	0.80	8.00	0.46
Sugar, 1kilogram	40.00	1.20	48.00	2.78
Vinegar, 1 liter	30.00	0.16	4.80	0.28
Baking soda, 500 gram	20.00	0.24	4.80	0.28
Total cost glue 80 leafpads			65.60	3.80
Total cost glue per leafpad			0.82	0.05

Table 7 – Costs for glue



160 Banana or Plantain leaves

For standard-size crates, the following leaf pieces are necessary per crate. These are calculated with the average leaf size of the plantain plant.

- Small: 9 pieces of 20x60 cm = 1 to 2 leaves
- Medium: 9 pieces of 23.5x70 cm = 2 to 3 leaves
- Large: 12 pieces of 20x80 cm = 2 to 3 leaves

Leaves can be obtained from The farmers own farm or other farms. To use the leaves a pre-treatment has to be completed which is explained in chapter 5.3, figure 9. With the pre-treated leaves the leafpads can be made, visible in figure 88. Currently, the leaves can be obtained for free at farms.

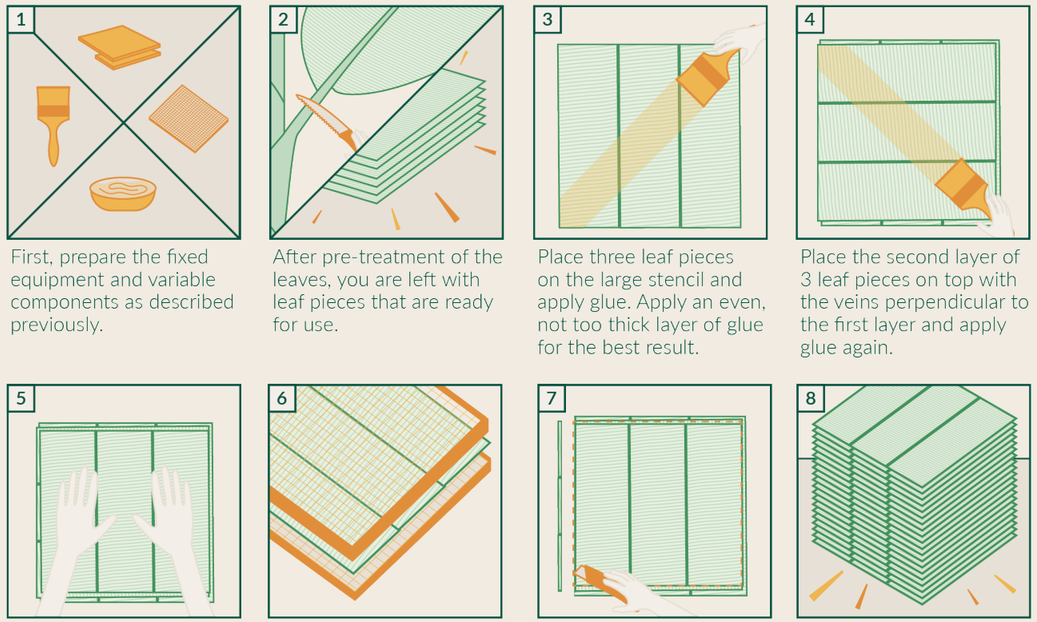


Figure 88 – Instructions to make the sheets

7.2.3 Duration

The time necessary to assemble 80 leafpads is 3 hours (table 8). As mentioned before the production is spread over two weeks in which the leafpads are dried in 4 cycles of 20 sheets. This means 45 minutes is needed for each cycle, so 1.5 hours is necessary per week to assemble the leafpads. The pre-treatment of the leaves (see 5.3), including harvesting, necessary for 80 leafpads takes an additional 4 hours. This means in total 7 hours are necessary to produce 80 sheets from harvesting to using them. If, in this case, production is spread over two weeks it takes 3.5 hours per week or 5.25 minutes per leafpad (table 9).

Activity	Duration
Making the glue	20 minutes
Arranging the leaf pieces and glueing	160 minutes
Total time to assemble 80 leafpads	**3 hours**

Table 8 – Duration of assembling the sheets

Activity	Duration
Pre-treatment for 80 sheets	4 hours
Assembling 80 sheets	3 hours
Total time to produce 80 leafpads	**7 hours**
Total time to produce 1 leafpad	**5.25 minutes**

Table 9 – Duration of assembling the sheets

7.2.4 Investment

The total initial investment and variable costs for 80 leafpads, good for 10 medium-sized crates can be found in table 10 & 11.

Component	Cost GH₵	Cost €
Stacked drying rack with 6 sides	621.14	36.03
Large leaf cutting stencil for full leafpadt	16.00	0.93
Small leaf cutting stencil for leaf pieces	4.80	0.28
Paintbrush	20.00	1.16
Total initial investment	**641.94**	**37.23**

Table 10 – Initial investment to dry 20 sheets at the same time

Component	Cost GH₵	Cost €
160 banana or plantain leaves	0.00	0.00
50 milliliter of glue	0.82	0.05
Total investment per leafpad	**0.82**	**0.05**
Total investment 80 leafpads	**65.60**	**3.80**

Table 11 – Variable costs for production of the sheets

7.3 Effectiveness of the design

The leafpads are designed to reduce post-harvest losses and increase revenue for farmers. To test their actual effectiveness in doing so a simulated transport test is performed. To realistically validate the design the test needs to resemble the real context of use as much as possible, this is described in appendix 16. The test is performed with tomatoes placed in a wooden crate together with the leafpads. The crate is then placed on a cargo bike and driven around over uneven roads after which the quantitative and qualitative loss of tomatoes is measured.

7.3.1 Transport simulation test

In Ghana, tomatoes are usually transported in medium-sized crates measuring 70x70x70 cm. For the test, a smaller wooden crate with the same height of 70 cm but width and length of 35 cm was created, visible in figure 89. This smaller size was chosen to reduce costs and waste. The height was maintained to simulate the same compression on the lower layers of tomatoes. Ripe, undamaged tomatoes, were ordered online and checked upon arrival to ensure only firm, healthy ones were used in the test.

The leafpads for the test were made as they would be in real use. Each sheet contains 3 layers of leaves with their veins arranged perpendicular to each other that are glued with cassava flour glue and left to dry between wire mesh racks for 3 days (figure 90). In the test, one sheet was placed at the bottom of the crate, followed by two layers of tomatoes, then another sheet, and so on.

Due to the high tomato quantity required for a control group test, existing research is used to compare the results of the simulated test to. The test closely mirrors

Figure 89 - Test crate of 70x35x35 cm

Figure 90 - Prototypes of transport protection sheets

Figure 91 - Testride with tomato crate

Figure 92 – Tomatoes used for testride

those studies, including measurement methods. For quantitative post-harvest loss, the comparison study shows a 33% loss (Wongnaa et al., 2023), measuring weight before and after transport, excluding tomatoes that are too damaged to be sold. This study was conducted in northern Ashanti towns, about 115 km from Kumasi, with a typical car or truck journey taking around 2.5 hours. For qualitative loss, 55% of tomatoes are damaged (Dari et al., 2017), with damages like bruises, rot, and punctures counted after transport. This study took place in northern Ghana, where tomatoes arriving from Burkina Faso were transported 207 km from Paga to Tamale, a 3-hour 50-minute trip. In this study, only healthy and firm tomatoes were used. The test ride with the cargo bikes took the average travel time of both studies, 3 hours and 10 minutes (figure 91 & 92). The chosen route mimics Ghana's rough, pothole-filled roads, avoiding smooth pavement to simulate typical transport conditions.

The average yearly temperatures are 26°C in Kumasi and 28°C in Tamale (Weatherbase, 2024), with transporters often driving in cooler mornings or evenings to protect the tomatoes. During the test, the temperature was 26°C, with sunny weather for 2 hours and partly cloudy conditions afterwards, closely matching typical transport conditions in Ghana.

7.3.2 Results of the test

In the test, all tomatoes remained intact and very few showed damages visible on the outside such as rot, punctures and scratches. There were however dents and shrivelling visible and when taken out of the crate you can feel that some tomatoes had soft spots, visible in figure 93. Since all tomatoes were firm before transport these tomatoes are the ones that are counted as damaged tomatoes, visible below. Overall the test resulted in 25% qualitative loss and 2.5% quantitative loss. Although test conditions are mimicked there are still differences in road quality, travelled distance, amount of crates, amount of tomatoes and most importantly quality of tomatoes between a test in the Netherlands with a cargo bike versus the real transport in Ghana by truck. Therefore, the results of the test are analysed and expected estimates are made.

7.3.3 Estimated qualitative loss

In the comparison study, firm tomatoes from Burkina Faso were packed in wooden crates with jute, paper, or foam liners, resulting in 20% to 25% reduced qualitative loss. The test in this report uses a similar amount and quality of tomatoes with a comparable solution, resulting in 25% overall quality loss. Though all damaged tomatoes in the test still appear sellable, lower-quality tomatoes, like those in Ghana, would likely suffer more damage and sell for less. Therefore, it's estimated that the transport protection sheets would reduce qualitative loss by about 20%.

7.3.4 Estimated quantitative loss

In the comparison study for quantitative loss, results were based on questionnaires, calculating the difference between harvested and sold tomatoes, which includes losses from handling by farmers, transporters, and market vendors. While transport-specific loss is hard to determine, other research indicates a 20% loss during transport (Bani et al., 2006). Additionally, heat buildup in trucks causes more rapid water and weight loss. Unlike in reality, where some tomatoes are already damaged before transport, the test in this report used only firm tomatoes, resulting in minimal weight loss. The test showed a 2.5% quantitative loss compared to 33% in the comparison study. Considering tomato quality, transport conditions, and reduced qualitative losses, the estimated effect of the transport protection sheets is a 10% reduction in quantitative loss. This is also in line with a test performed with lulo fruits where banana leaves were used as layers between fruits (Forero-Cabrera et al., 2017).

Figure 93 - Damages to tomatoes during the test

7.3.5 Number of tomatoes per crate

To calculate the realistic effect of the leafpads on the revenue of farmers it is also important to take into account the space that is taken up in the crate by the leafpad. Placing the leafpads in the crate leaves less room for tomatoes which means less tomatoes can be transported per crate. When packing spheres or in this case tomatoes in a space there are different ways to do so resulting in different packing arrangements and packaging densities. In Ghana tomatoes are thrown into a crate rather than placed into it in the most efficient way and the tomatoes come in different shapes and sizes. This packing arrangement is known as random loose packing and is realistic for when packing is done by hand without much effort to optimize space (Weisstein, 2024). The packing efficiency of this arrangment is approximately 64%, meaning 64% of the volume of the crate is taken up by tomatoes. If this volume is divided by the volume of one tomato the number of tomatoes can be calculated. For the volume for each individual tomato an average number is taken which takes into account the different sizes and shapes of tomato and the fact that a tomato is not a perfect sphere. For the calculation an average diameter of 6 cm per tomato is taken. The number of tomatoes in the differently sized crates without the use of the sheets can then be calculated with equation 1.

$$\text{Number of tomatoes in crate} = \frac{\text{PackingEfficiency} \times \text{Vcrate}}{\text{Vtomato}} = \frac{0.64 \times LWH}{\frac{\pi d^3}{6}} = \frac{0.64 \times LWH}{0.000113097}$$

Equation 1

When the leafpads are also placed in the crate a different approach has to be taken. The leafpads basically divide the crate into several individual spaces where the packing arrangement starts over since the tomatoes cannot fit that neatly into each other when a leafpad is placed in between. Since the crates of tomatoes will contain 8 leafpads the crate will be divided into 8 smaller boxes. Next to this the leafpads themselves take up volume in the crate. They cover the full width and length of the box and are compressed to a thickness of 2 mm when a load is applied. To calculate the number of tomatoes in the crate with the use of leafpads first the volume of the leafpads is subtracted from the volume of the crate. The remaining volume is divided into 8 parts. The number of tomatoes for an individual part can be calculated and by multiplying that with 8 the total number of tomatoes in the crate as in equation 2.

$$\text{Number of tomatoes in crate with sheet} = 8 \times \frac{\text{RandomEfficiency} \times \frac{\text{Vcrate} - 8 \times \text{Vsheet}}{8}}{\text{Vtomato}}$$

Equation 2

By calculating the number of tomatoes for the different crate sizes with and without the use of leafpads you get the results of table 12. The full calculation can be found in appendix 17.1.

Crate size	Number of tomatoes without sheets	Number of tomatoes with sheets	Decrease in number of tomatoes
0.6x0.6x0.6 m	1222	1190	2.6%
0.7x0.7x0.7 m	1941	1897	2.3%
0.8x0.8x0.8 m	2897	2839	2.0%

Table 12– Number of tomatoes per crate

7.3.6 Expected post-harvest loss decrease

On average for the different crate sizes this is 2.3% less tomatoes that arrive at the market with the use of sheets. This means 2.3% has to be subtracted from the sellable tomatoes.

By considering this in combination with the expected decrease in post-harvest losses as a result from the validation test the final expected numbers of qualitative and quantitative loss can be found in table 13.

Quantitative and qualitative loss over the year	Percentage
Percentage of damaged tomatoes from the comparison study (Dari et al., 2017)	55%
Amount of sellable tomatoes from the comparison study (Wongnaa et al., 2023)	67%
Percentage of damaged tomatoes from validation test	25%
Amount of sellable tomatoes from validation test	98%
Expected percentage of damaged tomatoes with the use of the leafpads in Ghana	35%
Expected amount of sellable tomatoes with the use of the leafpads in Ghana	75%

Table 13 – Post-harvest loss numbers for comparative studies and test

7.4 Revenue and payout time

With the expected amount of decreased losses the effect on revenue and payout time can be calculated. The factors that are taken into account are explained and the expected results are discussed. The full explanation and calculation are visible in appendix 18 & 19.

7.4.1 The Results on revenue

To determine the increased revenue resulting from the decreased losses a few factors are important. First, it is important to note that revenue will increase differently in different parts of the chain. When farmers sell to traders at wholesale level tomatoes are sold in crates per weight, here quantitative loss is used to calculate revenue. When selling to market women or consumers directly qualitative loss comes into play since more money is paid for undamaged, healthy vegetables. Therefore, depending on how the farmers' chain is organized a more direct link with the market with fewer margins applied by different stakeholders results in significantly more increase in profit. Next to this, losses differ per season since price, supply and demand differ in the major and minor seasons. In the major season, demand is lower and supply is higher, resulting in more losses while demand in the minor season is high and supply lower, resulting in a higher portion of the harvest being sold. The difference in quantitative post-harvest loss between the seasons can lie around 20% (Wongnaa et al., 2023) (appendix 17.2). The difference in qualitative loss between the seasons is unknown. Lastly, farmers need to spend time and effort on the production of the leafpads and tools which they cannot spend on their regular farming activities. Ideally this would be taken into account, since it is a factor that they will need to compensate in. Unfortunately, since there is no information on hours and wages of farmers in Ghana, this factor could not be included in the calculations but should be kept in mind.

With this in mind, the expected effect on revenue at wholesale level is an average of 12% increase of revenue throughout the year. In the major season, 14% more revenue is made with a worth of 257.20 cedi (15.96 euro) for the average farmer and in the minor season, 10% more revenue is made with a worth of 767.25 cedi (44.50 euro) for the average farmer (table 14).

	Major season		Minor season	
	GH₵	€	GH₵	€
Price 100 kg tomatoes, Ashanti area (Wongnaa et al., 2023)	51.61	2.99	307.70	17.85
Revenue obtained in control group for 100 kg harvest	29.42	1.71	236.93	13.74
Revenue obtained with sheets for 100 kg harvest	33.55	1.95	261.55	15.17
Potential increase in revenue with leafpad (%)	14%		10%	
Worth of increased revenue per season with leafpad	275.20	15.96	767.25	44.50

Table 14 – Expected effect on revenue at wholesale level

	GH₵	€	GH₵	€
Price undamaged tomatoes at local market per 100 kg in Kumasi (appendix 5.1)	200.00	11.60	350.00	20.30
Price damaged tomatoes at local market for 100 kg (1/4 of the price of undamaged (appendix 5.1))	50.00	2.90	87.50	5.08
Revenue obtained in control group for 100 kg tomatoes	117.50	6.82	205.63	11.93
Revenue obtained with sheets for 100 kg tomatoes	147.50	8.56	258.13	14.97
Potential increased revenue with leafpad (%)	26%		26%	

Table 15 – Expected effect on revenue at market level

For the effect at market level, the results are about a 26% increase in revenue (table 15). Since no data can be found on the revenue of market women and the percentage tomatoes play in this the worth of this revenue cannot be calculated.

Reuse

After the transport test the leafpads were assessed on their ability to be reused. Out of the eight leafpads, only one leafpad lost one leaf piece and the rest was intact. The leafpads with thicker, stiffer leaves came apart more easily than the thinner leaves. Overall, the sheets have become more dented and deformed and are less flat than before the test (figure 94). They look a bit more rugged but could still be used for another 2 rounds of transport since they do keep their damping abilities.

7.4.2 Payout time

With the increase in profit, it is possible to calculate the payout time. Many factors have an influence on the payout time such as the size of the farm and harvest, reuse of the sheets or not, the way in which the farmer organizes their chain or not, is it direct or does it have many players. Since it is hard to calculate payout time for all the situations it is done for 2 situations: one with 2 times reuse of the leafpads and one without reuse of the leafpads. Many farmers do not always do bookkeeping so not very much information is present about revenue and profits. They are now taken from the paper of Wongnaa et al., 2023 with data from a large questionnaire. From this, the commercial smallholder tomato farmer with an average amount of land of 1.68 ha is taken with the average amount of revenue.

Fixed and variable costs are calculated and depend on the production rate which is influenced by the size of the farm and reuse of the leafpads. It is counted that 6 drying racks are necessary without reuse and 3 with reuse, leaving production rates to producing 48 leafpads per week without reuse and 16 leafpads with reuse. Many of the factors vary throughout the year because of the growing seasons. This includes revenue, profits and production of sheets. Since Wongnaa et al., 2023 use average revenue for what the average farmers produce in minor and major seasons this is also adopted in the calculations of the payout time. With this data the payout time comes down to about half a month if the sheets are used 3 times and about 1.5 months if the sheets are not reused (table 16), falling within the boundaries of the requirements.

The expected payout times and effectiveness of the design in reducing losses and increasing revenue highly depend on farm size. It is more likely that smaller-scale farmers with more direct links to the market could benefit more from using the leafpads than larger-scale farmers or farmers with a less direct link to markets. For large farmers production will need to be large which requires a higher initial investment for the drying racks and more time to produce the leafpads, making it more difficult. And as for the direct links they make it possible to make more revenue for the farmer shortening the payout time, making it more attractive to use the leafpads.

Figure 94 – Before (left) and after (right) picture of the sheet used during the test

	Cost GH₵	Cost €
Total revenue for major and minor season (1 year) (Wongnaa et al., 2023)	9345.60	542.04
Total cost of production major and minor season (1 year) (Wongnaa et al., 2023)	2759.94	160.08
Total revenue for the major and minor season (1 year) with the use of leafpads	10467.07	607.09
Total profit for the major and minor season (1 year) with the use of leafpads	7707.13	447.01
Total profit per month with the use of leafpads	642.26	37.25
Amount of medium-sized crates sold per year with the use of leafpads	282	
Amount of leafpads necessary per month without reuse	188	
Amount of leafpads drying at a time without reuse (production: 48 per week)	24	
Initial investment for drying rack without reuse	724.67	42.03
Amount of leafpads necessary per month with reuse of 3 times	63	
Amount of leafpads drying at a time with reuse of 3 times (production: 16 per week)	8	
Initial investment for drying rack with reuse of 3 times	310.57	18.01
Initial investment for cutting stencils	20.80	1.21
Initial investment for a paintbrush	20.00	1.16
Initial total investment without reuse	765.47	44.40
Initial total investment with reuse of 3 times	351.37	20.38
Investment per leafpad	0.82	0.05
Investment per month in sheets without reuse for the average farmer	153.99	8.93
Investment per month in sheets with reuse of 3 times for the average farmer	51.33	2.98
Payout time in months without reuse of the leafpads	1.6	
Payout time in months with3 use cycles per leafpad	0.6	

Table 16 – Payout time for average farmer with and without reuse

7.5 Stakeholder validation

After the feasibility and effectiveness are proven, the validation of the leafpad with stakeholders follows. Several stakeholders of the project are contacted to discuss the strengths and weaknesses of the sheets in order to improve the design and develop an implementation strategy. Complementary to acquiring qualitative validation, a questionnaire is spread under the target group, Ghanaian farmers, for quantitative validation.

7.5.1 Stakeholder interviews

To acquire qualitative validation and have an open discussion about the leafpad and its possibilities interviews are conducted with 5 Ghanaian stakeholders. The questions can be found in appendix 20.1. Out of the interviewed people two are involved in the ACHI project as manager and coordinator, one is HGT manager in Ghana and 2 are farmers from the Kumasi and Volta region. Their individual opinions can be found in appendix 20.2 and the overall conclusions are highlighted here.

Overall, the first impression of the leafpads is positive. The interviewees think the design is innovative and can bring something new to the market. It is great that it is biodegradable and therefore safe for the produce as well as for the environment. Next to this, the materials can easily be locally obtained in Ghana (figure 95) and some production or use methods are somewhat familiar such as using fresh leaves to package hot food or using cassava starch as glue. The opinion about the price of the leafpads is also positive and the initial investment seems reasonable for commercial smallholder farmers. The production steps that need to be executed for the fixed equipment as well as producing the leafpads are doable and easy enough for Ghanaian farmers. The main insecurity around the leafpads is the necessary effort and time farmers need to put in and simultaneously the implementation plan needs some more attention. Depending on the farmer and the size of the farm, farmers might prefer to make the leafpads themselves or not. While the interviewees are convinced a portion of the farmers would be very motivated and excited to produce the leafpads themselves, they also think that a part of the farmers wouldn't.

Farmers are often already quite busy and taking time to produce the sheets might be a threshold since there are also other options, like placing grass in the crates, that are easier and also slightly help in driving back losses. It is therefore really important that the value proposition of the sheets is convincing and the advantages and effects of using the sheets are clear. These concerns are talked through with the interviewees and from the discussions ideas for development emerged. Next to this, some ideas around targeting the solution were discussed. The main matters are:

Figure 95 - Small woodshop next to the road

Targeting
The leafpads could also be targeted towards traders or middlewomen. They are often involved in transport, so would have a direct benefit and they could be actively involved in making sure the leafpads find their way back to the farms with the crates so they can be reused. In this case leafpads could be sold at the local market where market women and traders sell their produce. It is however more unlikely that they would be interested in producing the sheets themselves as opposed to buying them.

Value proposition & marketing
Since there are definitely farmers who would be interested in producing the leafpads themselves, marketing with an emphasis on a strong value proposition towards farmers would help the implementation of the solution. Through word-of-mouth marketing, they can also reach other farmers and stakeholders in the chain such as traders and middle women.

Proof of concept
Overall, people want to be sure their investment will be profitable. They prefer to have proof of the effectiveness of the leafpads before putting in the time and effort. Providing samples of sheets to test out could help people experience the effectiveness firsthand and convince them of the benefits.

Turning it into a business
Since farmers would definitely like to use the solution and spend money on it if they don't have to put in time and effort, making the leafpads could be turned into a business. Someone could take up production and sell the leafpads which could be attractive to both farmers, traders and middle women. In this case, the production process could be designed to be more technologically advanced and faster, possibly creating higher-end leafpads that can be reused for more use cycles.

Identifying the right output channels
To spread the word and reach the right people, fitting channels for selling need to be identified. A smart idea would for example be to sell leafpads through or together with the crate manufacturers where farmers and traders come to buy crates.

Figure 96 - Busy road next to local market (left side)

7.5.2 Farmers questionnaire

An online questionnaire was conducted to validate the leafpads with various stakeholders in Ghana. The participants were first presented with the use, effect and investment of the sheets along with a picture and asked if they would use the leafpads for the given investment. They were then informed about the effort and production involved to assess their willingness to handle production themselves.

Despite sharing the questionnaire in Facebook farming groups, the Holland Greentech and KAC networks, and with my personal contacts in Ghana, it was only completed 8 times after 3 weeks. The results will be analyzed considering this small sample. Of the 8 respondents, 5 are farmers and 3 are consumers. Unfortunately, no market women participated. The questions, results and full conclusion can be found in appendix 20.3 to 20.5, here the most important results are highlighted.

"Yes, (I would use the sheets) because we should not waste food and we must secure farmers income."

"Yes, (I would use the sheets) because the rate at which our tomatoes get damaged when transporting is very painful."

Effect and investment
All participants state they would use the leafpads for the named initial investment and investment per crate, citing reduced losses & spoilage, increased profits, and environmental benefits as reasons. Opinions on the size of the investment were split, with 50% rating it on the lower side and 37.5% on the higher side, where consumers rated the investment significantly higher than farmers.

"The banana leaves are available for free in various plantation farms but nails, glue and wood have to be bought."

Effort and production
After learning about the effort to produce the leafpads, 7 out of 8 respondents would still use them, with one consumer opting out.

All participants felt confident they could produce the sheets with a guide. On difficulty, 50% found it easy, 37.5% were neutral, and 12.5% found it hard. They also felt capable of making the tools, with 75% neutral on difficulty and 25% finding it easy. They would get the materials either at the market or the hardware store and the leaves from their own or other farms.

If the leafpads were available to buy, all respondents state they would purchase them due to their economic value and possible reduction of losses. Prices ranged from 1 to 15 cedi per sheet, depending on quantity.

" Anything amount around 2% of the current production cost is okey considering the extra protection it will to the produce."

7.6 Guide for farmers

A big part of the implementation is enabling independent reproduction of the tools and leafpads for farmers. For this a farmers guide is created that includes a concise version of the information in chapter 7 without compromising on important information. The guide contains a general explanation of the benefits, the use scenario of the leafpads, the production instructions for the tools & the sheets, the required investment and the effect on revenue & payout time. Handy tips to facilitate optimal handling of the leaves are also shared throughout the production instructions. The guide is included to this report as a separate deliverable. When implemented, the guide could also be translated to different domestic languages in Ghana to maximize proper understanding and make the guide more accessible.

Figure 97 - Farmers guide

7.7 Sheet production test Ghana

To enable easy, independent reproduction of the leafpads a farmers guide with instructions is developed, discussed in chapter 7.6. To see if this guide is clear and enables farmers to create the leafpads on their own without help a trial of the production of the sheets is done with a Ghanaian farmer. This farmer was presented with a slightly adapted version of the guide with instructions on how to substitue the necessary tools for household items since investing in making the tools for this trial was too much to ask.

After the trial a reflection was done on the challenges that arose and how they could be improved. The first challenge is that the wind can cause ripping of the leaves. A few rips in the leaves is still workable but too many becomes a problem. It is therefore best to harvest plantain leaves in a more vegetated area with protection from winds. Next to this the maturity of the leaf plays a role in the outcome of the sheet. Leaves that are too young are more fragile and flexible while old leaves become more brittle after drying. Using leaves in the right stage of maturity is the most beneficial. The exact boundaries of this stage should be researched or can be explored by experience. This is more visible after drying.

“ If they (the leaves) are in the correct state / age, they become strong, like leather sheets.”

During the trial cassava starch glue was used which worked well. The leaves took 2 days to dry and were dried in the sun, which is conform with the expected production rate in Ghana. If the sun is too strong it can also discolour the leaves or damage them, therefore drying in the shade gives the best result.

Unfortunately the desired end-result was not achieved. As is visible in figure 98 the leaves curled up to much during drying. The reason for this is that only one side of a drying rack was used which does not let the leafpads dry flat. This is emphasized extra in the farmers guide. If the challenges above can be mitigated the farmer believes that the sheets could work well.

Figure 98 - Trial of sheet production in Ghana

7.8 Evaluation & conclusion

This chapter assesses how succesful the leafpads are in solving the design challenge by evaluating the design with the list of requirements in chapter 4.5. First the demands are evaluated (table 17) with an explanation of how they are achieved. Then the wishes are evaluated (table 18). Since not all wishes are worth mentioning only the important ones are discussed. Many wishes contain the words “to the fullest” or “as … as possible”. They can only be achieved in a certain degree and are therefore marked with a “-“.

Functionality		
D-F-1	Reduced quantity loss by 10%	✓
D-F-2	Reduced quality loss by 15%	✓
D-F-3	The solution allows for ventilation	✓
D-F-4	The solution lasts 6 days	✓
D-F-5	The crate contains at least 90% of the original number of tomatoes	✓
Acceptance		
D-A-1	75% of farmers and market women accept the use of banana leaves	-/+
D-A-2	75% of farmers in Kumasi accept the use of the solution	✓
D-A-3	Payout time is within 2 months	✓
D-A-4	Packaging a crate does not take more than 3 extra min	✓
Production		
D-P-1	Farmer can use & produce the solution themselves	✓
D-P-2	Building instructions, enabling reproduction, are available	✓
D-P-3	Materials for the solution and tool can be obtained in Ghana	✓
D-P-4	The tool can be produced locally	✓

Table 17 – Assesment of demands

7.8.1 Demands

D-F-1
The expected reduction in quantitative loss is exactly 10%. This number is determined by comparing the conducted post-harvest loss test to the comparison study in chapter 7.3. The number is also in line with a study where banana leaves were used as transport protection for other fruits (Forero-Cabrera et al., 2017).

D-F-2
The expected reduction in qualitative loss is 20%, which is 5% more than the demand of 15%. This number is determined by comparing the conducted post-harvest loss test to the comparison study in chapter 7.3.

D-F-3
The choice is made to place the leafpads between layers of tomatoes and not at the sides, lining the crate. This arrangement of sheets allows for ventilation between the layers.

D-F-4
As described in chapter 7.4 it is estimated that the leafpads can be reused 2 times with a total of 3 use cycles. After using the sheets in the test they were still in good condition and 5 weeks after the test they are still in that same condition, well surpassing the demand of 6 days. The exact amount of days that the leafpads last is not determined.

D-F-5
On average for the different size standard crate 2.3% less tomatoes fit in the crate with the use of the leafpads, which is well within the demand. The calculation for this can be found in chapter 7.3.

D-A-1
In the questionnaire about the perception of banana leaves, included in chapter 5.2, all farmers stated they would use banana leaves as a packaging material if it could benefit them. Unfortunately no market women participated in the survey so no data is available for them. Therefore this demand is only partly achieved. The sample size of this study was also relatively small which should be taken into account.

D-A-2
In the stakeholder validation questionnaire, included in chapter 7.5, all farmers stated they would want to use the leafpads for the named investment and effort. Again the sample size of this study was also relatively small which should be taken into account.

D-A-3
The determined payout time for the average farmer, mentioned in chapter 7.4, is approximately 1.5 months if the leafpads are not reused and 0.5 months if they are reused. This surpasses the demand of 2 months.

D-A-4
The extra time it takes to package the crate includes placing a leafpad in the crate 8 times. In total this does not surpass 3 minutes, meeting the demand.

D-P-1
In the stakeholder validation questionnaire, included in chapter 7.5, all farmers state that they feel confident that they could produce and use the leafpads themselves with the help of a guide.

D-P-2
Building instructions for the tools and sheets are created and can be found in chapter 7.6. The instructions are evaluated by a farmer in Ghana in chapter 7.7.

D-P-3
All used materials are easily obtainable in Ghana. This is confirmed by the project manager of the ACHI project in Ghana.

D-P-4
The tool can be produced in a wood working shop by the roadside or at the workshop at the hardware store. However all farmers that participated in the questionnaire in chapter 7.5 feel confident they could produce the tools themselves.

7.8.2. Wishes

W-F-3
In this case applicable to as many people as possible means that the leafpads work for as many people as possible outside of the original target group. In this case the leafpads can also be applicable to market women, farmers outside of the target group and other entrepeneurs that would be interested in starting a business in this field.

W-F-6
The leafpads form a barrier between layers of tomatoes that hinders the spread of microorganisms between layers, preventing fruits from decaying as a result of other rotting fruits.

W-A-5
The leafpads can be reused at least two times for the same purpose. Application for other purpose should be researched.

W-P-3
With the instructions available the leafpads would be reprodible in other low-middle income countries. The specific countries would however depend on what materials are available.

Functionality		
W-F-1	Reduces quantity loss to the fullest	—
W-F-2	Reduces quality loss to the fullest	—
W-F-3	Applies to as many people as possible	—
W-F-4	Reduces temperature of tomato compared to current situation	?
W-F-5	Protects tomato from dust	×
W-F-6	Protects tomatoes against contamination with microorganisms	✓
W-F-7	Lasts as long as possible	—
Acceptance		
W-A-1	Pays out as fast as possible	—
W-A-2	Requires the least possible investment	—
W-A-3	Packaging is as fast as possible	—
W-A-4	Packaging is as easy as possible	—
W-A-5	Reusable for same or other purposes	✓
W-A-6	100% of farmers and market women accept the use of banana leaves	×
Production		
W-P-1	Farmer can produce the tools	✓
W-P-2	Materials for the solution & tool are obtained in a 10km radius of Kumasi	✓
W-P-3	The solution is replicable for farmers in other low-middle income countries	✓

Table 18– Assesment of wishes

Take-aways from chapter 7

- The leafpad is a transport protection sheet that can be produced by Ghanaian farmers themselves. They are placed in between layers of tomatoes when being transported in wooden crates. The leafpads absorb shock and vibration during transport, function as a layer between the fruits so they don't bump directly into each other and divide weight from the layers of tomatoes above more evenly. They also form a barrier that hinders the spread of microorganisms between layers.

- The leafpads consist of 3 layers of banana leaves placed over each other and glued with the veins perpendicular to each other. This increases the strength of the sheet and prevents the sheet from ripping easily. During drying of the leafpads, the leaves shrink slightly, creating air pockets that give the sheets thickness that functions as padding.

- The leafpads are a cheap, easy and environmentally friendly solution that farmers can produce and use themselves to reduce losses and increase revenue. They help mitigate the effects of larger problems that take time to fix like low-quality roads, unrefrigerated transport, an unorganised chain and market availability.

- To make the leafpads cutting stencils, a drying rack and a paintbrush are necessary as fixed equipment. The variable components are self-made biodegradable glue and banana leaves. The components are all easy to obtain in Ghana.

- To test the effect of the leafpads on post-harvest losses and revenue a simulated transport test is performed, mimicking real conditions as closely as possible. Tomatoes are placed in a wooden crate with the leafpads, loaded onto a cargo bike, and driven over uneven roads. The resulting quantitative and qualitative losses are then measured and evaluated with the help of comparison studies. The estimated effect is 10% less quantitative post-harvest loss and 20% less qualitative post-harvest loss which creates a 12% increase in revenue at wholesale level over the year and a 26% increase at market level. With the used data the payout time for the average farmer comes down to about half a month if the leafpads are used 3 times and about 1.5 months if the leafpads are not reused.

- Overall, the design was described as innovative during evaluation with 5 Ghanaian stakeholders. They thought it was great that the design is biodegradable, the investment seems reasonable, and it is easy to obtain the necessary materials and work with them. The main insecurity named by the stakeholders is the effort and time required to put in and the implementation of the leafpads in the current context. Through discussing the questions and insecurities ideas for development emerged around targeting, value propositioning and marketing, turning it into a business and identifying the right output channels.

- All participants of the stakeholder validation questionnaire conducted amongst Ghanaian farmers and consumer stated the would use the leafpads for the current investment. 88% would still use it for the mentioned effort for production.

- To enable independent reproduction of the solution a farmers guide is created with instructions, information and tips. The instructions were tested by a Ghanaian farmer who did a trial of producing the sheets. Challenges included leaf tearing from wind, using leaves at the right maturity, and curling during drying due to improper rack use.

08.

Implementation & recommendations

The implementation of the leafpads requires several steps. First the implementation for the design as it currently is is layed out, including the guide for farmers to reproduce the leafpads. Then a recommendation for scaling up the production of the sheets to turn it into a business is added as is discussed during stakeholder validation. Following that, the project and solution will be discussed through acknowledging limitations and addressing the feasibility. Lastly recommendations for further research and the potential for application in other areas will be made.

8.1 Implementation roadmap

The plan suggests 3 horizons (figure 99). It includes the implementation of the leafpads for independent production and recommendations for scaling up the production to turn making the leafpads into a business. The bottom region includes the activities specifically for Kwadaso Agricultural college and the other colleges taking part in the ACHI programme.

8.1.1 Horizon 1: Implementing independent production

The goal of this horizon is to validate the leafpads and production process for self-use in Ghana and make optimizations where necessary. The first important action is to perform post-harvest loss tests in the real use context in Ghana. The second one is to conduct a large survey and interviews with farmers to identify the ones that are interested in producing the sheets themselves versus buying the sheets from a company in order to formulate a targeting plan.

8.1.2 Horizon 2: Scaling up production

The goal of this horizon is to develop a complete business plan and develop a scaled up production process. Making a business plan for a company is a regular assignment in the ACHI curriculum and would therefore fit perfectly. The plan for scaling up the production process would be recommended to cover in a separate project either in Ghana or for example with students in Delft. A more substantive recommendation for scaling up the production process is described in chapter 8.3

8.1.3 Horizon 3: Setting up a business

This horizon is about creating demand in several ways to acquire a customer base to sell the leafpads to. It aims to prepare everything necessary to actually start production of the leafpads as a company. The company space is set-up, a brand is created and samples are provided to show the effectiveness and build a network of customers.

Figure 99 - Implementation roadmap

8.2 Scaling up the process

When the production is scaled up a more “industrialized” process needs to be developed to facilitate a more efficient production process. Each of the steps of the current process in the pre-treatment and production of the leafpads is layed out below. For each of the steps the way it is executed in the final design in this report is described and options that are recommended to explore for scaling up the production. The recommended options are chosen based on their appropriateness for the banana leaves, sheet production and the context of Ghana, considering important factors such as increasing speed in the process, maintaining low costs and using the least amount of electricity. This is meant to keep the leafpads and their production accessible and cheap. For each of the steps a mention is made of what is important to consider when scaling up that specific step.

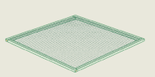
	Acquire leaves	Clean dirt & insects off	Cutting the leaves into the right size	Apply heat treatment	Quick drying	Assembling the leafpads	Drying the leafpads	Use phase
Final design	 For free from own farm or other farms	 Wipe a wet rag over the leaves	 Cutting around a stencil manually	 Boiling in a pot of water over a fire	 Airdrying or wipe with a cloth	 Apply glue manually and layer leaves	 Sun or air drying in a drying rack	 Farmer using themselves
Options for scaling up production	• Connect with farmers, discuss collaboration & fair price	• Gentle water spraying (Conference for Food Protection, 2018) • Rotating soft brush • Air blowing	• Press punching (Benson, 2003) • Die cutting (Interwell, n.d.) • Roller cutting	• Submerge in hot or boiling water bath • Steam treatment • Hot air treatment (Chua & Chou, 2003) • Infrared treatment (Chua & Chou, 2003)	• Air drying	• Spray adhesive (Ebnesajjad & Landrock, 2015) • Roll coating (Ebnesajjad & Landrock, 2015)	• Hot air treatment (Chua & Chou, 2003) • Solar drying or improved solar drying (Masud et al., 2020) • Infrared drying (Chua & Chou, 2003) • Hot sheet drying (Babar et al., 2020)	• Selling to farmers • Selling to other target groups
Important to consider	Setting up partnerships that benefit all involved stakeholders	Since leaves are prone to tearing leaves should be cleaned gently. Explore if heat treatment can be combined with cleaning	Cutting should be done by applying force from 1 side. An up and down motion dring cutting can tear the leaves	Heating & sterilizing only needs to be done in short time (1 min) and has to happen evenly to prevent deformation of the leaf	Leaves only need to be dried shortly in this step so they are not fully wet when glueing starts. A little moistness is okay.	An even and thin layer of glue needs to be applied. Leaves need to be placed over each other neatly, best done manually	This step currently takes the most time. Quickly drying many leafpads simultaneously is crucial to speed up the process.	Finding the right output channels, determining a price and building a customer base through marketing.

Figure 100 - Steps for scaling up the production

8.3 Discussion

Throughout the project there are several factors limiting the research and design process. These constraints are explained in detail and an assesment on feasibility is made through using the values of design for the base of the pyramid.

8.3.1 Constraints

The ways in which the project is limited have largely to do with the duration and location of the project. They are discussed below.

Project location

The project client, target group and other stakeholders are for the larger part from Ghana. For me it was unfortunately only possible to spend a part of the duration of this project in Ghana. The choice was made to plan the visit at the beginning of the project, conducting the majority of the reseach phase in Ghana which was very beneficial to get an idea of the context and identify opportunities. Almost the full design process is however conducted in the Netherlands. In an ideal situation the full length of the project would be conducted in Ghana. This would allow stakeholders to be more involved in every part of the project and especially the design phase. Also the testing of the solution would be more accurate in the real context.

Next to this the research is limited to Kumasi since all interviews and observations are conducted there (figure 101). Since the main beneficiary of the project is Kwadaso Agricultural College and the time in Ghana was limited Kumasi is a good place to conduct the research. However an even more developed solution could be designed if the locations of other agricultural colleges in Ghana to which the ACHI project will expand were taken into account.

Time contstraint

The full length of the project is 100 working days, which is already limited time in itself to execute a completely thorough project. Out of these 100 days a quarter were spend working in Ghana, meaning that physically speaking to and visiting stakeholders was only possible for 25 days. Simultaneously, getting familiar with the culture and customs in Ghana took time as well since prior knowledge about the country and horticulture were limited. Without the time constraint more research area's could have been explored in a richer way and a wider pool of stakeholders could have been included in interviews and observations.

Cultural differences

Difference in customs and sometimes the lack of knowledge thereof can account for misunderstandings or incorrect information. An example is a situation at the market. When asking market women their prices they might be wary to reveal them if certain people are present. Prices are competitive so if they suspect someone might also sell vegetables they will disclose a higher price than the actual price to set them of on the wrong foot (farmer, 2024; appendix 5.1).

Even though a translator was present during all interviews and observations, some constraints arise as a result of a language barrier. Some farmers have a hard time understanding english which limited their understanding of the questions. Also translation errors or mistakes can account for misunderstandings or semantic differences in the data.

Fragmented system

The fresh valuable chain in Ghana contains many individual players that function separately or handle matters in their own way. Overall there is a lack of cohesion and collaboration in the system. This fragmented system includes lots of complexity with which has to be dealt in the project. The system contains many different players that handle their own chain in a different way, making it hard to satisfy all stakeholders accordingly and bring them together.

Limited availability of information

For a part of the research conducted in the Netherlands relying on the internet for information was necessary. Unfortunataly data on most topics in Ghana is not largely available online, limiting this part of the research to what is available online.

Also available information on working with banana leaves is extremely limited. This had to be accounted for by experimenting with ways on how to handle and design with banana leaves. If this information would have been available already more time could have been spend in optimizing the final solution and assessing feasibility.

Figure 101- Several adjacent farm lots in Kumasi

8.3.2 Feasibility in the context

The feasibility of the solution is highly dependent on the context in which it operates. Especially when cultural differences arise, an open attitude and recognition of presumptions are necessary to design a feasible solution. Next to this, when designing for people who belong to the Base of the Pyramid (BoP) from an economical perspective there are several principles to which extra attention must be paid in general (Van Boeijen et al., 2020): affordability, accessibility, availability, reliability and sustainability. These principles are shortly discussed.

The leafpads are highly affordable due to the use of cheap materials and minimal tools, allowing production to be done at home. Scaling up production can also be done economically. Its accessibility is enhanced by the ability to produce the tools and sheets off-grid, making it suitable for farmers in rural areas without electricity (figure 102). However, the need for water may limit its use in regions where water is scarce. In terms of availability, all necessary materials are widely available in cities across Ghana, though access may be more difficult in rural areas which needs further research. The skills required for production are readily available. The leafpads are reliable as the tools are easy to maintain and repair by the farmers themselves, reducing dependence on others. Reusing

Figure 102 - Rural area in Ghana

the sheets does however depend on the cooperation of other stakeholders to return them with the crates. Finally, the leafpads are sustainable, being bio-sourced, biodegradable, and electricity-free in their production, while also reducing tomato losses and maintaining quality. On many aspects the leafpads do not harm the environment though resource acquisition still has some impact.

8.4 Recommendations

This chapter recommends several areas for continued research for the leafpads and areas into which research can be expanded.

Glue optimization

The glue recipe used for the leafpads works sufficiently for the current application, however a version with more adhesive strength that is still biodegradable could benefit the design even more. Therefore more different natural glue recipes could be tested to find the optimal combination of leaf and glue. Also research into an effective biodegradable spray version of the glue is recommended. Because of ingredients that are often used in spray adhesive the glue is harmful to the environment. With an effective recipe and method for spraying the glue the process would be more efficient and easy.

Researching other leaves

Plantain and banana plants can be found in abundance in Ghana but these are not the only ones. There is a wide variety of plants and trees throughout the country that could possibly also have potential to be used in the leafpads. There might be leaves with similar properties to the banana leaf that have different vein structures that make the leaf less prone to ripping. Other plants might also grow faster or produce bigger leaves that would decrease the amount of separate leaf pieces used for one sheet.

Next to trying different leaves tests could be done with different species of banana or plantain plants and stages of maturity of the leaf to determine if one works better than the other. During the project several different species and maturities were used from several suppliers (figure 103 & 104), all working sufficiently but giving different effects.

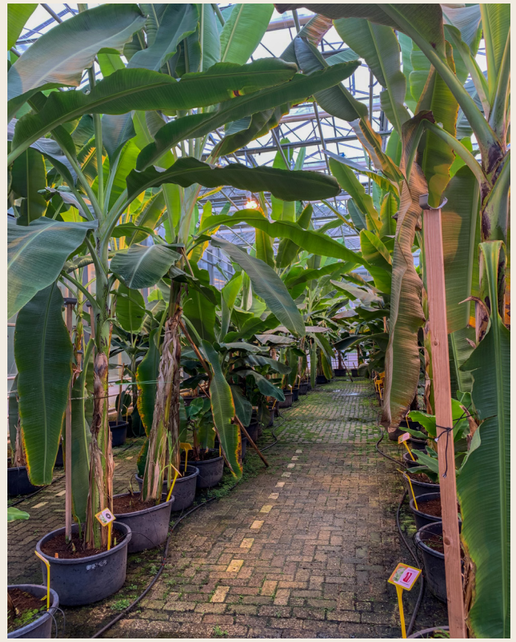


Figure 103 - Nederbanaan greenhouse

Figure 104 - Greenhouse from Utrecht University Botanic Gardens

Application to other horticulture products

For this project the focus is on tomatoes transported in wooden crates, but as described in chapter 2 there are many other horticulture products that are transported in different containers. The leafpads could for example also be useful for protecting horticulture products in plastic fibre bags, baskets or buckets (figure 105). Also, the application for different types of vegetables and fruits could be promising since every small decrease in losses helps.

Expansion to other countries

Within this project the solution is optimized for use in Ghana, but in many other African countries the resources are also available. Holland Greentech could play a role in this by helping the distribution of the farmers guide through their branches in different African countries. Expanding to other continents in the world where high amounts of post-harvest losses also occur could be promising if the solution is adapted to that specific context.

Exploring target groups

As discussed in chapter 8.4 the conducted research is focussed on Kumasi and optimized for this target group. Commercial smallholder farmers in different urban areas or rural areas in Ghana might have different needs for which the leafpad needs to be adapted. The target group could also be expanded to other stakeholder that would be interested in investing in the sheets such as market women or middle women.

Figure 105- Horticulture products in different containers at a local market

Take-aways from chapter 8

- For implementation a plan is suggested with 3 horizons:
  - Horizon 1 - This horizon focuses on validating leafpad production for self-use in Ghana through post-harvest loss tests and farmer surveys to determine interest in self-production versus purchasing.
  - Horizon 2 - The goal is to create a comprehensive business plan for scaling production, fitting within the ACHI curriculum.
  - Horizon 3 - This horizon aims to generate demand and set up a company producing the leafpads. Key actions include setting up the company, creating a brand, providing samples, and building a customer network.

- When the production is scaled up a more “industrialized” process needs to be developed to facilitate more efficient production process. An overview of the recommended steps and options is presented that focusses on increasing speed, low costs and appropriateness for the context.

- There are several constraints that limited the research and design process. Topics are the location of the project and stakeholders, time constraints, cultural differences, a complex fragmented system and limited availability of information on Ghana and banana leaves.

- Feasibility is assessed on values for design of the Base of the Pyramid (BoP). The leafpads are affordable due to inexpensive materials and minimal tools. They are accessible for off-grid farmers but limited by water availability in some areas. Materials are widely available in cities, though rural access needs further research. The leafpads are reliable, as farmers can maintain the tools themselves. It’s also sustainable, being bio-sourced, biodegradable, and reducing tomato losses.

- Further recommendations for continuation and expansion of the research are optimizing the glue recipe, researching biodegradable spray adhesive, exploring options for other types of leaves, application of the solution to other horticulture products, expansion to other countries and identifying new target groups.

09.

Personal reflection

This chapter will look back on several aspects of the project. I will reflect on my project and process management and on the evolution of the design challenge, the course of the research phase, the end-result and it’s impact.

9. Personal reflection

Now that the end of this project is in sight I want to take the time to reflect on several aspects of this project. At times it was challenging, but it mainly enabled me to experience yet another totally different approach and field of design which was exciting.

Project management & process

Throughout the project I have covered the topics I wanted to cover, although I would have loved to dive into some of them a bit deeper. I am satisfied with the amount of work I did, but would have liked to focus it better at some point in the process. At these points it was hard to find a balance between exploring all options there are or delving deeper into one option.

It was really fun to get familiar with new ways of working in different phases of the project. The research phase required me to be flexible and adapt to the schedule of Ghana, where plans were not always set in stone. On the other hand the prototyping phase required me to be structered and selective because there is a limit of what you can explore within one project. Overall this project mainly required me to be open. First towards a new culture and industry and then to the options of an unfamiliar material.

The design challenge

At the moment of submitting my original project brief (appendix 21) I would have never guessed to end up with this solution. I started with quite a broad challenge and the task to scope down during my research phase in Ghana. As a result of my research quite some opportunities arose, however choosing on which one to focus was a tough decision since I had spend only 5 weeks in Ghana to get to know the country, get familiar with the fresh vegetable value chain and talk to stakeholders. Because it was a tough decision I slightly postponed it. If I look back I would have pushed myself to be a bit more bold and take the decision earlier on. This would have left me with a few extra days in Ghana to spend on co-designing the solution with stakeholders.

Despite this I am very satisfied with the direction I chose because it led to a unique project that's different from what I have done before. Especially using a quite unfamiliar material about which very little information is available was exciting. Although I first felt a bit worried by the lack of information it gave me a lot of freedom to try new things and really make it my own project.

The research

One of my goals at the beginning of this project was to expand my field research skills to gain a rich understanding of the context. Given that the context is a totally different country with totally different customs where I am not familiar it was easier to leave biases behind because I didn't have a specific expectation. Being in this totally different context actually pushed me to ask more questions because it made me more curious.

I really enjoyed talking to all the different stakeholders in Ghana. Most of them were excited to share information about their farm and interested in what my project could bring them as well. Acquiring a wide variety of interview and observation participants while in Ghana went very well, however finding participants for online questionnaires in the later stages of the project was unfortunately very challenging. Looking back I should have acquired more phone numbers of stakeholders in Ghana and then specifically from market women.

The solution and its impact

Overall I am happy with the results and the potential the leafpads have to reduce post-harvest losses. I feel confident that the solution fits the target group and that it could work in the real context. I am however not fully satisfied about the time it takes to produce the sheets since this could be a barrier for farmers when implementing the leafpads. If the solution will be widely implemented remains uncertain for now and needs to be proven by time, but at least all materials to start production are available. It is available for anyone that wants to try it and it can be easily done with very few resources, which I think is very nice.

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Appendix guide

Appendix guide

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| Master thesis
| Integrated Product Design
| TU Delft