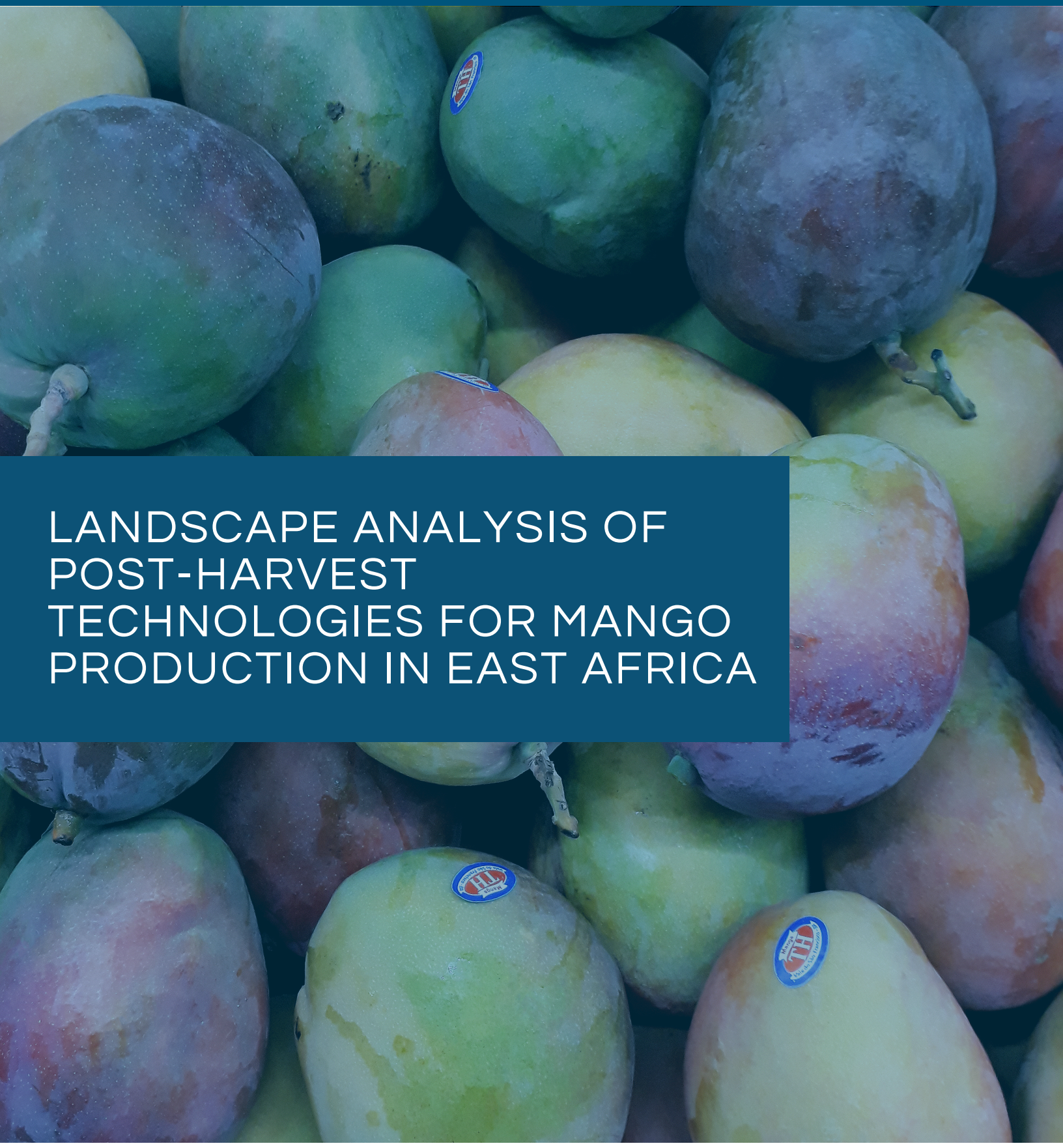

LANDSCAPE ANALYSIS OF POST-HARVEST TECHNOLOGIES FOR MANGO PRODUCTION IN EAST AFRICA

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Executive Summary

Mango cultivation is a major source of livelihood for many farmers in Kenya. Kenya produces 1,024,500 metric tonnes of mango annually but due to a number of factors, it is estimated that about half of the mangoes produced are lost. Among the contributors to the losses, poor postharvest handling techniques has been identified as a major contributor to mango postharvest losses in Kenya.

In order to help reduce these losses, this research sought to investigate the actors in the Kenyan mango value chain, identify the points in the value chain where the losses occur, highlight the current technologies that are being used for mango processing and propose new technologies that can be adopted for improved efficiency in the processing of mangoes to reduce postharvest losses. The research involved both desk research and semi-structured interviews of farmers, academics and other actors.

The data synthesized from the desk research and interviews shows that the value chain actors include farmers, government agencies, NGOs, academic institutions and processors. It was noted that the postharvest losses occur throughout the value chain, beginning right after harvesting, through transportation to the fresh mango markets and even during processing. Nonetheless, the volume of mangoes lost at the various stages in the value chain has not been quantified across the country, hence, it is difficult to determine the exact volume lost. The losses were found mainly to be the result of a lack of suitable technologies for the postharvest handling and production of a wider range of mango products.

Additionally, a number of processing technologies were identified. These technologies are currently used mainly by small-scale processors, self-help groups and some farmers to make products such as mango juice, mango leather and dried mango slices. However, the use of some of these technologies came with challenges which affected the quality of the mango products produced.

To achieve a significant reduction in mango postharvest losses in Kenya, new technologies have been proposed in this research to offer small-scale processors a wider pool to choose from to process mangoes. Also, some of these technologies open the way for new avenues that have not yet been explored in the mango processing sector in Kenya.

Finally, it is proposed that the value chain actors consider the adoption of a circular economy to allow for the use of the by-products from mango processing for the production of other high value products like pectin and polyphenols. These can be used in other food and cosmetic applications, thereby creating new markets for the mangoes.

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Introduction

Globally, about 25-40% of mangoes are lost between the point of harvesting and the point where mangoes reach the consumers.[1] These postharvest losses occur due to a wide range of factors throughout the mango value chain. Kenya is among the leading producers of mango in Africa, producing an estimated 1,024,500 metric tonnes of mango annually,[2] with the most developed mango production in the East African region.[3,4] However, Kenya's high production is accompanied by major losses throughout the value chain; these losses are estimated at 40-50%, slightly higher than the global average.[5] Further, a 2018 United Nations Women report[6] indicates that the mango losses in Kenya are largely due to a variety of harvesting and postharvest handling techniques, as well as pests and diseases. And, since there are many technologies and solutions available for reducing mango postharvest loss across the value chain, this research aims to provide needed synthesis and landscape analysis for practitioners, implementers, and mango farmers.

The United Nations Sustainable Development Goal 12 Target 3 (12.3) is to halve postharvest loss by 2030.[7] In order to inform practitioners working to help Kenya achieve this target, this research sought to understand the Kenyan mango value chain and the ways in which the actors and technologies throughout the chain influence the postharvest losses. This research provides a landscape analysis of the technologies used in Kenya to process mangoes. Additionally, other technologies are reviewed to offer mango farmers and other value chain actors a wide array of technology options that can be implemented to improve postharvest handling of the mangoes, thereby, reducing postharvest losses.

Methods

In partnership with the Institute of Food Technologists (IFT) and the FEAST Lab at the University of Missouri - Columbia, E4C Fellows explored losses in the mango value chain in East Africa, specifically Kenya, and the technologies and processes that can reduce these losses through desk research and expert interviews. News articles, research reports, and peer-reviewed articles were examined for case studies across the region. Next, Fellows conducted eight semi-structured interviews with academics, farmers and development practitioners who had relevant experiences in the topic of interest. Data from both desk research and interviews were coded and organized for claims and themes, while technologies identified were used to compile a table of technologies that can help to reduce post-harvest losses.

The primary limitation of the research was the inability to travel to Kenya to directly observe the postharvest handling of mangoes and to have in-person interviews due to travel restrictions in place during the global COVID-19 pandemic. Another limitation was the time constraint of the research and the inability to conduct interviews with all of the prospective interviewees within the time allotted. In particular, the Fellows were not able to interview any personnel in mango processing facilities in Kenya.

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[1] Evans, E. A., Ballen, F. H., & Siddiq, M. (2017). Mango production, global trade, consumption trends and postharvest processing and nutrition. Handbook of Mango Fruit; John Wiley & Sons: Chichester, UK, 1-16.
[2] Food and Agriculture Organization, Major Tropical Fruits Statistical Compendium, 2017.
[3] Interview with Prof. Dr. William Kyamuhangire, Food Technology and Business Incubation Centre, Makerere University, Uganda, September 2020
[4] The Association of Mango Growers, Mango Value Chain Analysis in Tanzania, 2011
[5] Mujuka, E., Mburu, J., Ogutu, A., & Ambuko, J. (2020). Returns to investment in postharvest loss reduction technologies among mango farmers in Embu County, Kenya. *Food and Energy Security*, *9*(1), e195.
[6] United Nations Women, Mango farmers in Kenya get access to new technology to counter post-harvest losses, 2018.
[7] United Nations, Sustainable Development Goal 12, 2016

Mango Product Economy

Value chains are commonly used to represent and evaluate agricultural outputs and assess product economies. A value chain is a graphical representation of the actors required to bring a product from its inception to its final sales point. In this context, an actor is any person, organization, company, or resource that has a direct affect on the product's path. Common elements of a value chain are input supplies, producers, processors, and buyers.[8] Developing a value chain allows researchers to identify problems and places of potential growth for a product.

Value added processing of Mango

Mango can be processed into a wide range of products. The mature fruit has 79-83% water, 16-17% carbohydrates[9] in the form of simple sugars like glucose, fructose, and sucrose as well as other carbohydrates such as starch and pectins.[10] Generally, about 90% of the fruit is edible flesh since it has a thin, flat seed.[11] From this edible flesh, a variety of products can be made. These include juice, vinegar, pulp, wine, mango leather, jam, puree and others. The thin flat seed is a good source of essential fatty acids oils that can be extracted and used in food and pharmaceutical applications. The fatty acid profile of the mango seed includes palmitic acid, stearic acid, arachidic acid and linoleic acid, ranging anywhere from 0.67% up to 58% of the seed, depending on the mango variety and the fatty acid.[6]

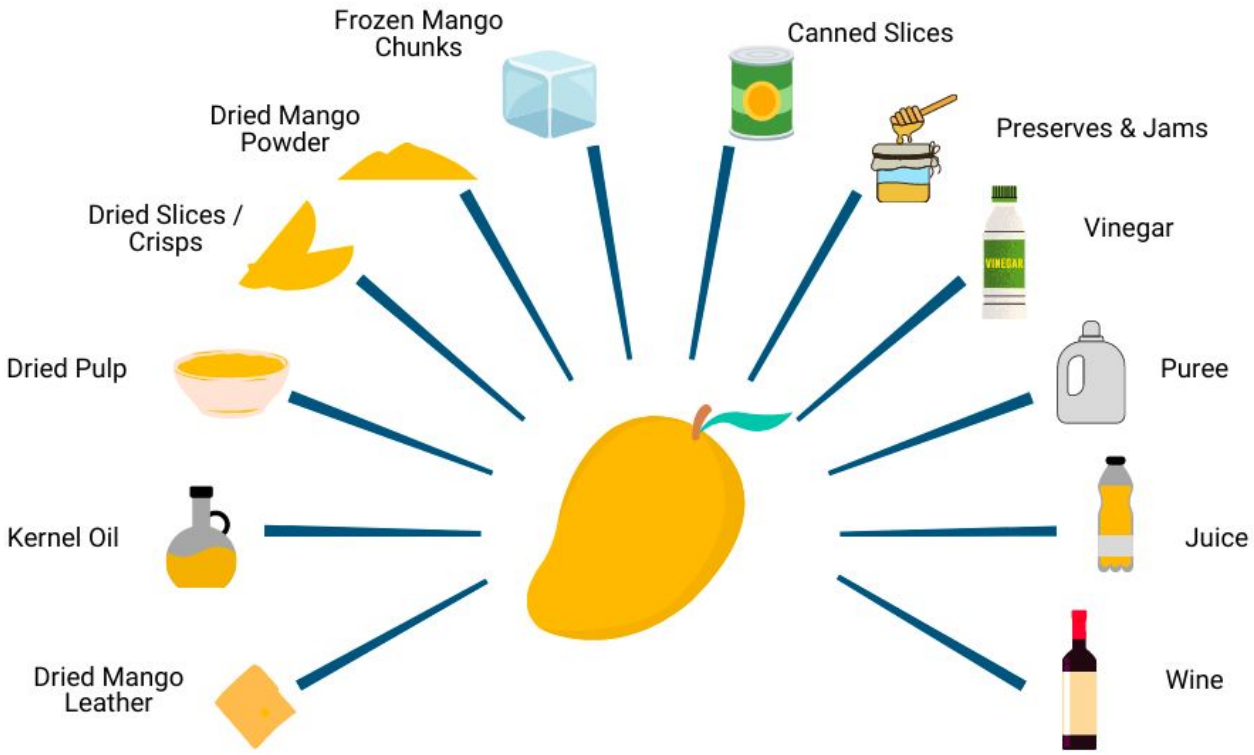


Figure 1. Products that can be produced from mango.

[8] Marketlinks by USAID, Learning Value Chain Basics, 2020.
[9] Maldonado-Celis, M. E., Yahia, E. M., Bedoya, R., Landázuri, P., Loango, N., Aguillón, J., ... & Ospina, J. C. G. (2019). Chemical composition of mango (Mangifera indica L.) fruit: nutritional and phytochemical compounds. Frontiers in Plant Science, 10: 1073.
[10] Bello-Pérez, L. A., García-Suárez, F. J., & Agama-Acevedo, E. (2007). Mango carbohydrates. Food, 1(1), 36-40.
[11] University of Hawaii, General Crop Information: Mango, 2011.

Demand exists in Kenyan cities for processed mango products as long as they are of a high quality; however, Kenyan products often lose out to better quality and cheaper imported alternatives. Many mango processors in Kenya fail to conduct an adequate market analysis, so they are not able to produce a desirable product. In addition, many farmer cooperatives that produce mango products will try to create many products of low or medium quality instead of focusing on improving the quality of one product. All food products in Kenya must have quality certification, but producers may try to cheat the system by only sending their best products for analysis, leading to distrust from consumers.[12,13]

The Kenyan Mango Value Chain

The mango value chain involves non-governmental organizations (NGOs), who provide training and incentives to the farmers, farmer cooperative groups, financial institutions who provide loans to farmers, mango processors and others. Farmers may be able to access loans from financial institutions to support their farming activities. Some farmers have received training on postharvest handling of mangoes from NGOs, government agencies, universities and international organizations like the Food and Agriculture Organization of the United Nations (FAO).[14] The training has enabled the trained farmers to adopt better postharvest practices. One of such practices is turning the harvested mangoes upside down immediately after harvesting and transporting them from the farm in paper boxes which can hold one layer of mangoes at a time per each box. This practice is important because when mangoes are harvested, the drippings from the stalk leave burn marks on the mangoes when the drippings touch the mango skin. This leads to some postharvest losses as the skin of the mango becomes compromised, allowing for easy entry of pests or microbes which cause spoilage. According to findings by Wageningen University and YieldWise, about 13% of mangoes harvested in Kenya are lost on the farm, 80% of which are a result of pests, disease, or poor harvesting.[15]

In order to help farmers have easy access to training, increase their bargaining power, and reduce losses, many farmers have formed cooperative groups. In an interview with Emmanuel Amwoka, a Graduate Research Assistant at the University of Nairobi, it was noted that cooperatives have collective bargaining power, allowing farmers to negotiate a good price with brokers/traders and processing plants. Further, he indicated cooperatives can approach brokers with a deal instead of single farmers relying on brokers to come to them. According to a Farmers TV Kenya report, one of such cooperatives, the Makueni Fruit Processors cooperative has about 250 members who pool their mangoes together to get better access to some markets and better prices for their mangoes.[16] NGOs encourage farmers to form such groups to help them market their produce to processors and exporters, reducing postharvest losses and increasing the farmers' income.

Brokers and traders in the Kenyan mango value chain are often middlemen who sell mangoes to export markets and local markets. Often, these brokers and traders are contracted by the farmers to harvest the mangoes and transport them to the respective markets.[14,17] In some instances, per the agreement with the broker or trader, the farmer may be required to harvest the mangoes onto the farm to wait for the trader to come and purchase them. In such situations, the brokers and traders often come very late when the mangoes are almost going bad, resulting in significant losses in the value chain.[14]

[12] Interview with Isaac Nyangena, Kenya Bureau of Standards, July 2020
[13] Interview with Emmanuel Amwoka, University of Nairobi, July 2020
[14] Interview with Prof. Willis Owino, Jomo Kenyatta University of Agriculture & Technology, August 2020
[15] Wageningen University and YieldWise, Sustainable Food Lab and Wageningen University & Research Action Research Project, 2018
[16] Farmers TV Kenya, Mango farmers from Makueni supplying their produce to Mango processing plant - Part 2, March 2020
[17] Interview with Benson Maina, Apeel Sciences, July 2020

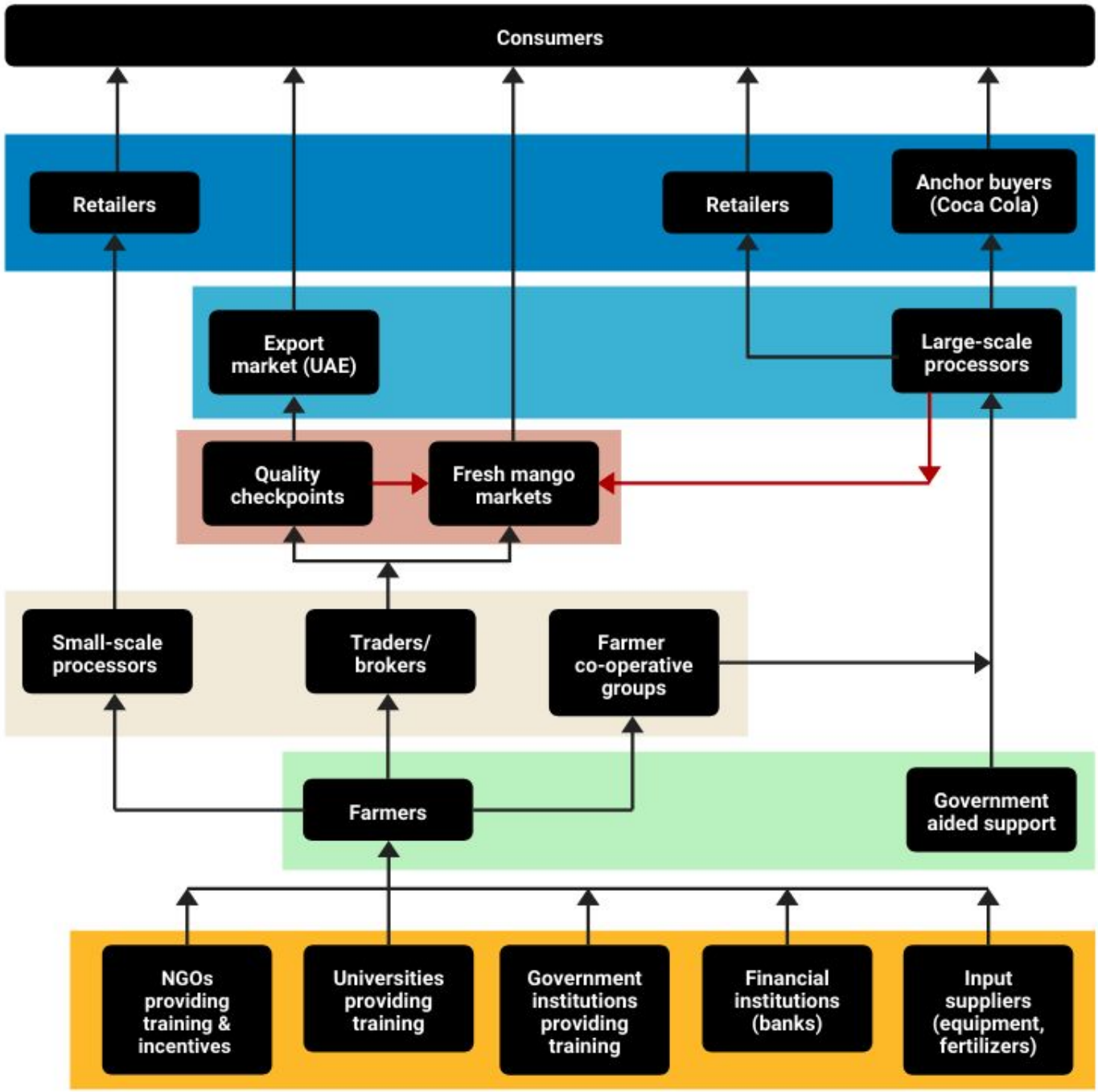


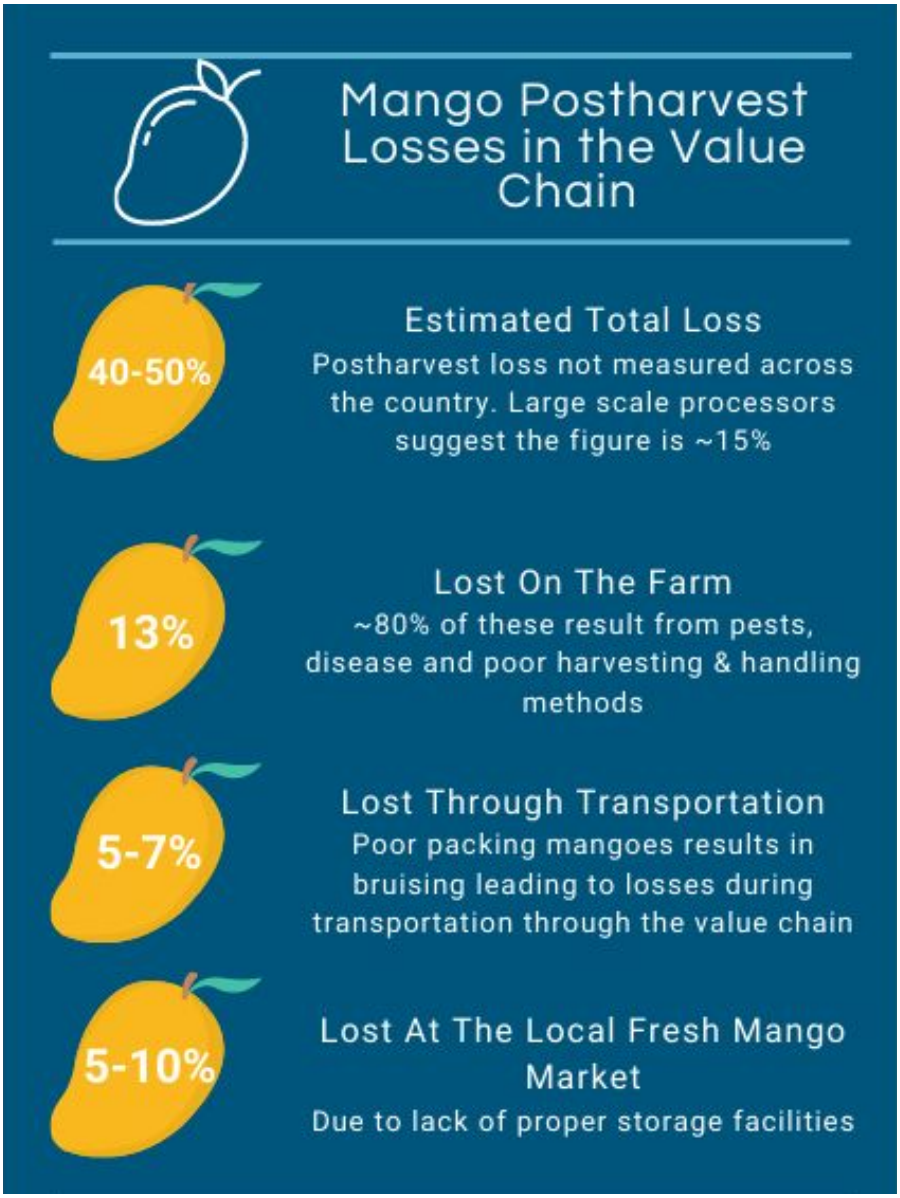
Figure 2. The Kenyan mango value chain.

Also in the value chain are aggregation centers where mangoes are processed. Groups of farmers have formed self-help groups, similar to the cooperatives. These self-help groups have aggregation centers where member farmers send their mangoes to be processed into products like mango leather, mango wine, mango juice and mango pulp.[14,18]

Aside from these aggregation centers where mangoes are collectively processed, some farmers also directly dry

[18] Interview with Mr. Muigai, Farmer & Secretary - Karurumo Horticultural Cooperative Society, July 2020

their mangoes. However, drying is a growing area many farmers are yet to explore. In Kambiti, Kenya, where 400 kg of dried mangoes are produced annually, more than 80% of the mangoes harvested are lost.[19] It is not clear what proportion of these losses occur during drying. Nonetheless, Wageningen University analysis shows that there are high losses during mango drying in Kenya.[10] In March 2020, two new processing plants were opened to dry mangoes and process some into juice.[20] The combined capacity of these new plants is 10,000 metric tons of mango per year. Along with the Kalamba Fruit Processing Plant, established in Makueni county by the county government, these two facilities will help Kenya process more mangoes, reducing postharvest losses.



Local markets play a substantially larger role in the value chain than Anchor buyers. Coca Cola, one of the largest anchor buyers, purchases puree from partner processors to use in the production of its Minute Maid product.[21] Despite this, Coca Cola still only purchases approximately 17% of it's partner farmers' mango yields for when processed as puree, with the vast majority (80%) instead being sold at local markets. In addition, those mangoes which do not meet export or processing specifications are sent to the local markets, indicated by the red arrows in Figure 2.

Given their particularly important role within the value chain, mango losses at the local fresh mango market and during transportation are notable. Based on data collected by Technoserve, a Rockefeller Foundation funded NGO working on reducing mango postharvest losses in Kenya, 5-10% of the mangoes are lost at the local fresh mango market due to inadequate storage facilities to help extend the shelf life.[21] Additionally, approximately 5-7% of the mangoes are lost during transportation through the value chain. This is mainly due to poor packaging, as noted by a report by Deloitte.[21] For instance, mangoes are packed into sacks instead of crates, which results in bruises on the mangoes and subsequent microbial and pest spoilage.

[19] Technoserve, Eliminating Waste, Increasing Profits, 2020
[20] Stephen Rutto, Kerio Valley mango farmers to earn more from two new firms, 2020
[21] Deloitte & Touche, Reducing Post-Harvest Loss Through a Market-Led Approach, 2015

Choke Points: Areas of Opportunity

Throughout the value chain of an agricultural product, there are often points of losses and inefficiencies, which are referred to as *choke points*. These choke points offer opportunities for improvements and loss reductions. In Kenya, choke points in the mango value chain exist that can be addressed by (1) pre-cooling at point of harvest, (2) damage prevention during transportation, (3) packaging during transportation, (4) mango storage solutions, (5) processing of surplus mangoes into shelf-stable products, (6) drying technologies, (7) meeting certification and consumer standards, and (8) utilizing mango byproducts.

1 Pre-cooling at point of harvest

Pre-cooling involves removing field heat from any agricultural produce quickly following harvesting to reduce the respiration rate and resultant degradation. Pre-cooling mangoes can substantially reduce losses that occur both immediately following harvesting and further along the value chain where field heat otherwise accelerates mango degradation. Specifically, pre-cooling prevents quality degradation, increases shelf-life, minimises microbial growth and reduces spoilage.[22,23] Researchers investigating the Kent variety of mango in Kenya found that pre-cooling and cold storage in a cool room at 12 °C increased in shelf-life by 19 days compared to storage in ambient room conditions of 25 °C (for which typical shelf life is under 10 days);[24] however, specific shelf life improvements and optimum cooling temperatures vary between different varieties.[25,26] In addition, data from Junagadh Agricultural University when testing an Indian variety of mango (Kesar) found that 20 days after pre-cooling to 8 °C and subsequent storage at 25 - 28 °C, spoilage was reduced by 20.55%, with 55.48% more mangoes being marketable and a physiological weight loss reduction of 22%.[27] While this data is not directly transferable to the Kenyan context, by postulating that a 20% reduction in losses is possible as a result of pre-cooling, the potential annual Kenyan mango loss reduction would reach 81,960 MT, although the reality would be lower due to other loss factors such as bruising during transport.[28] One additional benefit of pre-cooling is that losses during transport are somewhat reduced since the pre-cooling increases mangoes firmness,[22] and subsequently their resilience to bruising.[12] Highlighting the value of pre-cooling, the FAO recommends that it is one of the most efficient and essential steps in fruit value chains.[29]

Despite the potential benefits for the mango value chain in Kenya, pre-cooling is rarely performed by smallholder farmers due to lack of cooling options and farmers' role within the value chain. Many Kenyan farmers lack capacity to pre-cool their mangoes, with over 60% of smallholder farmers lacking specified storage for mangoes following harvesting.[30] Further, farmers typically sell mangoes to traders on the tree, with the traders employing people to harvest the mangoes and load them onto vehicles for transport to wholesale or markets.[12] As a result,

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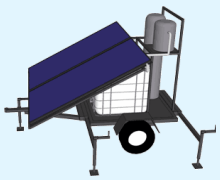
[22] Macs Cool Inc, Precooling, 2020
[23] Niranjana, P, Golpalakrishna, KPR, Sudhakar, DVR, and Madhusudhan, B, 2009, Effect of pre-cooling and heat treatment on antioxidant enzymes profile of mango and banana, African Journal of Food, Agriculture, Nutrition, and Development, 9(5), pp. 1210-1225.
[24] Amwoka, E., Ambuko, J., Jesang, H., Owino, W., 2019, Effectiveness of Cold Chain Management Practices to Extend Shelf Life of Mango Fruit. In: *6th RUFORUM Biennial Conference*. Nairobi, Kenya: RUFORUM.
[25] Karithi, E. M. (2016). Evaluation of the efficacy of coolbot™ cold storage technology to preserve quality and extend shelf life of mango fruits (Doctoral dissertation, University of Nairobi).
[26] Kitinoja, L. (2013). Use of cold chains for reducing food losses in developing countries. Population, 6(1.23), pp. 5-60.
[27] Makwana, S. A., Polara, N. D., & Viradia, R. R. (2014). Effect of Pre-cooling on post harvest life of mango (Mangifera Indica L.) cv. Kesar. Food Sci. Tech, 2(1), pp. 6-13.
[28] This figure was found by taking the FAO figure that 1,024,500 MT of mangoes were produced in Kenya in 2017 (FAO 2017), assuming total losses of 40% (i.e. 409,800 MT of mangoes) and taking 20% of the total losses, since the pre-cooling savings are against a background of mangoes being stored.
[29] FAO, Horticultural chain management for countries of Asia and the Pacific region: a training package, 2009
[30] Korir, M. K., Mutwiwa, U., Kituu, G. M., and Sila, D. N., 2014, Assessment of Postharvest Challenges of Mango Fruits in Upper Athi River Basin, Kenya, Scientific Conference Proceedings.

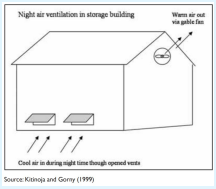
there is little incentive under the current system for farmers to invest in cooling technology; however, this could be different for cooperatives who are aggregating their mangoes before sale.

While access is currently limited, affordable technologies that can be constructed from locally sourced materials and used for farm- and cooperative-scale pre-cooling do exist. These technologies include evaporative cooling chambers and zero-energy brick coolers, in which construction has been supported by NGOs to provide mango storage for farmer cooperatives in Kenya.[12] Further, even simple measures such as harvesting early in the morning when ambient temperatures are lower or late in the afternoon to leverage night-time drops in ambient temperature,[19,31,32] placing harvested mangoes in the shade,[33] placing them in underground in caves or cellars,[34] and spraying them with clean water can provide some temperature reduction.[26] Using locally accessible options is recommended for affordability.[26] Those interested in selecting a suitable pre-cooling technology for their context may find Lisa Kitinoja's work to document and compare different pre-cooling technologies to be relevant resources, as well as USAID's Empowering Agriculture: Energy Options for Horticulture report.[29,28,26]

Table 1. Technologies involved in pre-cooling (full details in the appendix)

Image	Name	Technology Sub-category	User (value chain actor)	Image Source
N/A	Shade	Shade from sun	Farmers	N/A
	Zeer Pot	Small chamber evaporative cooling	Farmers	https://www.techxlab.org/solutions/practical-action-zeer-pot-fridge
	TRJ forced-air coolers	Forced-Air Cooling	Small-scale processors, Fresh Mango Markets, Large-scale processors	http://www.trj-inc.com/forcedAirCool.html
	TRJ Hydrocooler	Hydro-cooling	Farmer co-operative groups, Small-scale processors, Fresh Mango Markets, Large-scale processors	http://www.trj-inc.com/hydroCooler.html
	SunChill	Solar chilling	Farmer co-operative groups	© Rebound Technology: https://energypedia.info/wiki/SunChill:_Solar_Cooling_for_Horticultural_Preservation
No image available	Liquid Nitrogen cooling	Other	Large-scale processors	N/A

[31] USAID, Empowering Agriculture: Energy Options for Horticulture, 2009
[32] FAO, Rural structures in the tropics: Design and Development, 2011
[33] Kitinoja, L. (2013). Innovative Small-scale Post harvest Technologies for reducing losses in Horticultural Crops. Ethiopian Journal of Applied Science and Technology, 1 pp. 9-15.
[34] Kitinoja, L., & Thompson, J. F. (2010). Pre-cooling systems for small-scale producers. Stewart Postharvest Review, 6(2), pp. 1-14.

	Evaporative cooling chambers	Passive evaporative room cooling	Farmer co-operative groups, small-scale processors, Fresh Mango Markets	Benson Maina (interviewee)
	Mango Cold Storage Room	Refrigerated room cooling	Small-scale processors, Fresh Mango Markets, Large-scale processors	https://www.indiamart.com/proddetail/packaging-shredded-paper-16769291897.html
	Night Air Ventilation	Other	Farmer co-operative groups, small-scale processors	http://ucce.ucdavis.edu/files/datastore/234-1386.pdf

2 Damage prevention during transportation

Mangos, like many other agricultural products, are susceptible to damage during transportation, particularly from farm to processing facility, farm to sales point, and processing facility to sales point. Mangoes can become bruised due to rough handling, and bruised mangoes may sell for less or be outright rejected by retailers, making it important for farmers, processors, and sellers to have good transportation practices.[35] Many farmers rely on brokers to transport mangoes, and these brokers may not have appropriate equipment. Some mangoes are transported over 170 miles in trucks that are not specifically designed for mangoes, and many of the farms are in remote locations with poor road networks.[36] Even where better quality roads are available, sometimes transporters use alternative lower quality routes to avoid paying a tariff.[36] Furthermore, the farmers may be taken advantage of by transporters, with some brokers buying mangoes at the farm for USD 0.03 a piece and selling them for USD 0.06 to processing facilities.[31,37]

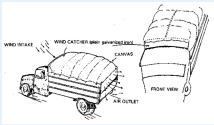
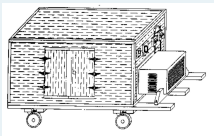
New technologies and improved approaches may reduce transportation-related losses during mango postharvest processing. Simple options such as using straw padding on the bed of existing trucks can reduce jolting and subsequent bruising,[38] while shifts to using trucks designed for transporting fruit could reduce losses and be profitable if the improved quality and reduced losses lead to increased sales for transporters.[31] Where pickups and open trucks are used, low-cost alterations can be made to increase ventilation by adding a wind catching space above the cab, but care must be taken to avoid excess drying out of the mangoes when using a wind catcher.[33] Processors such as Mucho Mangoes are even considering investment in refrigerated trucks for improved transportation.[39,40] Beyond these technologies, measures such as transporting mangoes at night or

[35] TechnoServe, Reducing Waste in Fruit Production, 2017
[36] Rockefeller Foundation, Reducing food loss in the mango value chain in Kenya: A good investment opportunity, 2017
[37] Interview with Peninah Yumbya, University of Nairobi, July 2020
[38] FAO, Small-Scale Postharvest Handling Practices: A Manual for Horticultural Crops, 2003
[39] Global Innovation Exchange, Mucho Mangoes Ltd, 2019
[40] Farm Biz Africa, Transport company launches refrigerated bus to ferry fresh produce between Nairobi and Mombasa, 2018

early in the morning can also reduce the heat the mangoes are exposed to, reducing physiological deterioration and susceptibility to bruising.[27]

The Kenyan government is aware of challenges in agricultural transportation and are taking steps to improve the situation. The Mombasa-Nairobi Standard Gauge Railway connects the two largest cities in Kenya, but the railway lacks suitable container carriages for mangoes and has poor coordination when it comes to shipping the fruit in bulk. The Kenyan Government is also investing in road construction, significantly including small roads, which are important for accessing agricultural areas.[41] Looking to improve practices, the Kenyan Ministry of Agriculture, Livestock and Fisheries (MOALF) is planning to encourage new small and medium-sized enterprises (SMEs) to enter the transporting space and provide them with training in good handling practices.[42]

Table 2. Technologies to reduce losses during transportation (full details in the appendix)

Image	Name	Technology Sub-category	User (value chain actor)	Image Source
	Straw padding	Improved open vehicles	Traders/brokers, Farmer co-operative groups	http://bic.kau.in/mango/frame20.php
	Ventilation for open trucks	Improved open vehicles	Traders/Brokers	http://www.fao.org/3/ae075e/ae075e20.htm
	USDA Porta-Cooler	Refrigerated vehicles	Traders/Brokers, Large-scale processors	https://naldc.nal.usda.gov/download/33418/PDF
	Controlled atmosphere and temperature (Reefer) containers	Shipping containers	Exporters, Anchor buyers, possibly very large-scale processors	https://www.hapag-lloyd.com/en/products/cargo/reefer/controlled-atmosphere.html

3 Packaging during transportation

Inadequate packing and packaging, particularly during transportation, can lead to bruising and damage to mangoes, causing substantial losses. Typically, mangoes are loaded directly into a truck and transported to the market. In some cases, mangoes are packed into sacks before loading them into the trucks for transportation. This increases the force exerted on the mangoes at the bottom, leaving them bruised and susceptible to pest and microbial infestation.[9] Further, these bruised mangoes may sell for less or be outright rejected by retailers,[30] contributing to the loss of those mangoes. The type of packaging used during transport can affect the

[41] Eberhart Capital, Optimizing Cold Chain Transport: Applying U.S. Lessons in Refrigerated Hauling in the Developing World, 2015
[42] Interview with Joshua Oluyali, Kenyan Ministry of Agriculture, Livestock and Fisheries, August 2020

susceptibility of bruising.[43] It is recommended that farmers pack 7-9 mangoes per 5-kg corrugated paper box, depending on the size and variety, to ensure mangoes are not bruised during transportation.[44] Use of cushioning material within boxes may also help prevent damage to mangoes, with tissue paper being particularly effective.[45]

Packaging decisions early on in the value chain affect the quality and shelf-life of the fruit later on in the value chain, particularly during storage. Unavailability of appropriate low-cost packaging materials is currently inhibiting effective storage and shortening shelf life.[46] Studies have shown that the choice of packaging material and the way the product is stacked can have an impact on the effectiveness of temperature-controlled storage.[10]

While packaging at the early stages of the value chain is causing these issues, neither desk research nor interviews identified any notable loss associated with the packaging quality for processed products. This indicates that packaging (and storage) of the processed products is sufficiently effective at delaying deterioration and preventing physical damage for the products to reach consumers in a good condition. Supporting this, Isaac Nyangena, a representative from the Kenyan Bureau of Standards (KEBS), indicates that if processors follow the standards for packaging set by the KEBS as required for the sale of processed products, there should be minimal losses between the processors and consumers as a result of poor packaging.[47]

Table 3. Packaging technologies which can reduce losses (full details in the appendix)

Image	Name	Technology Sub-category	User (value chain actor)	Image Source
	Wooden crates	Fresh mango containers	Farmer co-operative groups, Traders/Brokers, small-scale processors, Fresh Mango Markets	https://www.indiamart.com/proddetail/wooden-box-4188576591.html
	Corrugated Fibreboard (or cardboard) boxes/cartons	Fresh mango containers	Farmer co-operative groups, Traders/Brokers, small-scale processors, Large-scale processors, Fresh Mango Markets	https://www.fruiticana.org/mangoes
	Plastic crates	Fresh mango containers	Farmer co-operative groups, Traders/Brokers, small-scale processors, Large-scale processors	http://www.rootsexport.com/mango-king.html

[43] Chonhenchob, V. and Singh, S.P., 2003, A Comparison of Corrugated Boxes and Reusable Plastic Containers for Mango Distribution, Packaging Technology and Science: An International Journal, 16(6), pp. 231-237.
[44] GRW Global, Mangoes, 2012
[45] Burondkar, Z. M., Pawar, C. D., Haldankar, P. M., Burondkar, M. M., Kardile, P. B., Borkar, P. G., & Dhekale, J. S. (2018). Chemical Fruit Quality of Alphonso Mango as Influenced by Packaging and Cushioning Material after Long Distance Road Transportation. *Int. J. Curr. Microbiol. App. Sci*, *7*(5), 2658-2666.
[46] Ng'ayu, B., and Audet-Belanger, G., 2014, Road Map for Developing and Strengthening the Processed Mango Sector, International Trade Centre, Geneva, Switzerland.
[47] Interview with Isaac Nyangena, Kenya Bureau of Standards, July 2020

	Pallets	Fresh mango containers	Large-scale processors, Exporters, Anchor Buyers, Retailers	https://www.mango.org/wp-content/uploads/2017/10/Packaging_Final_Report_Eng.pdf
	Tissue paper/ straw padding	Cushioning materials and wrap	Traders/brokers, Fresh Mango Markets	https://www.indiamart.com/proddetail/packaging-shredded-paper-16769291897.html
No image available	Shrink wrap	Cushioning materials and wrap	Exporters	N/A
	Expanded Polyethylene foam nets	Cushioning materials and wrap	Exporters	https://www.alibaba.com/product-detail/EPE-expanded-virgin-polyethylene-foam-layer_60733473374.html
	Insect-proof screens for box ventilation holes	Other	Large-scale processors, Exporters,	https://www.indiamart.com/proddetail/mango-packing-box-19383772562.html

4 Mango storage solutions

In many parts of Kenya, there is a lack of proper storage facilities on farms, at processing facilities, and at local markets. The lack of proper storage facilities is limiting mango shelf life for farmers, affecting sales prices and leading to high postharvest losses.[30] Mangoes ripen on the tree all at the same time, and they have a short shelf life once picked, about 5-15 days depending on the variety.[48] Mangoes that are not kept in cold storage lose quality during the transportation and sales process.[37] A majority of farmers do not have anywhere to store their mangoes, and very few have access to proper storehouses. Only 5% of farmers can store their mangoes for more than a week, and none surveyed can store them for more than two weeks.[25] A lack of cold storage facilities available to processors prevents them from buying mangoes in bulk during harvest season to use for processing at a later date.[41]

There are simple storage technologies available to keep mangoes fresh longer. The most common storage options used in Kenya are evaporative coolers, brick coolers, and charcoal coolers, all forms of passive

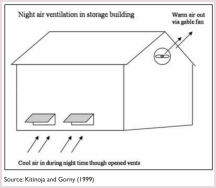
[48] Interview with Benson Maina, Apeel Sciences, July 2020

evaporative cooling.[37,48,49] Evaporative coolers do not require grid energy, making them an appealing option for rural farmers; however, Kenya's climate limits their effectiveness, as they rely on a low humidity level to function well. The coolers also require a clean water supply which is usually limited in remote areas.[48] Charcoal coolers and brick coolers are popular choices because they can be easily made from readily available materials, but they also require a low humidity level and have not seen much success.[14,48] Where storage rooms are available but lack cooling, one option is to adapt them for night air ventilation with closeable vents close to the ground and near the top of the structure. Manually opening the vents at night allows natural convection to draw cold air into the structure at night and closing the vents in the morning seals the cold air in through the day, keeping the produce temperature lower than it would be in a normal storehouse.[50] In the absence of viable technology, allowing mangoes to rest under a shade structure on farms or at local markets, compared to mangoes left exposed to direct sunlight, reduces overall loss.[51]

Long-term mango storage requires access to a powered cold or controlled atmosphere storage facility. The availability and use of these facilities are limited in Kenya, but measures such as pay-as-you-go cold storage access may provide a route to affordably increase capacity. Companies such as Solar Freeze and FreshBox offer pay-as-you-go access to cold rooms, which can be an affordable option for smallholder farmers.[52,53] However, some storage facilities in Kenya in may not be properly sealed, leading to pathogens entering the facility, accelerating the growth protein in the stored mangoes and causing rapid over-ripeness.[37] Another option to overcome this challenge and still lengthen storage time is modified atmosphere packaging (MAP), where a food processor manipulates the air composition inside a product's packaging, typically through the use of semi-permeable membrane packages.[54] A study conducted in India found that mangoes could be stored for 21 days when packaged with 50% carbon dioxide.[55] While sealed plastic bags or shrink wrap around the mango or plastic membranes over a stack of mangoes are the typical manifestations of MAP, a similar effect can be achieved at a lower cost through waxing the mango. Waxing involves coating it with an edible coating immediately after washing (before sorting and placing in a storage room). Waxing reduces the respiration rate of mangoes, slowing their post-harvest deterioration, and also helps to retain moisture and improve visual appeal for those mangoes being sold whole to consumers.[56]

[49] Interview with Emmanuel Amwoka, University of Nairobi, July 2020
[50] USAID, Empowering Agriculture: Energy Options for Horticulture, 2009
[51] Msogoya, T. J., & Kimaro, E. S. (2011). Assessment and management of post harvest losses of fresh mango under small-scale business in Morogoro, Tanzania. Journal of Animal & Plant Sciences, 11(1), pp. 1358-1363.
[52] Solar Freeze, Mobile Solar Powered Cold Room, 2020
[53] Disrupt Africa, Kenya's FreshBox pioneers solar-powered refrigeration in East Africa, 2018
[54] Industrial Packaging, What is Modified Atmosphere Packaging?, 2019
[55] Ramayya, N., Niranjan, K., & Duncan, E. (2012). Effects of modified atmosphere packaging on quality of 'Alphonso' mangoes. Journal of food science and technology, 49(6), pp. 721-728.
[56] Alkan, N., & Kumar, P. (2018). Postharvest storage management of mango fruit. *Achieving Sustainable Cultivation of Mango; Galán Saúco, V., Lu, P., Eds*, 377-402.

Table 4. Storage technologies to reduce losses (full details in the appendix)

Image	Name	Technology Sub-category	User (value chain actor)	Image Source
	Evaporative cooling chambers	Passive evaporative room cooling	Farmer co-operative groups, small-scale processors, Fresh Mango Markets	Benson Maina (interviewee)
	Night Air Ventilation	Other	Farmer co-operative groups, small-scale processors	http://ucce.ucdavis.edu/files/datastore/234-1386.pdf
	Mango Cold Storage Room	Refrigerated room cooling	Small-scale processors, Fresh Mango Markets, Large-scale processors	https://www.indiamart.com/proddetail/packaging-shredded-paper-16769291897.html
	Absorption/ adsorption refrigerators/ chillers	Cold storage	Fresh Mango Markets, Large-scale processors	https://jrkplumbing.com.au/projects-gallery/sortech-adsorption-chiller-in-umuwa/
	Controlled Atmosphere Storage	Altered atmosphere	Large-scale processors, Exporters	https://www.dtcoldstorage.com/project/CA-storage-for-fruits-and-vegetables.html
	Modified atmosphere bags	Altered atmosphere	Large-scale processors, Exporters	https://www.peakfreshusa.com/about-pallet-covers

	Mango Waxing Machine	Altered atmosphere	Small-scale processors, Large-scale processors	https://www.alibaba.com/product-detail/Electric-Mango-waxing-machine-apple-waxing_60603631269.html

5 Processing of surplus mangoes into shelf-stable products

Processing mango can increase its shelf life. For example, since mango pulp has a longer shelf life than fresh mango, it can be stored and used to make mango products in the off-season. While whole mangoes can last for two weeks under good storage conditions, pulp packaged aseptically lasts up to 18 months.[57] The standard approach of storing aseptically-bagged pulp in drums enables transport with minimal risk of damage or quality degradation to further commercial processors,[58] who use it in the production of various mango drinks, jams and food leathers.[59] In addition, demand for pulp remains high through the off-season, since mango juice processing plants often operate under capacity during this period when there are no fresh mangoes to juice.[60]

Juice processing has a significant positive impact on the mango value chain; adding value, reducing waste and providing higher and more stable prices to farmers. Experts interviewed agree that mango products such as juice provide a higher profit margin than whole mangoes.[61,62] Juice processing also typically involves dilution of pulp,[63] and increasing pulping and juicing capacity is considered one of the most effective ways to decrease a harvest season surplus of mangoes.[64] A recent expansion of the mango processing facility in Makueni County to be capable of juice production has supported its efforts to reduce waste by increasing its capacity.[65] Further, such county government juice processing plants provide a consistent price for mangoes to local farmers and purchase mangoes that may not meet the quality standards or demand to be sold as whole fruit.[66,67]

The Kenyan Ministry of Agriculture, Livestock and Fisheries (MOALF) plan for local, county level pulping facilities may help to increase the amount of mango processing nationally, particularly for varieties that are highly suitable for pulping and juicing. Ngowe is one of the two major cultivars of mango in Kenya, and is known for its suitability for processing to pulp and juice;[68] however, only 5% of Kenya's mangoes go to processing plants.[69] Furthermore, most farmers in Kenya can't find buyers for all their mango during the harvest season.[70] The MOALF plan of local processing facilities would support an increase in pulping at a local level, with the pulp then being frozen for transport to larger processors.[71] This would help to overcome the current shortage of

[57] MEDA, Mango Time, 2018
[58] CBI, Entering the European market for mango puree, 2020
[59] Siddiq, Muhammad, Brecht, Jeffrey K., and Sidhu, Jiwan S., 2017, Handbook of Mango Fruit. Wiley Blackwell, Oxford.
[60] Ng'ayu, B., and Audet-Belanger, G., 2014, Road Map for Developing and Strengthening the Processed Mango Sector, International Trade Centre, Geneva, Switzerland.
[61] Interview with Emmanuel Amwoka, University of Nairobi, July 2020
[62] Interview with Peninah Yumbya, University of Nairobi, July 2020
[63] Siddiq, Muhammad, Brecht, Jeffrey K., and Sidhu, Jiwan S., 2017, Handbook of Mango Fruit. Wiley Blackwell, Oxford.
[64] Interview with Prof. Dr. William Kyamuhangire, Food Technology and Business Incubation Centre, Makerere University, Uganda, September 2020
[65] Africa Inc, Kenyan county government sets up ready to drink juice processing plant, 2020
[66] Farm Africa, Mango juicing bears fruit, 2012
[67] Nation, Makueni mango juice plant gets Sh110m EU boost, 2018
[68] ITC, Kenya: Roadmap for Developing & Strengthening the Processed Mango Sector, 2014
[69] ICRA, Sweetening the Mango: Strengthening the Value Chain, 2010
[70] African Woman and Child Feature Service, Technology brings value addition to Kambiti mango farmers, 2019
[71] Interview with Joshua Oluyali, Kenyan Ministry of Agriculture, Livestock and Fisheries, August 2020

processing capacity during the harvest season and decrease the amount of mangoes that go unsold by buying the surplus produced by local farmers.[72]

Pulping offers a good option for groups of farmers or small processors who cannot afford to set up juicing to add value and reduce their losses. In Kenya, pulping a mango increases its value by 2.8 times.[60] Pulping machines, used to create pulp, will be affordable to some co-operatives and others may be able to receive them from donor-funded projects through universities and NGOs.[61] While it may seem appealing for small processors to try to create juice, processing of pulp into juice requires a multi-step process, adding to the cost.[63,73] For pulping, only low-cost processing steps such as pre-sorting and cleaning are necessary,[60] and other steps including destoning and peeling are not needed when using typical machines which press the pulp through successively smaller sized screens to remove all residual parts.[63]

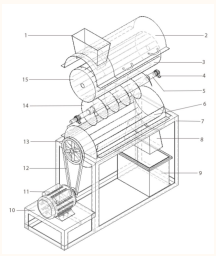
Smallholder farmers typically struggle to compete in the mango juice market; however, some co-operatives supported by NGOs have found success with juicing. Kenya currently imports almost 5000 MT of fruit juice annually,[68] including a majority of the mango juice consumed in Kenya, since local producers struggle to produce an affordable product with sufficient quality to meet local demand.[86] Achieving such quality is even harder for smallholder farmers due to the lower standard of small-scale processing machines.[64] For smallholders who do plan to take part in juice processing, market training and quality training is necessary to offer a chance for success when competing with large national and international companies.[48] Despite these higher barriers to entry, some donors do provide juicing machines to local groups such as Kithethesyo Women Self Help Group, who have seen significantly increased incomes since being supported with a fruit processing machine by The Arid Lands Resource Management Project.[72]

For large scale processors who can access urban markets, juice processing is worth investing in as there is substantial demand. Mango juice is found in most hotels, sold on streets in the South of the country, and considered by the Horticulture Division of the MOALF to be Kenya's most important processed mango product.[71] Furthermore, demand exists for increased domestic supply of high-quality, affordable juice.[68]

While processing mangoes to alcohol has potential, it is not currently a priority due to uncertainty of demand. Some Kenyans have been able to develop mango wine, however this and other products being developed at the universities are still research products and not currently on the markets.[14] Making the transition to market is expected to be challenging because there is a high religious population who will not take part in producing alcohol.[62] Religious beliefs and lifestyle choices also reduce potential demand for mango alcohol.[14] Increasing mango alcohol production should therefore be considered a low priority compared to pulping and juicing when planning how to increase capacity for processing the harvest-season surplus of mangoes.

[72] HLPE, Food losses and waste in the context of sustainable food systems, 2014
[73] Selina Wamucii, A Take on Kenya's Orange and Mango juice Processing Industry, 2020

Table 5. Technologies involved in production of shelf-stable mango products (excluding dried mangoes; full technology details in the appendix)

Image	Name	Technology Sub-category	User (value chain actor)	Image Source
	Mango depulping-destoning machine	Pulping machine	Small-scale processors, Large-scale processors	http://www.fruitok.com/product/fruit-pitting-machine/mango-pulping-machine.html
	Mango Hand juice maker	Juice extraction machine	Farmer co-operatives, small-scale processors (maybe)	https://www.indiamart.com/proddetail/mango-hand-juice-maker-11715279188.html
	Small Scale Mango Juice Extractor	Juice extraction machine	Small-scale processors, Large-scale processors	https://www.researchgate.net/publication/306032196_Design_Development_and_Test_of_a_Small_Scale_Mango_Juice_Extractor
	Centrifugal Filtration Machine	Filtration stage	Large-scale processors	http://www.fruitprocessingline.com/processing-line/mango-juice-processing-line/
	Pasteurizing Machine	Pasteurization stage	Large-scale processors	https://www.alibaba.com/product-detail/Juice-Pasteurizer-Milk-Pasteurizer-20L-H_62156791695.html?spm=a2700.drainage_lp_1.0.0.5c823ca648n1wP&s=p
	Mobile Fruit Juice Processing Plant	Full juicing process	Large-scale processors	http://www.alvanblanchgroup.com/mobile-fruit-juice-processing-plant

	Fruit wine fermentation tank	Mango wine/ vinegar processing	Small-scale processors, Large-scale processors	https://www.zhbrewing.com/product-83.html

6 Drying technologies

Drying technologies reduce post-harvest losses and increase sales value of mangoes, but experience a specific choke point in the value chain due to the types of technology available. As with processing into any other shelf-stable product, drying decreases losses of surplus mangoes and extends mango shelf life.[71] Anecdotally, farmers participating in the Yieldwise initiative were able to sell their dried mangoes for more,[74] and a group of farmers in Murang'a county were able to multiply their earnings by 6 times through mango drying.[75]

Selection of which drying technology to use depends on factors including finances, necessary capacity and target quality of drying, with the lowest-cost approach of sun-drying being accessible but often producing a lower quality product. Possible methods for drying include osmotic dehydration, hot air drying, vacuum drying, spray drying, freeze drying and foam-mat drying.[63] Most commonly used by smallholders in Kenya are variations on hot air drying, including open-air sun drying, solar tunnel drying, oven drying and the household-scale dehytray,[74] typically with natural airflow although forced convection is being investigated.[76] Of these technologies, sun drying requires the least capital and does not require specific technology, involving simply exposing mangoes to the sun in open air; however, it is only safe in ideal conditions, with high temperatures, no rain, and the right humidity level.[77] Further, even in ideal conditions, sun drying takes about two days and is often less hygienic, leading to reduced quality in comparison to more advanced drying methods which can take only a few hours.[70] Recent projects have encouraged or financially supported use of tunnel solar dryers as an affordable drying technology for cooperatives that can achieve a good drying capacity, faster drying times and better quality than sun drying.[74] For larger-scale processors, other technologies such as steam, biogas and automated air drying are more viable from a financial and quality standpoint.[78,79,80]

The effectiveness of drying is affected by factors including mango variety, use of pre-treatment, slice thickness and weather conditions. The variety of mango chosen for drying should be considered carefully, since it will affect the color and consistency of the dried slice.[74] The best small-scale pre-treatment to maintain nutritional value of mango slices through drying is lemon juice; however, citric acid is a cheaper alternative on a commercial scale.[74,14] The optimum dimensions for mango slice drying are 4 mm thickness and 4-8 cm diameter.[74] Cloudy, cold and humid conditions slow solar drying, causing the mango slices to rot and discolor, decreasing quality.[74] The climatic factors are a particular hindrance in Kenya, which has a humid climate making some methods including many slower and solar-based drying methods such as sun drying and solar tunnel drying less effective.[74] In addition, the weather can often rapidly change, causing losses and reducing quality of mangoes dried by sun drying and solar drying technologies.[68] Despite this, commercial mango drying businesses in Kenya

[74] Interview with Isaac Nyangena, Kenya Bureau of Standards, July 2020
[75] Kenya CitizenTV, Smart Farm: Drying of Mangoes, 2017
[76] Energypedia, Energy Provision in Rural Areas of Kenya, 2015
[77] National Center for Home Food Preservation, Drying: Sun Drying, 2014
[78] Farm Radio International, Kenya: Farmers dry and process mangoes into value-added products, 2019
[79] Kenya Climate Innovation Center, Azuri launches new factory to increase production of dried fruits and vegetables, 2017
[80] Hortinews Kenya, Something can be Sweet N' Dried after all, 2017

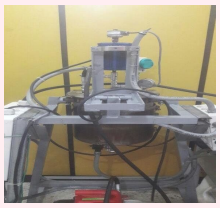
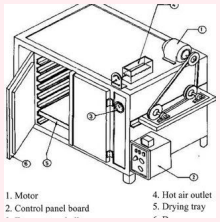
successfully continue to use solar dryers alongside more advanced technology.[81]

The primary demand for dried kenyan mangoes is from wealthier consumers in urban areas, purchasing from supermarkets; however, if the standards can be achieved, the European market is much larger still. Due to low demand for dried mangoes in most local markets across Kenya and only 2% of Kenyan dried mango slices being exported, the majority of dried mangoes are sold in supermarkets currently.[74] There is significant potential for sale to international markets such as Europe where demand is much higher, since Kenyans are yet to fully embrace dried mango as a product; however, a high quality is needed to meet the required standards and expectations.[14]

Table 6. Technologies involved in drying mangoes (full details in the appendix)

Image	Name	Technology Sub-category	Estimated Thermal Efficiency	User (value chain actor)	Image Source
	Tunnel Solar Dryer	Hot air drying - Solar	8.89%-53.1%	Farmer co-operatives, Small-scale processors	https://www.ctc-n.org/technology-library/renewable-energy/solar-dryer
	Small farm solar dryer	Hot air drying - Solar	Unknown	Farmer co-operatives, Small-scale processors	https://aptuk.org.uk/wp-content/uploads/2014/12/Solar-drying-of-mangoes-in-.jpg
	Industrial Fruit Dehydrator	Hot air drying - Oven	84%	Small-scale processors, Large-scale processors, (sometimes Consumers)	http://www.fruitok.com/product/washing-machine/fruit-dehydrator-machine.html
	Clean-Energy Steam Dryer	Steam drying	70%	Farmer co-operatives, Small-scale processors, Large-scale processors	https://www.technoserve.org/blog/eliminating-waste-increasing-profits/
	Freeze Dryer	Freeze drying	Unknown	Large-scale processors	https://www.shsqjx.cn/products/fruit-vegetable-drying/4.html

[81] Green Agri, Ultra-modern fruit drying machine opens export markets for hundreds of Kenyan smallholder farmers, 2017

	Osmotic dehydrator	Osmotic dehydration	Unknown	Large-scale processors	http://www.m-hikari.com/ces/ces2018/ces9-12-2018/p/acevedoCES9-12-2018-2.pdf
	Industrial microwave tunnel drying belt	Microwave drying	Unknown	Large-scale processors	https://www.nasandryer.com/industrial-microwave-dryer-p-1.html
	Spray dryer	Spray drying	25%-60%	Large-scale processors	https://fooddryingoven.com/food-drying-equipment/spray-drying-machine.html
	Foam-mat drying	Foam-mat drying	Unknown	Large-scale processors	https://www.researchgate.net/publication/233259460_Foam_Mat_Drying_of_Alphonso_Mango_Pulp

7 Meeting certification and consumer standards

Training and appropriate machinery must be combined to ensure hygiene and quality of mangoes and mango products. The Jomo Kenyatta University of Technology has been training entrepreneurs and small-scale processors on how to process mangoes hygienically.[14] However, despite training, processors currently damage mangoes during sorting and grading due to a lack of appropriate equipment.[71]

Table 7. Technologies involved in washing, sorting and grading mangoes (full details in the appendix)

Image	Name	Technology Sub-category	User (value chain actor)	Image Source
	Washing and air drying machine	Mango washing machine	Large-scale processors	http://www.fruitok.com/product/washing-machine/washing-and-air-drying-machine.html

	Mango Blanching Sterilizer Machine	Blanching machine	Large-scale processors	http://www.fruitok.com/product/vegetable-blanching-machine/fruit-blanch.html
	Olympias Sorting and Grading Line for Mangoes	Semi-automated sorting/grading	Large-scale processors	https://www.olimpias.gr/processing-sorting-grading-machines-for-prickly-mangoes.1
	Megastar Sorting Machine (AWETA)	Automated sorting/grading	Large-scale processors	https://www.aweta.com/en/produce/mango

Employing staff with food science experience enables processors to produce a high quality product that meets the standards for certification. Food science expertise is necessary to make a good quality product, yet it is often lacking for new processors.[71] If people with the right expertise are employed and allowed to apply their knowledge and skill, then products will easily achieve the standards for certification and meet customer demanded quality.[82]

Standards for mango products, developed and certified by the Kenyan Bureau of Standards, ensure both quality and safety of processed mango products and whole fruit sold in supermarkets. Regarding their focus, standards are primarily targeted at processors, supermarkets and exporters, not farmers. As a result, mangoes sold at the farm gate and in local markets are not tested/certified against the standards.[82]

Expanding standards to encompass international requirements may enable Kenya to regain some of its former export market. In the past, Kenya supplied mangoes to Europe but imposed a self-ban on exports to the European Union (EU) and USA following interception of several shipments containing fruit-fly between 2010 and 2014.[83] This was coupled with a major drop in demand from Western importers concerned about the risk of fruit-fly transmission and Kenya's high pesticide usage.[84] Essentially, poor infrastructure for standards and quality is impeding access to these markets since for the ban to be lifted Kenya must become fruit-fly free and reduce pesticide usage.[71,85] In addition, international standards and certifications must be met for export of mango products including pulp; this may prove to be difficult for Kenyan farmers.[86] Fortunately for farmers and processors, ensuring all mangoes produced in Kenya meet quality and safety standards to help the sector regain and expand its export markets is part of the Horticulture department's vision for the sector,[71] suggesting some degree of government support may be available.

8 Utilizing mango byproducts

The byproducts of mango processing are often not used and are therefore left to waste. Mango products; juice, leather, wine, dried slices, etc., are made from the fleshy pulp of the fruit. The fleshy pulp makes up about 30-40%

[82] Interview with Isaac Nyangena, Kenya Bureau of Standards, July 2020
[83] Kenyan Wall Street, Kenya Acts to Lift Mango Exports Ban, 2020
[84] The Guardian, Kenya's mango farmers ditch chemicals to boost exports, 2016
[85] The Standard, Kenya missing out on mango billions after export ban over fruit fly, 2020
[86] Hortfresh Journal, What is ailing Kenya Mangoes that only few make it to the market, 2013

of the total weight of the mango.[14] As a result, the peels (or skin) and the kernel form a major part of the waste products from the processing of mangoes in Kenya.[14] Additionally, when processing juice directly from fresh mangoes, low-moisture pulp is also created as a by-product.[82] These losses contribute to the environmental impact of food losses in Kenya, and they can be converted into other useful products for a more sustainable use of the whole mango.

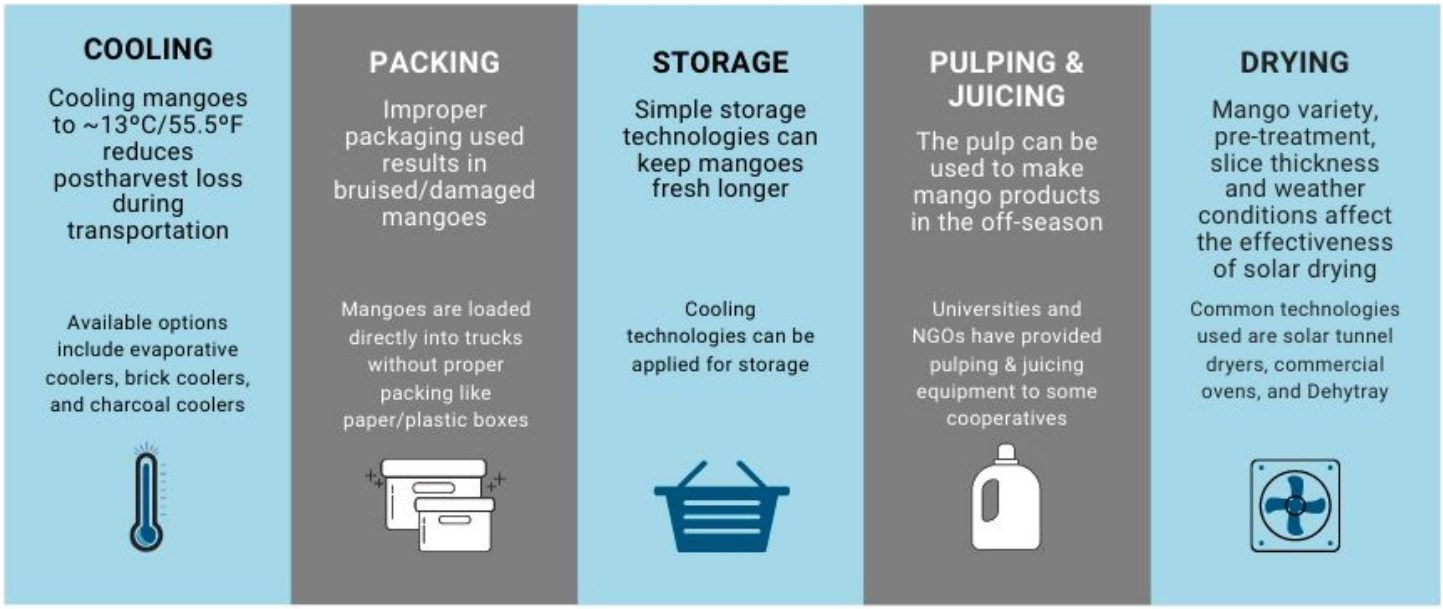


Figure 4. Postharvest technologies for Mango Processing in Kenya

Factors for Technology Implementation

Key factors influencing selection and implementation of postharvest mango technologies in Kenya were assessed. These factors fell into four broad categories: socio-cultural factors, farming cooperatives, mango varieties, and government involvement.

Socio-cultural factors

There are many cultural factors that are important to address when researching postharvest loss and implementing technologies in Kenya such as age, gender inequality, religion, and hierarchies of political power. Most often, mango farms in Kenya are inherited land from father to son, often passed on when both are too old to work the land themselves. Thus, these farmers may need to hire younger people to work on the farm. Many mango farmers are married couples, and while the wife often does most of the work on the farm and has more first-hand knowledge, the husband is considered the head of the household and holds the decision-making power.[87] Farmers in the Kenyan counties that produce the most mangoes are predominantly religious Muslims or Christians who will not participate in the production of alcohol products.[88] The national government in Kenya primarily supports cash crops, so help for mango farmers falls to county governments. However, smallholder farmers often lack political power in county governments, so it is difficult to get funding for public services that would aid their businesses.[87]

Farming cooperatives

Cooperatives and other farmer groups can provide substantial benefits to smallholder farmers in regards to profit and postharvest loss reduction. Many smallholder mango farmers in Kenya have formed cooperatives, where the members of the group collect their mangoes in a central location to be sold in bulk and use some of the profits to purchase equipment the group can share. Traditionally, a smallholder farmer would sell his or her mangoes to a broker who dictated the price and would often buy only the best quality mangoes. Instead, cooperatives have collective bargaining power, meaning the group can negotiate deals with brokers, generating more income for the farmers. Cooperatives also have the option of selling all of their mangoes to a processing facility which would not be willing to take a small amount of mangoes from a single farmer.[87] The Kambiti East Mango Group, composed of 15 farmers, formed in Kenya in 2013 and saw increased profits due to the formation of their cooperative and help from the company Village Industrial Power. Before the group's formation, one of the farmers would earn only 0.13 USD per kilogram of whole mango at the local market. After the group formed and purchased a steam dryer from Village Industrial Power, they were able to sell dried mango slices for 4.70-7.53 USD per kilogram. The group also saw mango production increase from 96 kg in 2016 to 400 kg in 2019 due to agronomy training from the non-governmental organization YieldWise.[89]

Mango varieties

In addition to the points of losses discussed above, data collected from the interviews with the experts indicated that there is significantly lower demand for certain mango varieties produced in Kenya, which contributes to the mango postharvest losses in the country. In an interview with Joshua Oluyali, Head of the Horticulture Division and Chair of the National Horticulture Transformation Technical Working Group (NHTTWG) at the MOALF, it was noted that the main varieties of mangoes grown in many mango-producing counties, the Apple and Tommy Atkins varieties, are not suitable for processing and most of these mangoes are grown for sale as fresh

[87] Interview with Emmanuel Amwoka, University of Nairobi, July 2020
[88] Interview with Peninah Yumbya, University of Nairobi, July 2020
[89] African Woman and Child Feature Service, Technology brings value addition to Kambiti mango farmers, 2019

mangoes.[90] Further, Prof Willis Owino indicated that the varieties that are suitable for processing are often grown in places that are far away from the processing facilities. Given the associated losses, increasing the range of mango varieties grown across the country will enable a growth in mango processing and a reduction in postharvest losses.[91]

Government involvement

An interview with Joshua Oluyali, the Head of Horticulture Division at the MOALF, highlighted several key insights regarding the role of the Kenyan Government in supporting the mango sector and their current plans.[90]

Oluyali revealed that plans are in place for the MOALF to collect and collate cumulative loss data for the mango value chain in key mango producing counties. The NHTTWG of the MOALF, which Oluyali chairs, is planning to develop a strategy for growth of the mango sector, beginning in the fourth quarter of 2020, in conversation with various partners. During planning the strategy development, the absence of solid data on losses and flow of mangoes through the value chain has been identified, so the Horticulture Division of MOALF will conduct a baseline study of the mango sector. The monitoring will involve a written form for all mango value chain actors to complete, with individuals reporting on the losses they experience and their role in the value chain. Oluyali explained that the baseline information will be used to inform the strategy development process.

Existing Kenyan government strategy for the mango sector involves coordination between national- and county-level MOALF to provide the technology and skills necessary for the local private sector to establish and run new facilities efficiently. The NHTTWG and working groups at county level were established to coordinate growth of key horticulture sectors, which include the mango sector, claimed Oluyali. Simultaneously, the broader national Vision 2030 development strategy involves promotion of processing and creation of industry. Therefore, Oluyali claims MOALF will provide skills training to local SMEs and clusters (groups of co-operatives), including in production, planning, record keeping, marketing, financial management and business planning.

In Kenya, *wards* typically refer to administrative-level classifications between villages and sub-counties in Kenya, comprising of 2500 - 3000 households. Another MOALF initiative is to establish aggregation centres at ward level, owned and run by 'clusters', to improve coordination of production, marketing and processing for all crops including mangoes. Oluyali explained that aggregation centres of a similar scale used to exist and that testing which indicates strong demand for them is expected to provide the local private sector with confidence to invest in new post-harvest technology. MOALF plans to implement these centres in every horticulture-focused ward to improve post-harvest handling, enable investment in new technology and provide an improved structure for testing of mango quality and standards. Aggregation centres are expected to ensure adequate supply in quantity and quality of produce for both fresh and processed mango markets. MOALF plans to facilitate centre establishment by mobilising households, providing information and skills training and connecting clusters to private and financial sector investment as well as existing projects, to ensure that centres are locally owned and actually used.

MOALF also hopes to expand the role of SMEs in the mango value chain, including for harvesting, transport, and ward-scale processing, highlighted Oluyali. Through promotion of cottage-industry processing; local factories will be established close to farmers that will extract mango pulp, freeze it and transport it to larger processors. These local factories will experience higher volumes of mango supply than small farmer groups have previously and so will enable cost sharing, Oluyali explained. Further, Oluyali believes that expanding processing will create jobs

[90] Interview with Joshua Oluyali, Kenyan Ministry of Agriculture, Livestock and Fisheries, August 2020
[91] Interview with Prof. Willis Owino, Jomo Kenyatta University of Agriculture & Technology, August 2020

and increase the range of products on the market. Beyond this, MOALF is looking to promote SMEs' role in the value chain including harvesting the mangoes, delivering mangoes to the aggregation centres, and transporting mangoes from aggregation centres to markets. The SMEs will receive training in mango handling best practices from MOALF at the aggregation centres, which is expected to reduce losses associated with damage during harvesting and transport, highlighted Oluyali.

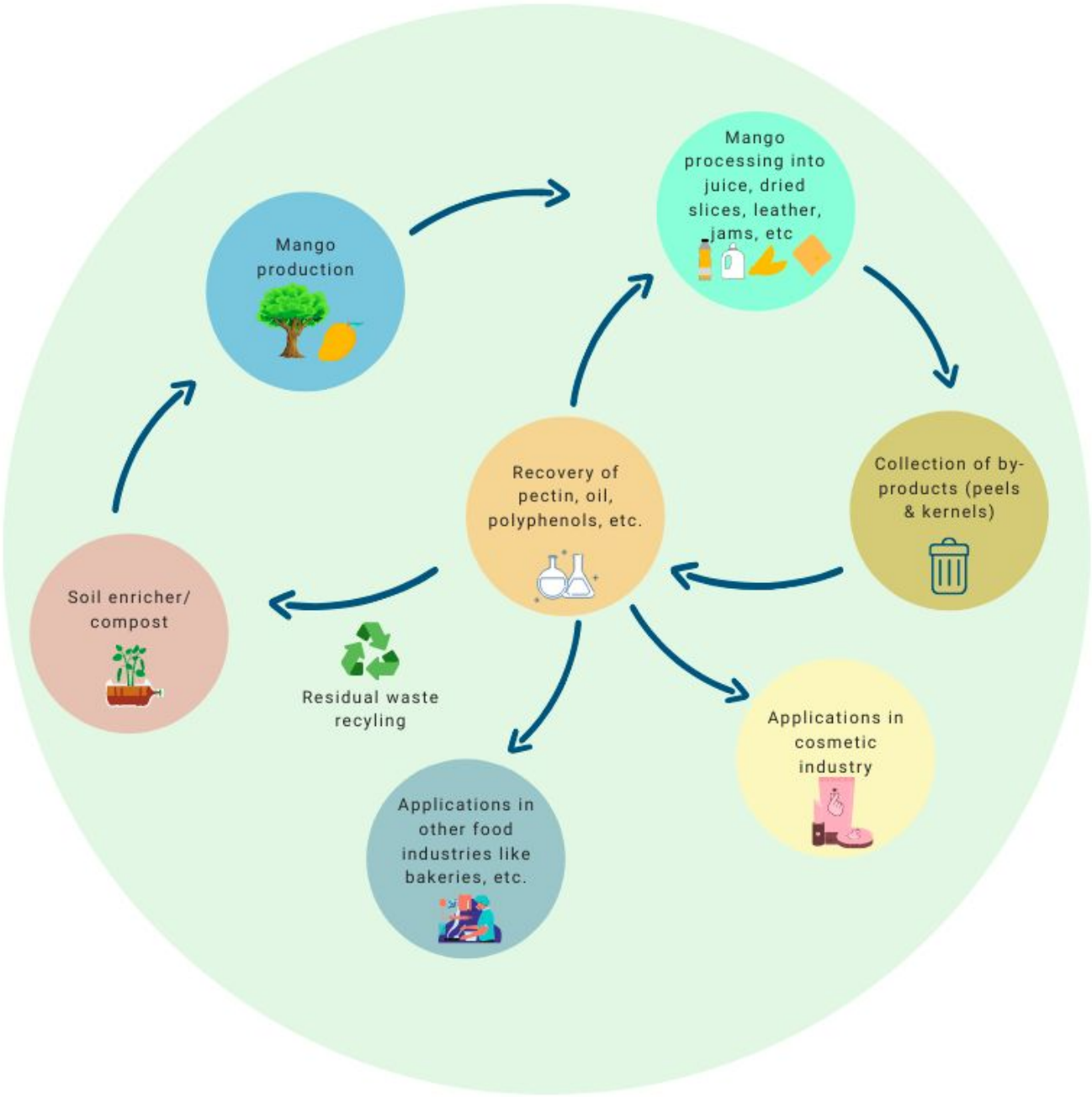


Figure 5. A proposed circular economy for mango processing in Kenya

Mango Processing: Striving for a Circular Economy

The mango kernel (seed) and the peels are the byproducts from the processing, which are normally discarded after processing operations. These byproducts can be used as starting material for the production of other high value products, which can be used in various stages in the food value chain as a whole. A variety of products can be extracted from mango peels for use in other food processing applications. Studies performed by Rojas *et al.* (2020) demonstrate that mango peels are a good source of antioxidant and antifungal polyphenols.[92] These polyphenols can be used as natural additives in functional foods. Further, Rojas *et al*. (2020) note that using a series of six steps, pectin can also be recovered from mango peels along with the polyphenols.[92] Pectin has a wide range of food applications. It can be used as a gelling agent in jams, marmalades and preserves and it can be used as an emulsifier to stabilize the oil and water phases in foods like mayonnaise and dressings.[93]

Furthermore, mango peels can be dried, pulverized and added to various food preparations as a source of antioxidants and dietary fiber. As an example, Ajila *et al*. (2010) demonstrated that mango peel powder can be incorporated into macaroni without affecting the macaroni's cooking, textural and sensory properties.[94]

Studies have shown that the mango kernel contains oils that make up approximately 15% of the kernel's weight.[95] The mango kernel oil has high unsaponifiable matter, making it suitable for use in cosmetic products. Other experiments have shown that the mango kernel fat can be used in the production of a heat-tolerant cocoa butter replacer.[96] Currently, some scientists in Kenya are extracting the mango kernel oil on a laboratory scale and studying its potential for use in other applications.[9] Additionally, other Kenyan researchers are experimenting with powdered mango kernel to understand how it can be incorporated into baked goods.[91] These, when done on a larger scale, could significantly improve the value Kenya gets for the mangoes it produces while contributing to the sustainability of the value chain.

Further, extracts from both the peels and the kernel can be used in the production of biodegradable cling films for food packaging.[97] The by-products from the recovery of pectin, polyphenols, oil and powder from the peels and kernels can be used as soil conditioners to enrich the soil for cultivating mango and other crops. Also, spoiled mangoes can be composted and used as soil fertilizers for crop production, thereby increasing the value of every piece of mango, creating new jobs and ensuring a more sustainable mango value chain.

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[92] Rojas, R., Alvarez-Pérez, O. B., Contreras-Esquivel, J. C., Vicente, A., Flores, A., Sandoval, J., & Aguilar, C. N. (2020). Valorisation of mango peels: Extraction of pectin and antioxidant and antifungal polyphenols. Waste and Biomass Valorization, 11(1), pp. 89-98.
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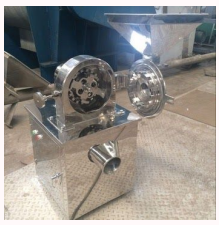
Table 8. Some technologies contributing to the circular economy (full details in the appendix)

Image	Name	Technology Sub-category	User (value chain actor)	Image Source
	Mango kernel oil press	Mango Kernel	Large-scale processors	https://www.alibaba.com/product-detail/Mango-butter-oil-processing-machine-high_62297772258.html
	Mango seed crusher	Mango Kernel	Small-scale processors, Large-scale processors	https://www.alibaba.com/product-detail/Mango-seed-grinding-machine_60720929694.html
	Composting mangoes	Spoiled mangoes & waste from processing	Farmers, Farmer Co-operatives	http://homesteadingdreams.com/growing-mango-plant/

Conclusion

Though the initial plan for this research included travel to Kenya to have firsthand insights on the postharvest handling and processing of mangoes, the travel restrictions as a result of the COVID-19 pandemic made this impossible. Hence, data for this research was collected through desk research and interviews with academics, farmers and other stakeholders in the mango sector.

It was found that in addition to the farmers, the Kenyan mango value chain also involved the active participation of non-governmental organizations, universities, traders/brokers, export markets, county governments, cooperative groups as well as small-scale and large-scale processors. It was found that losses, which are estimated somewhere between 15-40%, occur throughout the value chain, and are notably less than the 40-50% often reported in literature. The variations in the reported data on postharvest losses were all given from estimations on what the losses were and not quantitatively measured data across the country.

A number of choke points were identified in the value chain as the major contributors to the mango postharvest losses in Kenya. Among these was the lack of appropriate cooling and storage technologies as well as poor transportation practices such as the use of inappropriate packaging during transportation which causes bruising on the mangoes and subsequent losses. In addition, it was found that during the harvest season, there is a flux of mangoes, most of which are not suitable for processing. Hence, these end up in the fresh mango markets where there is the lack of appropriate facilities for preserving the mangoes, leading to the spoilage of these mangoes. Other factors such as the main mango varieties that are cultivated in Kenya and inhibiting cultural factors were also observed to contribute to the significant losses that occur in the value chain.

To help reduce the mango postharvest losses in Kenya, it is recommended that farmers, cooperatives and self-help groups adopt new technologies as suggested in the tables below to process their mangoes into high quality mango products. Also, it is necessary to adopt a circular economy as shown in Figure 5 to help recover other high value products from the by-products of mango processing. This will also help create new job opportunities in the mango sector, making it more profitable for all the actors involved.

Appendix: Technology Index

The following table is intended to provide a reference for different technologies available to reduce post-harvest mango losses. The contents are not exhaustive and the authors make no recommendation for any manufacturer over another. For each type of technology, either one example product or general information about that type of technology is included, and some may include links to other options. Information on capacity and relative price are drawn from all similar options of the specific type of technology, and also in some cases involved estimation based on the authors' judgement. Resources necessary for operation of any technology are suggested by the authors based on how the technology operates, and suitability of a technology for use by different value chain actors is also somewhat subjective. Several of the technologies are included in Engineering for Change's Solutions Library, which can provide additional detail on those products.

The full table is available here:
https://docs.google.com/spreadsheets/d/1zQC_nLpb7BgKw9KAmIEdPeViMxH8GUfS1EHq-oQxp3E/edit?usp=sharing

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