Synthèses

SUSTAINABLE FOOD SYSTEMS FOR FOOD SECURITY

Need for combination of local and global approaches

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Chapter 8

Reducing food loss and waste in meat and fruit supply chains: how food engineering can help

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Plant and animal products are seldom consumed immediately after harvesting or slaughtering, which means appropriate measures (processing, conditioning, storage) must be taken to ensure food safety. As the number of processing and distribution steps multiplies, the inevitable result is food loss and waste (FLW). *Food losses* occur along the food supply chain from harvest (or slaughter) up to, but not including, the retail level, while *food waste* occurs at the retail and consumer stages (FAO, 2019). While FLW occur across the entire supply chain, they reach their maximal level at the end of chain, i.e., households or catering. The European Union (EU) has set a target to halve its food waste by 2030. Extending product shelf lives through optimized, innovative processing and preservation technologies is a key way to reach this objective. It is therefore urgent for the policymakers and for all the players involved in the supply chains to quantify the impact of processing and preservation technologies on FLW reduction to assess the benefit/cost ratio of FLW reduction achieved using innovative technology and the trade-offs involved.

It is important to mention that the FLW discussed in this chapter focuses on the decrease in quantity and quality[13] of food at processing, distribution and consumption steps caused by a lack of processing and preservation technologies, and/or poor grasp of these technologies by food chain stakeholders (including consumers). FLW studied here do not include FLW due to farming and harvesting, and more generally post-harvest losses, i.e., those occurring before a product reaches processing facilities. Our main question is to quantify the impact of processing technologies on FLW mitigation. Other mitigation actions not directly related to optimization of

13. Decrease in quantity refers to food that exits the food supply chain, while decrease in quality refers to the decrease in food attributes that reduces its value in terms of intended use (FAO, 2019).

processing and storage, such as programmes to redistribute foods that are about to expire, are not in the scope of this study but could be found in other initiatives (see, for example, the European project Reamit, Interreg, 2021).

This chapter briefly presents the results on FLW reductions obtained within a meat supply chain and a fresh fruit supply chain. Common perspectives are then discussed to further reduce losses in these chains through well-optimized processing and preservation technologies using a generic food engineering approach.

⏩ Objectives and approach

Our objective was to quantify the share of FLW caused by a lack or poor management of preservation technologies in two types of food supply chains: meat, and fresh fruit and vegetables (F&V). The first step was to study the impact of processing and preservation technologies on product shelf-life extension and the concomitant FLW reduction obtained at the different stages of the post-slaughter and post-harvest chains. To do this, we first used food engineering approaches based on the development of mathematical models. Such approaches are crucial because efficient processing, preservation, and packaging prevent losses not only in the factory or during food distribution, but also in consumers' homes. The second step was to link the product shelf-life extension to a decrease in FLW at different stages of the food chain, and especially in households. Making such determinations required experimental data on FLW. Given that such data were scarce and fragmented, surveys were carried out to get more information on FLW at the different stages of the meat and F&V chains. Where possible, the impact of stakeholder and consumer behaviours, such as common practices, knowledge and beliefs about the technologies used to preserve their food, was also included for FLW prediction. Published data on FLW often confuse losses due to degradation reactions and wastage of edible food (due to unpredictable behaviour of consumers, who sometimes discard edible products). As a result, published FLW data did not clearly quantify the share of losses that food technologists could improve.

Two types of biological phenomena with an impact on retail products can explain the loss (or rejection) of foods by consumers: 1) the growth of spoilage microorganisms and 2) biochemical degradations. It is often important to consider both phenomena to predict and prevent food chain losses. In practice, many processes can improve food preservation and limit losses, and they can often be combined or adapted for greater efficiency. Research has been conducted on meat to develop processes that are adaptable and affordable, or which can be applied at different scales, both in France and South Africa. These processes are similar to the approach used to disinfect water using solar energy (McGuigan et al., 2012). Since food quality is multi-faceted, and durability is major issue for processes, multi-objective modelling was an interesting way to properly address the problem. Research on the F&V chain focused on strawberry, an emblematic fruit in France. As a highly perishable product with very short shelf life, strawberry is the most difficult case study for the overall F&V chain. In this case, work focused on quantifying shelf-life gain and concomitant FLW reduction achieved in the post-harvest chain by using well-designed modified atmosphere packaging, either in addition to, or instead of, the exclusive use of cold storage. Mathematical modelling was indispensable to explore the many different post-harvest scenarios and consumer practices.

⏩ Loss and waste along meat chains

Compared to plant protein production, producing meat protein requires more energy, land and water and generates more CO_2 emissions. The result is a greater environmental impact. Moreover, world population growth and rising living standards have increased the demand for meat protein, which is unlikely to be satisfied in the future. It is therefore critical to limit the losses at every stage of the chain. In particular, controlling the cold chain and using appropriate packaging is crucial to limit FLW. In Western countries, most meat is sold after slaughter and butchering. In the Global South, where the cold chain cannot be guaranteed to keep meat fresh, meat is often stabilized using traditional processes – e.g., salting, drying, and smoking – to be consumed later or to be transported to remote areas. FLW were compared in two different countries, France and South Africa.

Fresh meat chain in France

Because data on FLW are scarce, we conducted a survey to evaluate FLW in a French context to determine the step at which most losses occur within the fresh meat chain. Data were collected from five companies located in the Auvergne-Allier area (central France), including small companies engaged in regional trade and larger companies engaged in national or international trade. The results showed that losses were very low in factories during meat processing, while they became significant during food distribution (Comparet et al., 2016). While the losses appear small (2% to 4% of production), they must be put into perspective because they represent significant tonnages. Additionally, only big supermarkets were surveyed, but losses are known to be higher in smaller stores due to lower activity levels. Moreover, the impact of these small losses can be very high in terms of sustainability, especially for the beef industry; some authors estimate that a 3.5% loss of beef in a supermarket is equivalent to 29% of overall food losses when translated into a carbon footprint (Eriksson et al., 2014). Based on the difference of the total amount of loss already known, the most important conclusion of our survey was that fresh meat losses occur mostly in consumer homes. This can be partly explained by better food preservation control by industrial players and distributors. Professionals also minimized storage duration, which transferred FLW to the end of the chain (i.e., consumers). One technical solution for the microbial stabilization of meat using flexible processes is the heat treatment of the meat surface, which is contaminated during slaughter and successive cutting of muscles. Prior research has proven that flash heat treatments can be an effective way to decontaminate the surface of carcass and muscles, while further recontamination can be controlled by using natural chemicals (Kondjoyan and Portanguen, 2008; Lecompte et al., 2008). However, consumers often find even natural preservatives to be less acceptable. Thus, the formation of a dried crust over the meat surface, by further heating, was considered in our project to avoid surface recontamination and microorganism growth. But this barrier effect is only effective until the crust is rehydrated. We performed calculations to estimate the time during which the crust will remain a barrier against recontamination. Under usual temperatures and packaging conditions, the crust loses its barrier effect quite rapidly. Thus, the crusting technique would have to be combined with modified packaging to control the humidity and/or gas composition of the product environment.

Processed meat chain in South Africa

The consumption of livestock and game meat is widespread in South Africa. Traditional processed meats such as biltong (a small piece of meat, cured with salt, vinegar and spices, and then dried) and droëwors (literally, 'dry sausage') can be preserved without cold storage. The traditional sector of these intermediate moisture meat products in South Africa is becoming more and more industrialized to meet rising market demand. The objectives of our project were to 1) better understand the FLW due to meat processing, either in artisanal or industrial units, and 2) study the mass transfers that occur during processing and their effects on the quality criteria. The focus was the control of the process, based on a global mathematical simulator, considering the change in product quality during the three main processing stages (tumbling, drying and storage).

To achieve the first objective of better understanding the FLW during meat processing, a survey was conducted of the main biltong manufacturers and distributors in the Western Cape province of South Africa (Beyers, 2016). This study identified that manufacturing generates very few losses of a non-quantifiable level. In fact, during meat preparation, meat pieces that are not large enough for biltong and other trimmed scraps are used to make droëwors. In addition, the biltong distributors very rarely return products to their suppliers. When they did, most of the time it was because of mould development. Moreover, the distributors destroy marginal quantities when the products approach the end of their shelf life. Sometimes, when there are issues with the finished product, such as when it too dry, they will turn it into powder for use by the food industry or in pet food. The concept of best before dates in this sector is vague because products reach consumers in a variety of formats: from bulk products, which are hung and sold by piece cutting, to pre-sliced consumer portions, which may be packed in modified atmosphere packaging (MAP), where a gas mixture are injected in the package. It would be interesting to extend the study of losses to non-specialized distributors and consumers. In addition to these highly stabilized products, there is a growing demand for less-processed products (less salted, less dried, softer texture). Such products require much better stability control, which largely relies on good control of the process (formulation, drying and preservation). However, the absence of a regulatory framework and the lack of infrastructures for product characterization and process monitoring are all threats to the sustainability of these new niche markets, which are nevertheless economically and socially promising. The formulation of biltong and the links between mass transfers and product properties such as texture, pH, water activity (a_w) and salt content were studied in the project. The aim was to develop a multi-criteria optimization tool based on a global process model. This simulator used simplified models developed at the unit operations scale for a better control of the end product quality in terms of reducing the variability of the finished products, improving storage conditions and extending shelf life by reducing yeasts and mould, while ensuring a sustainable technological route. Until now, only the tumbling operation had been modelled, which made it possible to identify the experimental solute profiles obtained in the meat, and thus, numerically, the diffusion coefficients for salt and acid during the tumbling formulation (Mirade et al., 2020). Further studies are under way to define the best salt and acid concentration profiles for post-tumbling in order to obtain, once the final drying operation is complete, a finished product offering the best trade-off between good stability and the organoleptic characteristics (e.g., tenderness, taste) that consumers want.

⏩ Loss and waste along fruit chains

Loss and waste percentages are generally higher for fruits and vegetables than for other products, especially in situations where cold storage or processing conditions are inadequate (FAO, 2019). Even in Western countries where cold chain facilities are well developed, the high fragility and perishability of fresh fruits and vegetables lead to considerable FLW, especially at the retail and consumer levels. Many innovative technologies were considered to extend the shelf life of fruits and vegetables and reduce their FLW. Although the link between food shelf life and losses is not straightforward or perfectly formalized, well-designed packaging can help preserve food and reduces FLW. In the post-harvest chain for fresh fruits, the use of equilibrium modified atmosphere packaging (known as eMAP[14]) could help extend the product shelf life and mitigate losses and waste along the supply chain, especially in consumer homes (Angellier-Coussy et al., 2013; Guillard et al., 2018). The project focused on exploring the link between shelf-life gain and loss reduction through eMAP, as well as the environmental benefit of using such packaging technology, either to replace or in addition to cold storage, which is currently the most-used preservation technology.

The objective was to develop a mathematical model for predicting shelf-life extension of strawberry and losses at the distribution and household stages. Stakeholder practices and beliefs, particularly those of consumers, were collected through intensive field surveys. Mathematical modelling integrated these consumer practices in order to predict losses at home based on the occurrence of each consumer behaviour: for instance, some consumers always store strawberries in the refrigerator, while others store them at ambient temperature; some consumers always open the pack immediately after purchase, which disrupts the modified atmosphere and thus

14. eMAP is a type of Modified Atmosphere Packaging (MAP), used more specifically for fruits and vegetables, that creates an optimal gas mixture in the closed product environment. The mixture of gases around the product is the result of product respiration and gas permeation through the film. Equilibrium between these two phenomena leads to an optimal gas composition around the product. Suitable gas composition can be achieved only if the gas (oxygen and carbon dioxide) permeation properties of the packaging film match the respiration characteristics of the product under set conditions of surface, package volume and fruit mass.

eliminates its benefit on fruit preservation. The environmental benefit of implementing eMAP in the post-harvest strawberry chain was also evaluated in comparison with the impact of refrigeration and considering the diversity of consumer behaviours. To quantify the gain in shelf life obtained using eMAP, a mathematical model was developed for predicting strawberry deterioration, coupled with mass transfers of O_2 and CO_2 into the package and fruit respiration. The level of deterioration depended on the temperature and CO_2 content in the package at equilibrium. This model allowed numerical exploration of storage conditions at different times and temperatures as well as prediction of the shelf-life gain for more than one day; as a result, significant benefits in terms of shelf-life gain could be expected for this product under eMAP (Matar et al., 2018a, 2018b). Matar et al. (2018a) calculated a 13% maximal acceptable deterioration based on consumers' readiness to buy and measured deterioration curves. In other words, if deterioration is less than 13%, the consumer will purchase the punnet of strawberries; if it is more than 13%, the consumer will reject the punnet, and then it will be thrown away by the retailer. Once at home, losses were considered as proportional to product degradation; this degradation depending on storage conditions (temperature and internal atmosphere composition under eMAP conditions and consumer practices). In order to evaluate the consumer practices, we conducted a consumer survey during the two last weeks of May 2016, during the strawberry harvest period. The survey was completed by 749 participants over 20 years old and representative of the French population in terms of age, gender, and occupation. Among other findings, 79% of consumers removed the packaging just after purchase. A total of 57% of consumers kept the fruit at ambient temperature, while 43% of them kept the strawberries in the fridge.

To account for the many post-harvest storage conditions and consumer practices that could reduce food losses, 132 scenarios for storage of fresh strawberries were investigated with the developed numerical model. These scenarios were used as inputs to calculate the losses generated in the post-harvest chain as a function of product deterioration. Considering the probability of occurrence of each scenario and consumer practices, the use of eMAP instead of commercial macro-perforated packaging would reduce losses by an average of 17%. The loss reduction is low because 50% of consumers open the packaging before storing the fruit in the refrigerator, thus disrupting the benefit of eMAP before the fruit is consumed. Losses might be reduced by 74% if all consumers stored the strawberries in the fridge with the packaging intact (Matar et al., 2020).

Finally, the life cycle assessment (LCA) method was used to address the environmental benefit of using eMAP at ambient temperature as an alternative to the use of conventional macro-perforated packaging and refrigeration. LCA was applied to the strawberry supply chain, from production to consumer level, considering losses at each stage as well as packaging production, disposal and usage benefit, if any, in terms of food loss reduction. Our findings confirmed that for highly perishable products such as strawberry, the production stage is the main source of environmental impacts. Accordingly, the preservation technology that minimizes losses has the lowest environmental impact in spite of its direct impacts. The main conclusions of this study are that eMAP could be, under various conditions, a valuable option compared to standard packaging strategies (Matar et al., 2020).

⏩ Smart design and application of innovative technologies to reduce FLW

FLW can be reduced in the future by using engineering approaches that combine the use of food degradation models and the smart design and application of innovative technologies that slow this degradation. This section details the different steps needed to reach that objective.

The need to develop representative food degradation models for better shelf-life evaluation

Extending product shelf life and reducing losses requires limiting microbial growth and enzymatic degradation at the surface of fresh products. In Western countries, the intensive use of cold storage and packaging solutions are traditionally used to reach this objective. Low O_2 and high CO_2 concentrations in eMAP reduced strawberry losses. Both the inhibition of microbial growth and the decrease of respiration and enzymatic deterioration were considered using a unique degradation mathematical model. In the case of red meat, MAP are used instead of eMAP. These MAP usually contain a high level of CO_2 to slow bacterial growth, as well as a high quantity of O_2 to maintain the attractive red colour of meat. To correctly predict food degradation, two different degradation models are needed to separately model microbial growth inhibition and the change in meat colour. Recent work has been done to connect the change in the red colour parameter to the oxidation-reduction potential during preservation of a piece of steak, stored either using an oxygen totally permeable package or a modified atmosphere package (MAP) totally impermeable to oxygen (Cucci et al., 2020). One can imagine using such a simple model and artificial intelligence algorithms to reduce losses in factories. However, this approach remains limited and cannot be applied directly to new processes, because the dynamic of the model is not yet fully explained. Another approach is to model oxygen diffusion and oxidation kinetics to predict the colour change of beef meat. These more fundamental models are under development, including complex reaction schemes (Tofteskov et al., 2017; Oueslati et al., 2018; Kondjoyan et al., 2022 a, 2022b). Within the framework of the H2020 GLOPACK project,[15] some MAP modelling tools are currently being upgraded and deployed to propose decision-aiding software in the field of food packaging. These models have integrated all mass transfer phenomena in the MAP of fresh produce and some degradation, such as microorganism growth. Even if the degradation models are still very elementary and do not provide a full overview of the reactions involved in a product's degradation, the software can be used to optimize MAP (atmosphere composition and selection of appropriate packaging materials) and avoid any loss of efficacy before the best before date. This tool has the advantage of being applicable on a wide variety of food products (dairy, meat, ready-to-eat foods), provided that the targeted optimal atmosphere for limiting degradation and optimizing shelf life is known. The more

15. https://glopack2020.eu/

fundamental models remain of interest to understand the effect of variation of food composition or treatments (cooking, etc.) on product degradation and to design new food products (Kondjoyan et al., 2022a, 2022b).

The need to clarify the benefit/cost ratio of innovative technologies for food loss reduction

Cold storage remains costly in terms of energy use and must be well managed; cold chain failures still occur, even in Western countries. To mitigate the overall environmental impact of the post-harvest chain, attempts were made for some fruits and vegetables to replace, either partially or totally, cold storage with eMAP technologies. Both technologies are designed to slow down product respiration and extend shelf life, but these effects still need to be quantified and compared. By reducing FLW, both technologies will generate environmental benefits. However, improved efficiency to reduce FLW does not automatically lead to environmental benefits. Some technologies that are used to reduce FLW may have their own impact on resources and greenhouse gas emissions, thus counterbalancing food loss reductions. This benefit/cost ratio is a key point for all innovations proposed to reduce FLW; however, it is rarely evaluated. Our research demonstrated that, in the specific case of fresh strawberries and for long-term storage (more than two days in consumer homes), eMAP at ambient temperature could not replace refrigerated storage. In spite of the additional environmental cost of cold storage, the costs were not high enough to offset the environmental benefit of reducing FLW. In several other conditions, eMAP could be a valuable option compared to standard strategies for strawberry storage. Our approach and methodology could be generalized to other food chains to better evaluate the efficiency of technologies for food loss reduction.

The need to quantify the efficiency of alternative food preservation technologies

Among innovative technologies used to extend the shelf life of fresh food and reduce losses, recent research has been dedicated to alternative methods of biopreservation or microbial inactivation and non-thermal physical processes. Biopreservation is based on known microorganisms or substances, but it is often limited by legislation on novel foods and by consumer aversion to biological or chemical additives. As a result, there has been new interest in non-thermal physical processes. The development of high hydrostatic pressure processing (HPP) can considerably extend the shelf life and limit losses of fresh products (Huang et al., 2014). However, HPP requires large, expensive infrastructures and is mostly reserved for high value-added products for exportation, large companies or regionally-funded platforms. Other non-thermal processes (NTP) have been studied to decontaminate fresh foods, extend shelf life and limit losses. Pulsed electric field, pulsed light, ultraviolet light and cold plasma are more acceptable to consumers than gamma rays or even X-rays (electron beams). Extending food shelf life is more efficient when the treatment is directly applied in the package, in homogeneous liquids, or on easily accessible flat surfaces. NTP effectiveness on solid food products of complex shapes, such as carcasses or meat pieces, is often lower and applications have so far been restricted to research. However, inactivating microorganisms on the food surface is not enough to preserve food, because biochemical reactions can also alter food sensory properties. Moreover, some microbial inactivation processes can promote these reactions in foods (such as HPP, which accelerates the oxidation reactions in red and fatty meats), and change their colour and flavour, thus increasing meat losses. It is therefore essential to better predict colour change according to oxidation. Moreover, the study of oxidation kinetics is of interest because these reactions generate the chemical radicals used in some non-thermal microbial inactivation processes. Further research is still needed to decipher the impact of these alternative technologies on food shelf-life extension.

The need for targeted actions to reduce food losses in the Global South

What solutions could be imagined to limit the loss of fresh products in the Global South where cold storage is not always possible, nor sustainable, and where expensive HPP regional platforms are not relevant or impossible to fund? One possibility is to move towards surface inactivation methods that combine simple and adaptable physical processes with the application of 'natural compounds', while using little energy and water. For example, low combustion energy and/or solar energy could be used to vaporize natural bacteriostatic or bactericidal compounds at temperatures of 75°C to 90°C. This technique is based on the ancestral principle of food smoking, but without smoke, mimicking recent applications of chlorine without the potential health risks (Sun et al., 2019). Many natural compounds with bactericidal or bacteriostatic effects have been proposed in Western countries (Tyagi et al., 2012), but many other compounds can certainly be extracted from flora found in the Global South. Another way to inactivate microorganisms on flat surfaces after cutting meat products could be the use of pulsed light involving ultraviolet light-emitting diode technology as proposed by Hinds et al. (2019). However, in the Global South, even if the surface of meat products has been microbiologically decontaminated, it is strongly recommended to treat the entire product due to the absence of cold storage, the dangers of recontamination, and the presence of parasites in animal muscles. The design of food processing systems in these countries is a complex activity driven by major health, economic, environmental and human issues, and it seems worth it in this case to develop efficient and sustainable locally-adapted transformation systems, based on traditional know-how but able to add value to food, including its nutritional quality, at affordable costs and with efficiency targets. Considering various performance criteria such as organoleptic characteristics, nutritional and sanitary qualities of the product, energy consumption, and environmental impact, as well as cost and system robustness, raises the question of how to prioritize them and determine how they should be aggregated for process optimization (Madoumier et al., 2019; Raffray et al., 2015; Rivier, 2017). For example, regarding biltong, the development of a multi-criteria optimization tool combining models developed at the unit operation scale could lead to a sustainable development of this product, satisfying consumer expectations in terms of less processed products while making it possible to identify the best technological pathways that limit product losses, especially during storage. Such a generic approach could be transposed to Western countries to design new food products and processing systems.

The need for an inclusive food engineering approach

A number of factors may prevent food supply chain stakeholders from taking fully rational decisions and adopting practices that would enable them to efficiently reduce FLW. In particular, food operators and consumers may have inadequate information on the options available for reducing loss and waste or the benefits of doing so. Indeed, our work highlighted the importance of consumer awareness and beliefs about technologies used to preserve food; for instance, French consumers habitually open packaged fresh fruit and vegetable products just after purchase, which leads to product respiration, thus disrupting any modified atmosphere and cancelling out its efficacy as a means of food waste reduction. Our work demonstrated that engineering modelling approaches could integrate consumer behaviours regarding food storage and consumption in order to explore and assess their impact on FLW reduction (Matar et al., 2020). It is therefore essential to improve awareness among individuals and convince them of the benefits of new technologies for reducing FLW. Additionally, stakeholders may also face constraints or preferences that prevent or deter them from implementing actions to reduce FLW. Knowing and integrating all these constraints in a more inclusive food engineering approach is key to designing technologies that align with stakeholder demands and practices. This issue is essential, especially in the Global South, where processing constraints are tricky. The biggest challenge for the future will be combining interdisciplinary forces, such as food science, food engineering and the social sciences.

⏩ Conclusion

A food engineering approach was proven to be efficient when considering how to reduce food loss and waste in meat and fresh fruit food supply chains. In Western countries, our study confirmed that a large part of fresh product loss and waste takes place in consumer homes, but that it is often due to problems that originate further up the chain. Mathematical models combining data on mass transfer and food quality can predict the share of FLW linked to food degradation. In the future, our results on combined models can be associated with smart sensors to improve processing and packaging design. Tailored, low-cost and small-scale preservation processes would be of paramount importance to reduce FLW in the Global South, where extensive use of cold storage is neither advisable nor sustainable. A tailored approach would require the implementation of a holistic approach for multi-objective optimization of whole food processing to be able to consider food safety constraints and new consumer expectations in terms of the sensory and nutritional quality of products as well as those related to processing sustainability. Finally, our work illustrated the importance of multidisciplinary approaches needed to evaluate the benefit/cost ratio of technologies to reduce FLW and deliver major societal benefits. Collaboration between the food science, food engineering, nutrition, environmental science, economics, and sociology fields is needed to carefully link the reduction of FLW and food security, market and consumer expectations, acceptances and practices, and environmental sustainability.

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Chapter 9

Artisanal palm oils: from quality design in southern Cameroon to consumption in Yaoundé

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African countries are facing high population growth, rural exodus and heterogeneous economic growth. These changes are reflected in different ways: rising demand for food, which is supplied by local production and imports; more sedentary lifestyles; and dietary changes, with people eating more out-of-home meals and fried foods, and consuming a higher proportion of fats in their total calorie intake, more processed foods, and less fruits and vegetables. As a result, undernutrition has decreased but still persists, while rates of overweight and metabolic diseases are rising and protein, vitamin A and micronutrient deficiencies remain a main concern (Nansseu et al., 2019; National Institute of Statistics [Cameroon] and ICF, 2020).

African countries around the Gulf of Guinea are traditional producers and eaters of red palm oil (RPO). In these countries, oil and fat consumption is continuously rising as a result of economic development (Ambagna and Dury, 2016), but the younger generations show a tendency to abandon RPO for sociocultural reasons (Lamine, 2006). Meanwhile, the increasing use of palm stearin from refined palm oil by food industries has led to a growing controversy at the international level due to both the environmental impact of industrial oil palm plantations and the health consequences of frequent consumption and high levels of dietary saturated fatty acids. This controversy should be carefully weighed with regard to Africa where RPO consumption could solve health problems related to vitamin A deficiency (Engle-Stone et al., 2017).

In the southern regions of Cameroon where oil palm (*Elaeis guineensis*) is endemic, the production of artisanal RPO is rising due to the development of artisanal mills (Ndjogui et al., 2014; Rafflegeau et al., 2018). Used as an ingredient in various local dishes, the artisanal and industrial RPOs are sold on the markets to local consumers without any quality control for the artisanal RPO. However, a decrease of its consumption per capita has been observed in the urban area of Yaoundé. In 2001, RPO was reported to be the most-consumed oil by the population of Yaoundé, totalling 60% of oil consumption, 5% of household budgets and 10% of calorie intake for residents. In 2016, RPO accounted for 25% of the oil consumption and only about 20% of the edible oil market due to its lower price than refined palm, soya and cottonseed oils (Rébéna et al. 2019).

This chapter highlights the links between extraction conditions of artisanal RPOs in southern Cameroun and their physicochemical and nutritional characteristics. It also aims to identify the determining factors of consumer choice for specific RPO culinary applications in Yaoundé. The potential contribution (negative or positive) of RPO to nutritional intakes with regard to health issues and dietary trends is also underlined.

⏩ Characteristics of processed fruits, artisanal mills and production factors in the surveyed area

Over time, southern Cameroon farmers developed a deep understanding of how to manage the local wild *dura* palm. From the late 1970s, the African oil palm development plan named 'plan palmier' introduced farmers located near industrial mills to a new high-yield selected palms. This selected *tenera* palm, which produces 100% *tenera type fruits*, is obtained from selected *dura* × *pisifera* palms of different origins (Ndjogui et al., 2014). Farmers rapidly adopted this new selected palm, but they lacked information on its propagation: where to buy selected *tenera* seedlings or seeds and the reasons why they should buy them systematically. Curry et al. (2021) explain why without this propagation knowledge, farmers planted mainly open pollinated progenies, a mix of 50% *tenera* palms, 25% *dura* palms and 25% abortive *pisifera* palms instead of 100% selected *tenera* palms. Farmers located farther away from agro-industries adoped the selected tenera palms more slowly without any support from development projects. Meanwhile, non-governmental organizations promoted the artisanal extraction of RPO by training blacksmiths to replicate different models of small-scale presses (Poku, 2002). Nowadays in the whole palm oil production area, the outcome of these development efforts is a diversity of fruit types processed by artisanal millers, where every possible mixture of fruit types can be seen: 1) wild *dura* fruits with a very thin pulp layer and thick stone shell, 2) *tenera* fruits with thick pulp layer and thin stone shell, and 3) *dura* fruits with intermediate characteristics. Since palm oil is extracted from the pulp, the type of processed palm fruits is the main factor explaining the rate of oil extraction for a given extraction tool and process (Rafflegeau et al., 2018).

In 2015, we interviewed 32 artisanal millers from four production regions and described, for each artisanal mill, the processed fruits, the equipment and the processing conditions. The main technical factors differentiating these artisanal mills were the type of processed palm fruits, the production conditions from harvest to extraction and the type of extraction press, with characteristics varying from one region to another (Figure 9.1).

The survey revealed that the palm oil yield was the lowest in the West region where smallholders often processed wild *dura* palm fruits with water extractors. Using this method, one 200-litre drum of fruits yielded around 25 litres of RPO. In the