Artisanal mills and local production of palm oil by smallholders

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1 Introduction

Elaeis guineensis, the most commonly grown oil palm in the world, is native to the Gulf of Guinea. Before colonisation of the African continent, the African people were traditionally red palm oil producers and consumers. The existence of wild palm groves, regionally called 'natural' palm groves, substantiates the origin of such traditional production and consumption (Hartley, 1988). During the colonial period, European colons traded with African custom authorities to export artisanal red palm oil to Europe mainly for industrial uses (Rouzière, 1995). For centuries Africa remained as the main producer of traditionally processed red palm oil. Slaves exported the knowledge about production, culinary traditions and seeds to Brazil (Bahia region) and to some West Indies islands. During the twentieth century, the development of massive processing units occurred until the present-stage industrial mills and refinery with high processing capacities (i.e. 40 t/h).

Owing to the introduction of industrial mills and refineries, the oil palm development took a world scale from the 1960s, particularly in Southeast Asia, and also in Latin America. Nowadays, two types of consumers constitute the world consumption of palm oil on the basis of food uses:

- Artisanal and industrial red palm oil consumers, who are still mainly African people and the descendants of the African slaves; they know and appreciate the taste of red oil palm and its culinary properties, especially its use in the preparation of traditional

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African and Bahianese meals, although they are also consuming refined oil (Cheyns and Rafflegeau, 2005);
- Refined palm oil consumers are the people in the rest of the world who consume only refined, deodorised and bleached palm oil (after elimination of carotenes, vitamins and taste), because they are not used to the taste of the red palm oil in their culinary recipes.

From this brief historical context, we conclude that Africa is the continent of production and consumption of artisanal red palm oil. This chapter will focus on the artisanal red palm oil production in Africa, where more than 80% of the oil palm production area is controlled by smallholders, including family farms (Rafflegeau et al., 2015). Referring to the history of oil palm development in Africa, the first section will describe the emergence of red palm oil from pre-colonial times up to the recent actual supply chain of artisanal red palm oil, from production to markets.

The existing diversity between smallholders, from family farms to agricultural enterprises, has previously been explained. The different types of smallholders previously described induce a huge range of planting conditions, of technical management of smallholdings, during both immature and mature phases, and of replanting conditions. There are different reasons for smallholders to process by themselves their oil palm fresh fruit bunches (FFB), and a diversity of processing conditions. The second section will show which types of smallholders have embarked on the artisanal processing of red palm oil and will discuss why smallholders decide to do it according to the local context of oil palm development. The third section will describe the artisanal processes and tools associated with artisanal extraction units which are presently at work in Africa.

Due to smallholders' diversity, the processing diversity between smallholders induces a quality diversity of artisanal red palm oil. As a matter of fact, artisanal red palm oil is not a standardised product for the exporting market, but rather a heterogeneous artisanal product sold on the local market. The fourth section will present the quality, properties and uses of artisanal red palm oil. The range found in the proportions of the main chemical components will govern the heterogeneity of quality, which will be assessed in terms of its benefits and risks for human health.

2 Emergence of artisanal extraction of red palm oil in Africa

2.1 Production and consumption zones in Africa

Comparing three African oil crops, namely oil palm, cotton and peanuts, Jannot (2013) established a map showing where colonial agricultural services advised to grow each crop in the 1950s; thus before the independence of African nations, and after this period international institutions started funding the huge national development projects (see Fig. 1). However, the oil palm agricultural area was actually wider than the green line on the map, which just shows the recommended zone, but not the zone classified by colonial agronomists as 'marginal' , where family farms were producing artisanal red palm oil.

Important projects for oil palm development were located in the recommended zones, rather than in the so-called marginal zones, where the oil palm production is less due to climatic

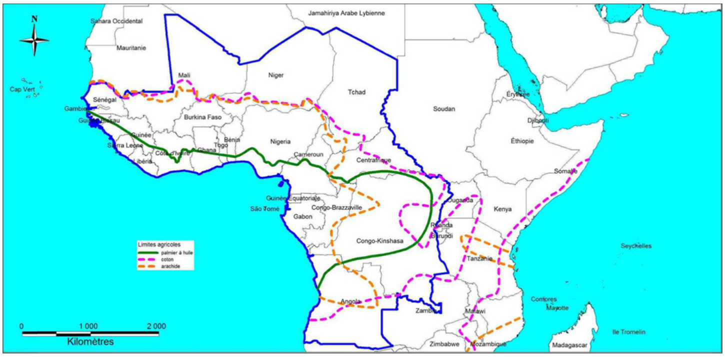

Figure 1 The green line on the map represents the agronomists' recommended zones for oil palm in the 1950s for colonial settlers. Post-independence, oil palm development projects were localised in these recommended zones. Traditional production zones of red palm oil by family farms are wider (from Jannot, 2013).

conditions. In the 1950s, the zone of artisanal red palm oil production by family farms was wider than what the green line on the map represents, and it is still the case. As local traders are selling artisanal red palm oil to south Sahelian population, its consumption zone is even wider.

2.2 Impact of oil palm development history

Ndjogui et al. (2014) described in detail the history of oil palm development in Cameroon, starting from the pre-colonial period. This historical review is not specific to Cameroon as it describes what happened in the palm-oil-producing countries located near the African equatorial zone already described by other authors (Hartley, 1988; Corley and Tinker, 2003). Regarding what we call now 'smallholdings' and 'smallholders', the interest of Ndjogui's review (2014) lies on the description of two parallel transitions due to oil palm development: an agricultural one and a technological one. These two transitions have impacted artisanal red palm oil production.

An agricultural transition

For ages, African men were climbing the palm trees to harvest ripe FFB in 'wild groves' (the community-owned groves of palms described by the European colons) and in agroforestry food crop systems (privately owned plots producing mixed food crops in rotation with fallows). In the 'marginal' zones where there was no planned action for oil palm development, African rural farmers were still harvesting local 'wild' palm in those agroforestry food systems and wild groves. In 'recommended' zones, farmers benefited from oil palm development actions after independence. Most of the smallholders first adopted harvesting tools, thus halting the very dangerous harvesting practice of climbing the palm trees for collecting bunches. They secondly adopted the use of selected planting materials because of its much higher red oil yield, even with a bit lower kernel oil yield. Following agricultural recommendations, they created monospecific oil palm plantation with palms planted in line with a spacing design such as 9 by 9 m in triangle, thus corresponding to 143 palms/ha (see Fig. 2).

Nowadays, palm groves exhibit two different situations:

- oil palm tree areas of high density (from 200 oil palm trees/ha), with trees being sowed or planted with no spacing design, no maintenance and are only harvested;
- area dedicated to food crop production, where few tens of trees (less than 50/ha in order to preserve sunshine for food crops) are saved while clearing fallows with slash-and-burn practices; these are agroforestry systems where the main products are food crops including oil palm bunches.

In both situations, local unselected planting materials (Dura type) or open-pollinated progenies collected in selected plantations (natural pollination between Tenera types giving progenies of 25% Dura type + 50% Tenera type + 25% Pisifera type) are used by family farms. Open-pollinated progenies of unselected materials still produce more oil, even with the 25% sterile Pisifera-type palm trees (Cochard et al., 2001). Figure 2 shows the impact of the type of planting materials on expected oil yields.

A technological transition

For ages, in the oil palm growing area, African people used two traditional methods of oil extraction:

i treading with feet and washing with water in order to extract the floating red oil from the pulp, and
ii heating of the kernel nuts in a saucepan in order to extract kernel oil.

After independence in the 1960s, the huge national development projects funded by international institutions provided access to industrial extraction for smallholders benefiting from the project with plantation credit and technical support. After the funding banks had become bankrupt, the smallholders located inside industrial mill supply areas decided to create their own oil palm plantations in order to benefit from existing industrial mills to

	Types of planting material more generally used			
Smallholders' main cropping systems	Selected (100% T)	Unselected (25%D + 50%T + 25%P)	Local (99% D local)	
Oil palm plantation with design ex: 143 palms/ha	X	X		Agricultural transition ↑
Wild grove + isolated palms in food crops plots		X	X	Traditional
Palm oil yields % of selected palms yield in the same conditions	100%	40%	10%	

Agricultural transition ← Traditional

Figure 2 Oil palm development induced an agricultural transition. The type of planting materials used impacts the oil extraction rate for both artisanal and industrial extraction processes (from Cochard, 2001; Rafflegeau, 2008; Ndjogui, 2014).

process their FFB without having to invest in an extracting tool. In French-speaking African countries, oil palm development was based on the extraction of oil by high-capacity industrial mills which belonged to state-owned development companies. These mills were built to process FFB production from industrial plantations managed by the development company and also from smallholdings developed inside the mill supply area. In English-speaking African countries, oil palm development was based on both industrial mills in large palm oil production area and small-scale processing units for smaller production area (Rouzière, 1995). Artisanal red palm oil production was thus supported by post-independence projects mainly in Nigeria and Ghana and, to a lesser extent, in Sierra Leone and Liberia. Those projects involved national research institutes such as Nigerian Institute for Oil Palm Research (Poku, 2002; Rouzière, 1995).

From the late 1980s, NGOs mostly took over the post-independence projects to promote the artisanal extraction of red palm oil using small-scale mills replicated from English-speaking countries. NGOs – such as APICA and SOWEDA in Cameroon and CFTS in Benin – worked in French- and English-speaking countries, within the recommended zone but also in the marginal zones where many people were involved in traditional oil extraction (Poku, 2002; Rouzière, 1995). Firstly, those NGOs trained blacksmiths to locally produce artisanal extraction tools and secondly they trained smallholders' group to establish and use the small-scale mills. Artisanal extraction immediately boomed because blacksmiths and smallholders copied each other's innovations. On the one hand, turning from traditional extraction of red oil palm into artisanal extraction using a small-scale mill does not affect the quality of the oil and significantly saves time, allowing the same quantity of cooked oil palm fruit to be processed (Fournier et al., 2001). On the other hand, traditional extraction by treading with water facilitated the collection of kernel nuts. As households generally used artisanal red palm oil for food preparation and kernel oil for traditional medicinal purposes, the artisanal extraction process too was adopted, paralleling agricultural innovations. Traditional and artisanal extraction processes coexist, but the artisanal process emerged where and when development occurred.

Figure 3 shows the present mosaic of technological situations for palm oil extraction according to the location – either recommended or marginal – and to the presence – or absence – of oil palm development plans. Trends are thus described: since the

		Types of extraction		
Oil palm agronomic suitability	Oil palm development action	Industrial	Artisanal	Traditional
Recommended zone	With	Frequent	Frequent	Uncommon
	Without	Possible	Common	Uncommon
Marginal zone	With	Never	Frequent	Disappearing
	Without	Never	Possible	Frequent
Oil extraction rate with selected planting material		**21-26%**	**15-18%**	**15-18%**

Figure 3 Oil palm development induced a technological transition as traditional extraction has slowly been disappearing from the 1980s with the boom of artisanal extraction. Artisanal extraction allows some sizeable saving of time to process the same quantity of cooked oil palm fruit.

1980s, traditional extraction has slowly been disappearing with the boom of artisanal extraction.

These two parallel transitions – agronomical and technological – occurred where oil palm development plans were undertaken. Oil palm production can still be traditional elsewhere, if technical innovations were not introduced and implemented. The result is that, nowadays, in a given African country, all types of agricultural and technological situations coexist. Within such a diversity of technical situations, the most important factors for artisanal palm oil production are i) the type of planting materials (see Fig. 2) and ii) the type of extraction method, tools and process, as described in Section 3.

2.3 The present supply chain for artisanal red palm oil

Like in other palm oil producing countries in Asia and Latin America, agro-industries are extracting crude palm oil (CPO) and palm kernel oil from their own industrial FFB and from FFB bought from smallholders. Many African smallholders and palm oil producers without plantation are producing artisanal red palm oil through both artisanal and traditional processes, and figures of such an informal production remain uncovered by international statistics (see Fig. 4). Nevertheless, it represents a huge part of national production in Nigeria. Indeed, Nigeria has not really increased its palm oil production in the last 50 years, dropping from the position of world's leading producer down to fifth rank now – trailing Indonesia, Malaysia, Thailand and Colombia. While it is clear that wild groves cannot satisfy the world's booming demand, artisanal red oil production does meet local demand and foot habits (Cheyns and Rafflegeau, 2005).

Palm groves produce exclusively artisanal red palm oil, but their actual acreage is totally off record and they cannot be considered as plantations because of their specific densities

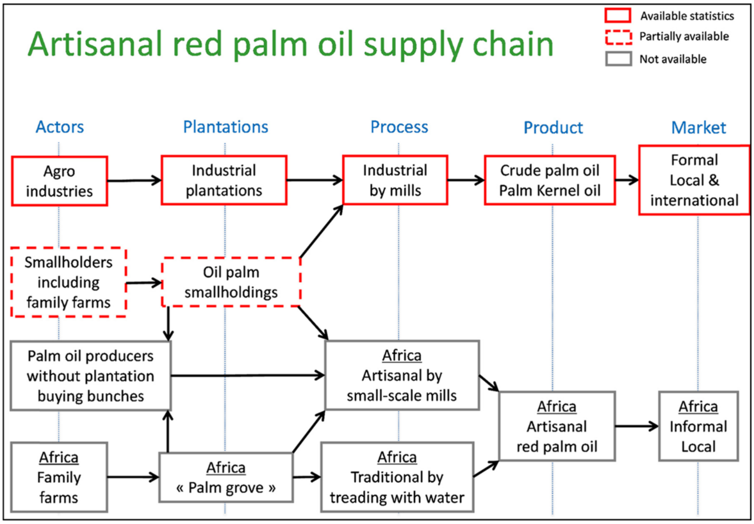

Figure 4 Smallholders are producing artisanal red palm oil by artisanal and traditional extraction, but there is no available production statistics because it is sold on informal market from Lacan et al. (2015).

and structures. They are mainly located out of official palm development zones and thus out of the supply areas of industrial mills.

Figure 4 shows first that artisanal red palm oil is exclusively produced from FFB harvested in smallholdings (except in case of theft from industrial plantations) by local actors: both smallholders and palm oil producers without plantation. Figure 4 also shows that inside a given mill supply area, smallholders can decide to sell their FFB either to the industrial mill or to an artisanal red palm oil producer who does not own any oil palm plantation. They also have the opportunity to process FFB through their own artisanal processing unit or their neighbours' one, the milling cost being traded against a part of the extracted oil (20% in general). In the next section we will describe the reasons governing smallholders' choice for one or the other of these options.

As artisanal red palm oil being sold on the informal market, there is no opportunity to collect production data from custom services or industrial mills similar to those collected for industrial red palm oil and refined palm oil. Because of this informal market, Jannot (2013) explains the difficulties to obtain accurate data of production and uses in Africa which cover both industrial and artisanal red palm oils. When palm oil data from Africa are presented, we must remember that they are only roughly estimated, both for areas (acreage of unselected plantations and palms out of plantation areas are not taken into account) and for production (artisanal palm oil is only roughly estimated or even not taken into account at all).

Artisanal red palm oil can be used for both alimentation and soap production (artisanal and industrial). Industrial refineries do prefer to buy industrial red palm oil rather than the artisanal one in order to reduce the risk of high free fatty acid (FFA) content linked to process conditions and poor preservation.

3 Who is producing artisanal red palm oil and why

We show in Fig. 4 that artisanal red palm oil is produced either by smallholders extracting oil from FFB harvested in their own smallholdings or by oil producers buying smallholders' FFB.

3.1 Diversity of actors producing artisanal red palm oil

Marzin et al. (2015) have characterised the diversity of farm types between entrepreneurial agriculture and family agriculture. Applying their typology to oil palm agricultural actors proved useful in order to show the diversity of farming situations hidden behind the general 'smallholders' name. This typology is built using labour as the main factor, with capital, management, home consumption, legal status and land status being considered as secondary factors. Family farms have no permanent labour, while managerial enterprises employ exclusively paid staff. Family business farms have at least one permanent labour. They could be a 'mature' family farm with enough oil palm area to employ one permanent labour, or an oil palm farm created by a small investor (retail trader, salaried employee, retired person, etc.) involving his family labour force (see Fig. 5).

Only agro-industries are able to invest millions of dollars necessary for setting up an industrial oil mill with high extraction performance and a high level of compliance with environmental requirements, especially regarding the treatments of effluents. Besides, the Caltech model of small-scale hand mill, which costs a few hundred dollars in Cameroon, is within the reach of family business farms and even of family farms. Outside of industrial

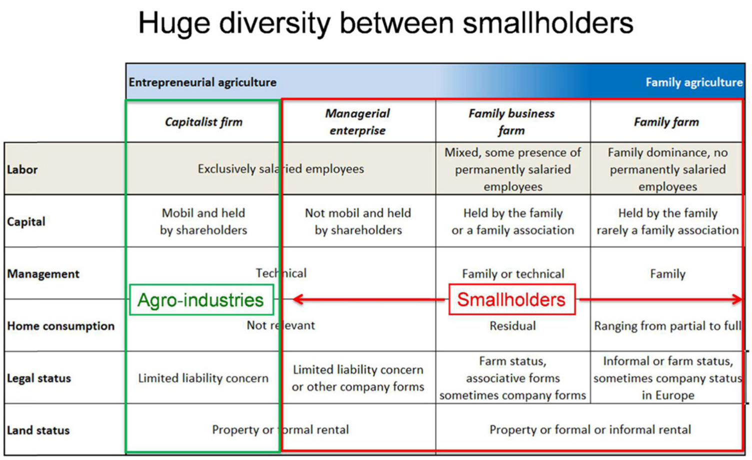

Figure 5 The name 'smallholder' hides a huge diversity of farm types, from family farms with no permanent labour to managerial enterprises with only salaried employees. In contrast, it is easy to imagine what an oil palm agro-industry is with its huge capital invested by multinational capitalist firms and its technical organisation of tasks by salaried labour from Marzin et al. (2015).

mill supply area, when a family business farm invests in some processing equipment which cannot be used at full capacity, it initiates momentum for local development by opening the facility to neighbours. This service will be paid by trading a portion of the produced oil. This is often the case in Africa: a small farmer buys a small-scale mill which he uses only a few days every fortnight. Either inside or outside a mill supply area, clear land tenure situations then allow the synergistic coexistence of family and entrepreneurial forms of production based on market needs for smallholders and on supply needs for all types of mills.

From one ton of FFB produced by selected palms, a small-scale mill usually produces 150–180 kg of artisanal red palm oil, whereas an industrial oil palm mill produces about 250 kg of CPO and palm kernel oil. Despite its low oil extraction efficiency, the small-scale process is considered as economically viable and socially sustainable outside the mill supply basin (Plédran et al., 2016).

Oil producers without oil palm plantations show the same diversity as found for smallholders' farms, with the same characteristics about the factors chosen to build the typology presented in Fig. 5, except for land tenure because such stakeholders do not really need agricultural land. Comparing the levels of investment channelled into extraction units really helps in representing the differences existing among the types of producers' exploitation. Some managerial enterprises of producers can invest to create a semi-industrial extraction unit, in between artisanal extraction units and industrial mills (see Fig. 6 and 7).

Where there is land conflict between state-owned development company and land owners, or between a private agro-industry and people from the neighbouring villages, some oil producers generally steal FFB from inside the industrial plantations at night. Sometimes, theft of FFB can be at the origin of the conflict. Conflicts can also flare up because of FFB stealing, land conflict or jealousy, outside of a mill supply area between a managerial oil palm farm and producers whose farms are adjacent to these managerial farms.

Figure 6 (S. Rafflegeau): Examples of investment in the mini-mill, a semi-industrial extraction unit by managerial enterprises of producers: Global view of a container extraction unit processing stemmed fruit in Côte d'Ivoire.

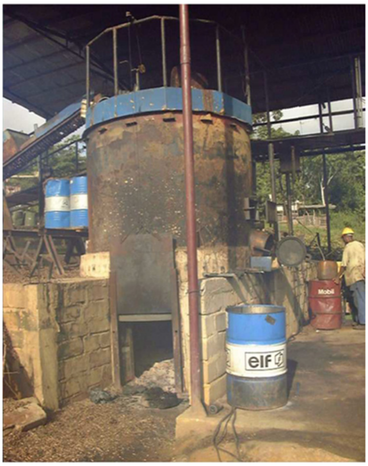

Figure 7 (S. Rafflegeau): Examples of investment in the mini-mill, a semi-industrial extraction unit, by managerial enterprises of producers: view of a self-made steam FFB cooker in Cameroon.

3.2 Reasons for artisanal extraction by smallholders

The way FFB is processed by smallholders or producers depends on market opportunities for smallholders and on labour available for processing operations. Smallholders have a maximum of four market opportunities for FFB:

1. to sell FFB to the industrial mill or to artisanal producers: this opportunity requires neither investment in processing tools nor labour for processing;
2. to process FFB using their own artisanal extraction unit: this opportunity requires some investment in processing tools and labour for processing;

3 to process FFB using the neighbour's artisanal extraction unit: this opportunity does not require any investment in processing tools, but a proportion of the produced oil must be given to the owner of the extraction unit (20% in general) and for the payment of labour time for processing;
4 to process FFB by traditional extraction: this opportunity requires almost no investment in processing tools, but much more labour for processing than through the artisanal process.

Figure 8 presents a decision chart of the reasons for smallholders and producers to choose between artisanal and traditional processes for the production of artisanal red palm oil.

Outside of industrial mill supply area, the first reason for smallholders to produce artisanal red palm oil is that there is neither industrial mill nor an oil producer for buying FFB. As a consequence, ripe FFB which is not harvested in due time will get rotten on the palm trees. That is the reason why during the peak season of production, extension services do recommend to harvest bunches every 10 days. Ripe FFB which are already harvested will rot much faster than the ones left on the palm tree.

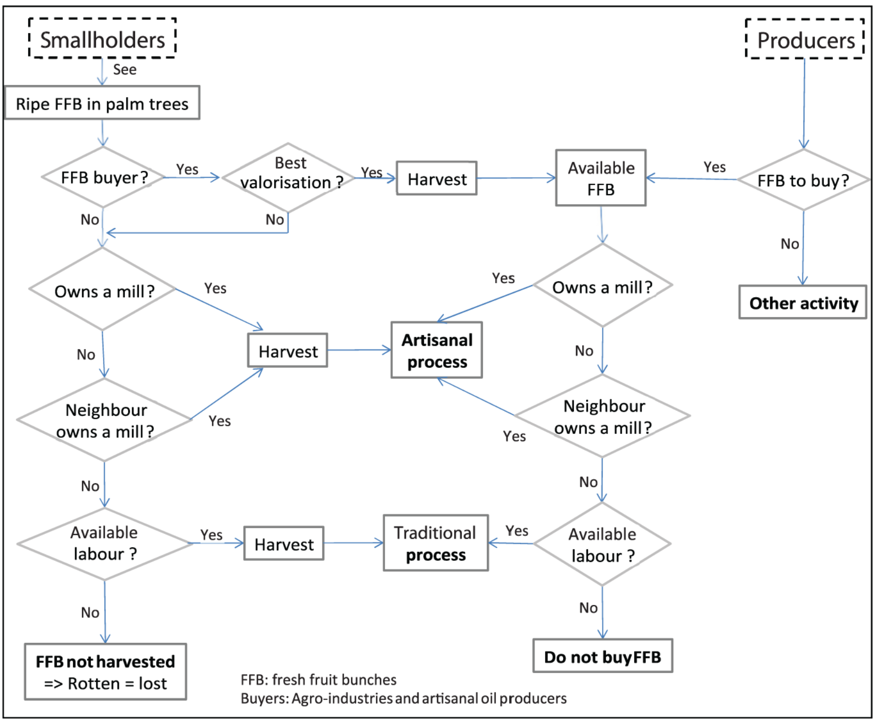

Figure 8 The decision chart shows how smallholders and producers select an extraction process in order to produce artisanal red palm oil. Selling FFB requires no labour for processing, and the traditional process requires the most labour.

Inside an industrial mill supply area, there are three reasons which bring smallholders to invest in an artisanal extraction equipment:

- if the industrial mill is structurally saturated during high production period, collecting from smallholders is temporarily stopped and smallholders lose their FFB;
- if the industrial mill experiences regular breakdowns due to lack of maintenance, smallholders regularly lose FFB;
- if the collecting is consistent during the high production period but voluntarily interrupted during the low production period. This can be due to long travel to farms for a too low quantity of FFB, or high risk for the trucks transporting FFB to get stuck in the mud during heavy rains.

Smallholders located inside an industrial mill supply area can also choose to invest in some processing equipment without any risk of losing FFB, in the following cases:

- if they want to self-process the lost fruit once a fortnight in between two harvests in order to get cash to pay harvesters (day labour) while the mill pay them on a monthly basis;
- if they get more profit from selling the artisanal red palm oil they have processed than from selling FFB to a mill, especially during the low production period when price of artisanal red palm oil is high in the local market, and when labour is not too busy in the food crops plots;
- if there is a disagreement between the industrial mill and the smallholder, like for reimbursing plantation credit.

Artisanal oil extraction is presently booming in Africa, due to investments made by all types of smallholders and producers presented in this section, for all the reasons cited in this section.

4 Major operations and equipment for artisanal processing

Palm oil extraction from FFB is usually done according to the following process (Jacquemard 1995; Nchanji et al., 2013): after harvesting, FFB are transported to the extraction site where bunches are stored. The risk of FFB being stolen increases if FFB stay in the field. The major operations are to stem the fruit, sift and cook them. Subsequently, the cooked fruits are crushed and the palm oil can be extracted by

- washing the mass with water: the lipid top phase obtained is clarified to give artisanal red palm oil;
- pressing the mass: the liquid obtained is clarified to give artisanal red palm oil.

For each operation of the process, we present the corresponding equipment.

4.1 Harvesting FFB

Even if it is not a technological one, this artisanal operation can directly impact oil quality. Harvesting with knife (Fig. 9) can cause cuts on the fruit which promotes the activation of

Figure 9 (S. Rafflegeau): Harvesting palm fruit with a specific tool.

the lipolysis reactions which are responsible for the increase of FFAs content in oil. It is therefore important to handle FFB carefully to limit these reactions (Ngando et al., 2011). When FFB are falling down from the top of a 10-m high old palm tree, some fruits may be damaged.

4.2 Storage

FFB are generally stored for several days (from two to more than ten days) in order to facilitate the destemming of fruit from the bunch. In other cases, bunches are stripped and the spikelets are then stored for a shorter time than bunches. This step induces a fermentation process leading to an increase in FFA content in the fruit due to lipase activity, thus affecting the quality of the oil (Ngando et al., 2011; Owolarafe et al., 2008).

4.3 Threshing (removal of fruit from bunches)

Fruit are removed from bunches and those which remain attached are removed using various objects such as machete, axe, stick and so on (Fig. 10).

Various NGOs have tried to disseminate the use of mechanical threshers but smallholders and producers are not investing in such equipment so they are rarely found.

4.4 Steam sterilising or cooking fruit in boilers

The simplest way of cooking the stemmed fruit is in boiling water in steel barrels (Fig. 11). Managerial smallholders or producers may have invested in the mini-version of industrial mills with the capacity to generate steam to sterilise FFB (Fig. 7). The dried oil cake or dried fibres and kernel, if the kernel oil is not extracted, are often used as cooking fuel. Kernel nuts can be burned as fuel in dried oil cakes, or given to cattle or hand-collected to make traditional kernel oil.

Figure 10 (D. Nanda): Removal of fruit from FFB after few days of storage**.**

Figure 11 (D. Nanda): Cooking stemmed fruit using firewood.

In most artisanal mills, firewood (with poor energy efficiency) is used, thus causing some environmental impact on surrounding forests (Rouzière, 1995). In some small-scale Ghanaian mills, they even burn old tyres for fuel causing further environmental and food security problems. Industrial mills, however, are self-sufficient in energy, by burning the fibres and nutshells and even produce extra electricity for villages surrounding those mills.

The cooking time very often depends on the amount of fruit and the intensity of the fire. Cooking softens fruit, thus facilitating the crushing process and it also inactivates mesocarp lipase (Babatundé et al., 2003).

4.5 Crushing and mixing

Home-made wood mortar and pestle are the cheapest tools for crushing cooked fruit (Fig. 12), although crushing can also be done mechanically (Fig. 13).

Figure 12 (S. Rafflegeau): Hand crushing.

Figure 13 (S. Rafflegeau): Mechanical crushing and mixing.

4.6 Oil extraction

Oil extracting tools are more often bought, adapted or created by smallholders and producers, whereas other innovative equipment such as clarifiers or mechanical threshers have poor success (Rouzière, 1995; Jannot, 2000). For this reason, there are much more tools for oil extraction than for other processing operations.

Extraction by washing with water

The simplest traditional oil extraction process, which does not require any tool or equipment, was historically the first way to extract oil from the mass of crushed cooked fruits. This method consists in washing it with water and foot treading. This practice still persists in marginal zones despite the harshness and low remuneration of labour (Fournier et al., 2001). A recent adaptation of the traditional extraction consists in building a concrete basin (see Fig. 14) rather than to dig a basin in the ground.

Oil extraction by washing with water can also be done using a motorised water extractor (Fig. 15). It consists of a metal cage inside which there is a rod, around which opposite blades are arranged, connected to a motor. During the oil extraction process water is added. The fruits are mixed and then water is poured into the extractor, which brings

Figure 14 (D. Nanda): Traditional extraction by foot treading and washing with water inside a concrete basin.

Figure 15 (D. Nanda): Workers emptying a motorised water extractor.

out the crude oil to the exhaust of the extractor. This equipment is the highest water-consuming one (Rouzière, 1995).

Extraction by pressing

In marginal zones, smallholders and producers are adapting their existing cassava press (see Fig. 16) or are using a stick and wood structure to press the mass inside a polyethylene bag, such as a rice bag (see Fig. 17). The oil palm cake remains really oily even after two following extraction cycles (pressing, mixing, pressing), showing poor efficiency in oil extraction of such home-made equipment.

There are two major types of oil extraction equipment made by local blacksmiths for smallholders (Jannot, 2000):

- Discontinuous press, with three steps per extraction cycle: filling, pressing and emptying (Fig. 18 and 19). They can be either manual or using hydraulic force to press (Fig. 20) with a manual or motorised pump. They were the first artisanal presses to be disseminated in Nigeria and Ghana. Manual discontinuous press similar to the small Ivorian model shown in Fig. 19 is considered as a valuable tool: it is cheap and provides good performance in terms of labour and oil extraction rate.

Figure 16 (S. Rafflegeau): Adaptation of a traditional cassava press for palm oil extraction.

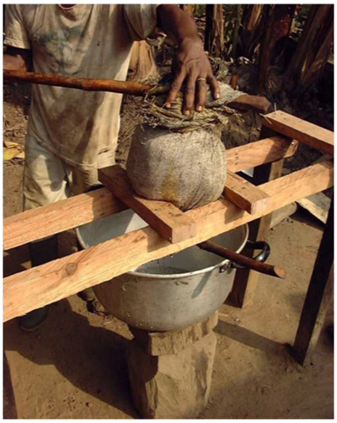

Figure 17 (S. Rafflegeau): The cooked fruits are manually mashed in the traditional mortar, and then are put in a bag and oil is extracted by pressure using a stick.

Figure 18 (S. Rafflegeau): Pressing with manual and robust discontinuous press imported from Nigeria to Southwest Cameroon for a few hundreds of dollars.

Figure 19 (S. Rafflegeau): Pressing with manual discontinuous press, a smaller model appreciated by women producers in Côte d'Ivoire because of its cheap price (few tens of dollars) and facility of handling.

Figure 20 (D. Nanda): Hydraulic discontinuous press: the cooked fruits are mashed with a digester. The mass is placed in a heavy metal cage and a metal plunger is used to press the materials. The pressure should be increased gradually to allow time for the oil to escape. The plunger can be moved manually or by a motor. If the depth of mass is too great, oil will be trapped in the centre of the mass.

- Continuous equipment: the press is filled from one side, while it is emptied by itself. This is the case of the Caltech-type screw press which also has the advantage of combining two functions into the same equipment: i) crushing the fruit by opposite blades at the beginning of the screw and ii) pressing. They can be either manual (Fig. 21) or motorised (Fig. 22). Today, such artisanal presses are the most appreciated tools because they need less labour, and they can rapidly process fruits (for the motorised ones). Screw presses, due to the turbulence and kneading action exerted on the fruit mass in the press cage, can effectively break open the oil-rich cells and thus release more oil. These presses act as an additional digester and are very efficient for oil extraction. Motorised Caltech-type screw presses are becoming the most popular press in Africa for artisanal palm oil extraction.

The efficiency in oil extraction of the various designs of fruit presses ranges from 60% to 70% for discontinuous presses, 80–87% for hydraulic discontinuous presses and

Figure 21 (S. Rafflegeau): Manual continuous screw press (Caltech type). This vertical model is sold for a few hundreds of dollars in Cameroon.

Figure 22 (D. Nanda): Continuous motorised screw press (Caltech type). This model has a mechanical speed reducer between the engine and the press. Motorised models are sold from about one thousand dollars for the cheapest to a few thousands for the best ones.

75–80% for the continuous Caltech-type screw presses (Poku, 2002). In another study, the press efficiencies ranged from 67% to 88%, with the lowest for discontinuous manual mills and the highest for Caltech-type screw press (Rouzière, 1995).

4.7 Clarification

This is the last major step in the production of artisanal red palm oil. The CPO is cooked with water. At the end of cooking, the palm oil (supernatant) is skimmed (Fig. 23). This operation is either manual or mechanised depending on the production site. The oil collected is then poured into containers.

Figure 23 (D. Nanda): Skimming clarified red palm oil before filling containers.

4.8 Oil drying

Drying the oil consists in heating the oil similar to the clarifying process, but without any water in order to evaporate the humidity that may cause oil alteration by oxidation. Generally, the oil drying operation is not often done after extracting oil by Caltech-type screw presses. However, oil drying is a common operation if extraction has been done with a motorised water extractor (Rouzière, 1995) or traditionally because of too high humidity content.

5 Artisanal extraction units

Artisanal extraction units are combinations of extraction equipment and many authors present the diversity of possibilities in grey literature rather than in scientific papers (Rouzière, 1995; Jannot, 2000; Poku, 2002). For a given extraction unit, the less performing equipment will behave as the bottleneck which will define the potential theoretical extraction capacity, assessed in tons of FFB processed by hour. If the succession of operations in the extraction unit is well organised with the right amount of dedicated labour force, its real extraction capacity equals its theoretical capacity. Traditional extraction units have no proper capacity because each operation is handmade. As most of artisanal extraction units are processing fruits but not FFB, the threshing operation is not taken into account, while it can easily become a bottleneck during the high production period because it requires a lot of labour force. Comparing the press capacity will then give a magnitude of what can be the capacity of the whole extraction unit. In order to rank the various types of artisanal extraction units available, we modified the typology presented by Rouzière (1995) in order to include the traditional extraction process by treading and washing with water (Table 1).

Traditional types of units correspond to marginal zones of palm oil production and also to women producers and young smallholders who are newly established. Micro-mills are the most common situations, as they can offer the best value for a quick investment return. Motorised continuous screw presses are the best systems in terms of oil extraction rate and labour need. Mini-mills are ‘businessmen extraction units’ showing the lowest labour need and the best extraction rates, but with the longest lag for investment return (Rouzière, 1995).

Table 1 Typology of extraction units

Type of extraction unit	Threshing	Oil extraction tool	Main characteristics	Oil extraction rate	Investment	Labour need
1-A Traditional by washing	Manual	Foot treading, washing with water	Hand process without extraction tool	Medium	None	Highest
1-B Traditional by pressing	Manual	Pressing mass in a bag with a manioc press	Hand process with a home-made tool	Lowest	None	Very high
2-A Micro-mills manual from 200kg to 500kg FFB/h	Manual	Manual press continuous or discontinuous	Hand process with a manual press made by a blacksmith	Medium (discontinuous) high (continuous)	Tens or hundreds of $	Very high (discontinuous) high (continuous)
2-B Micro-mills motorised by washing	Manual	Motorised water extractor	Hand process with an extractor made by a blacksmith	Medium	Tens or hundreds of $	High
2-C Micro-mills motorised from 500kg to 1t FFB/h	Manual or mechanic	Hydraulic continuous press with motorised pump or continuous screw press	Half motorised unit locally made	High	Thousands of $	Medium
3 Mini-mills mainly around 1 or 2 t FFB/h	Mechanic	Continuous screw press	Small-scale reproduction of industrial units extraction, often imported in container	Highest	Tens of thousands of $	Lowest

None of the artisanal extraction units is equipped for the treatment of mill effluents, even with the simplest lagoon for decantation. They quickly cause water pollution in the water courses and rivers surrounding the units and in the worst cases some contaminate the water table. Extraction by washing the mass is probably the process which produces a lot of effluents. Sometimes the quality of the water for processing itself becomes a problem because of the pollution of the rivers by effluents.

6 Artisanal red palm oil composition, quality and uses

6.1 Red palm oil composition and human health

Red palm oil is a lipid extract from the mesocarp of the fruits from oil palm tree (*E. guineensis*). Throughout the world, 90% of red palm oil is used for edible purposes, while the remaining 10% is used for soap and oleochemical manufacturing (Edem, 2002).

Acyl glycerol composition

Palm oil, like all other vegetable oils, consists mainly of acyl esters of glycerol (94–98%) and a minority of other compounds (O'Brien, 1998) (Table 2). TAGs are composed of: 7–10% saturated TAG (mostly tripalmitates) and 6–12% completely unsaturated TAG (Karleskind and Wolff, 1996).

The functional properties of palm oil and its components as ingredient in prepared foods are directly related to the type of triacylglycerols present in these oils (Williams and Hron, 1996). However, the types of triacylglycerols are determined by their fatty

Table 2 Fatty acid ester composition of palm oil (Che Man et al., 1999)

Triglycerides	Content (%)
OOO	3.90
OOL	1.22
PLO	10.02
POO	21.39
OOS	2.78
MPL	3.03
PPL	9.37
PPO	27.39
POS	5.29
SOS	1.39
MMM	0.76
MMP	2.38
PPP	4.81

L: linoleic acid; M: myristic acid; O: oleic acid; P: palmitic acid; S: stearic acid.

acid composition and by the distribution of fatty acids in the individual triacylglycerol molecules. The quantities of each type of triacylglycerols depend on the proportions of the individual fatty acids, the fat or oil source and the processing history of a product (Reske et al., 1997).

Fatty acid composition

The fatty acid composition of palm oil has been widely reported by many researchers (Tan et al., 1981; Che Man et al., 1999) (see Table 3).

Palmitic and oleic acids are the most abundant fatty acids in palm oil. The proportions of saturated, monounsatured and polyunsatured fatty acids are approximately 50%, 40% and 10%, respectively.

Over-consumption of any vegetable oil could have detrimental effects on health. There are two types of fatty acids in oils: the saturated ones and also the unsaturated ones that contain the essential fatty acids. Palm oil is made of about 50% naturally saturated fatty acids (SFA) (palmitic acid), but that does not make it unfit for human consumption. In fact since the 1990s, it has been considered by the food industry as a good alternative to hydrogenated vegetable oil, which could contain trans-fatty acids, a known cancer risk. Nestel et al. (1992) reported a more favourable LDL/HDL ratio with a diet rich in palmitic acid than with a diet rich in trans-fatty acid.

Minor components

They are represented by vitamin E, carotenoids, partial glycerides, sterols and polar lipids.

- Vitamin E (600–1000 ppm): fat-soluble vitamin is predominantly represented by tocotrienols (78–82%) and tocopherols (18–22%) (Tan and Oh, 1981). Tocopherols are structurally characterised by a saturated side chain on the

Table 3 Fatty acid composition of palm oil

Fatty acids (%)	Results[1]	Results[2]
Saturated fatty acids		
Lauric acid C12:0	Trace	0–0.4
Myristic acid C14:0	1–2	0.5–2
Palmitic acid C16:0	43–46	40–48
Stearic acid C18:0	4–6	3.5–6.5
Arachidonic acid C20:0	–	0–1
Unsaturated fatty acids		
Oleic acid C18 :1Δ^{9}	37–41	36–44
Linoleic acid C18: 1$\Delta^{9, 6}$	9–12	6.5–12
Linolenic acid C18: 1$\Delta^{9, 6, 3}$	Trace	0–0.5
Eicosenoic acid C20 :1Δ^{9}	–	0–0.2

Source : Karleskind, 1992[1]; Firestone, 2006[2].

chroman nucleus (Munne-Bosch and Alegre, 2002), whereas the tocotrienols possess an unsaturated side chain of phytyl. Tocotrienols are mainly in the form of alpha (22%), gamma (46%) and delta (12%), and tocopherols in the alpha form. During the refined, bleached and deodorised (RBD) process, the vitamin E content of palm oil is partially lost. Palm stearin, palm olein and palm oil RBD retain approximately 76, 72 and 69%, respectively, of the vitamin E content of red palm oil (Sambanthamurthi et al., 2000).

Palm oil is particularly rich in tocotrienols, unlike other vegetable oils (soya, sunflower) which contain only tocopherols. The α-tocotrienol is known for its protective effect of red blood cells against haemolysis (Sambanthamurthi et al., 2000). Qureshi et al. (1991), on evaluating the cholesterol-lowering effect in humans of tocotrienol-rich palm oil fractions, noted a significant reduction in total cholesterol and LDL in 20 hypercholesteremic subjects.

- Carotenoids, highly unsaturated tetraterpenes biosynthesised from 8 isoprene units (Sambanthamurthi et al., 2000), are responsible for the pronounced red colour of palm oil. They are subdivided into two classes: carotenes (700–800 ppm), which make up the majority of carotenoids (90%) and xanthophylls. Since plants are able to synthesise carotenoids *de novo*, the carotenoid composition of foods and plant origin is variable (Delia *et al*., 2008), so it is not strange for it to occur in various vegetable oils, for example, yellow maize oil, groundnut oil and soybean oil. However, the concentrations of carotenoids in these vegetable oils are very low, less than 100 ppm (Ong and Tee, 1992). Carotenes are present in the alpha, beta and gamma forms, the first two forms being the most abundant (Goh et al., 1985). They are removed during the refining and deodorisation of the crude oil to produce a light yellow palm oil preferred by consumers (Cottrell, 1991).

β-carotene is the precursor of vitamin A, which is essential for cell growth, differentiation and vision. Because of its rich β-carotene, red palm oil is recommended for the control of vitamin A deficiency (Seshadri, 1996; Gopalan et al., 1992), as it is available year-round, is cheaper and is an accessible resource for most developing countries. In addition, vitamin E, essential for the assimilation of vitamin A '*in vivo*', is present in palm oil (Ames, 1969). Murakoshi et al. (1992) showed the ability of α-carotene and carotenes isolated from palm oil to inhibit skin and liver cancers in mice. These authors concluded that carotenes naturally present in red palm oil possess chemopreventive activities against cancer. The same effects cannot be attributed to synthetic β-carotene.

Carotenoids and vitamin E found in red palm oil are particularly important from a nutritional point of view because of their antioxidant and anti-carcinogenic properties.

- Partial glycerides, generally present in very small quantities, except for oils produced from damaged fruits. Their content will also be high in oils extracted from fruits that were in a state of advanced maturity (Siew and Ng, 1997) or that were not treated immediately after harvest.
- Phytosterols, tetracyclic compounds with 27, 28 and 29 carbon atoms, are present in very small amounts (0.03% of the constituents of palm oil) and have anti-inflammatory properties.

6.2 Artisanal red palm oil uses for human consumption

Home consumption

Palm oil is the most widely consumed edible vegetable oil in the world. In African countries such as Côte d'Ivoire and Cameroon, red palm oil is highly valued and used in the preparation of many traditional dishes (Cheyns et al., 2000; Cheyns and Rafflegeau, 2005). The domestic consumption of red palm oil relies on the local demand for oil, the quality of which is intimately linked to the terroir, the type of planting materials and local processes (Cheyns et al., 2004). Artisanal palm oil is highly appreciated in the local market because of its organoleptic properties (smell, taste and colour) which make this oil an irreplaceable ingredient in several local culinary recipes. With its different characteristics from CPO, artisanal red oil meets local demand for use in cooking specific dishes of the region.

African artisanal palm oil shows the highest values with the FFA level reaching 9% (Ohimain, et al., 2012) and even exceeding 15% (Osei-Amponsah et al., 2012). According to the *Codex Alimentarius* standards, any oil containing more than 5% FFA content is considered as improper for human consumption.

The problem of acidification in artisanal oil is more acute for smallholders and producers who are used to storing FFB for long periods between harvesting and cooking. Indeed, the problem extends from the whole industry down to the consumer in those African countries where artisanal red palm oil is a major commodity oil. There is no guarantee of quality for the artisanal red palm oil found on local markets nor when it is sold to neighbouring countries. Assessing the artisanal red palm oil's quality is also a problem for housewives when they buy oil from the local market. For that reason, market retailers of artisanal palm oil have usually tried to develop loyalty relationship with their customers.

Uses in the food industry

Due to its richness in SFA, palm oil remains the best ingredient used to replace partially hydrogenated fat which may contain *trans*-fatty acids. Intake of high amounts of *trans*-fatty acids is positively correlated with increased risks of coronary heart disease (Hu et al., 1997), inflammation (Mozaffarian et al., 2004) and cancer (Astorg, 2005). The natural solid-fat fraction of palm oil, palm stearin, became a suitable main ingredient in margarines, shortenings and vanaspati.

Low level of polyunsaturated fatty acids and high proportion of vitamin E make palm oil and its products resistant to oxidation (Sambanthamurthi et al., 2000). This makes palm oil a good alternative as frying oil. In addition, its solid and semi-solid state at room temperature due to the presence of SFA is a property which is exploited in food products such as margarines. The combined effect of carotenoids, SFA (about 50% of total fatty acids), tocopherols and tocotrienols provides outstanding oxidation stability over time compared to other vegetable oils (Arora et al., 2006). The choice of the frying oil should be based on economic, nutritional and physico-chemical quality factors, so palm oil is obviously an interesting vegetable oil for food industries.

7 Sustainable development issues for artisanal red palm oil production

Outside the mill supply areas, the artisanal processing of FFB through small-scale extraction units can be considered as economically viable and socially sustainable, while offering job opportunities in rural areas. However, using tyres as fuel for cooking the fruit and clarify the oil has to be banished. It is of general interest to reduce the number of extraction units in order to promote fewer but more performing units – such as the mini-mills described in Table 1 – owned and managed by local businessmen creating managerial enterprises. We recommend to support smallholders and producers for creating cooperatives or better kind of inclusive business by Alliances, for example, the South American 'Alianzas', to really build a win–win partnership between the managerial oil producer and the smallholders who will become shareholders of the Alliance (Rafflegeau and Feintrenie, 2013). In such partnerships, shareholders are taking part to decide the rules, such as fixing the price to pay smallholders.

There are three reasons for supporting such a development of mini-mills outside the supply area of industrial mills, rather than promoting the installation of micro-mills:

- with a higher oil extraction rate, oil palm production can increase without changing anything else;
- as mini-mills are processing FFB rather than stemmed fruit, the delay between harvest and process can be drastically reduced if compared with other technologies, thus having a direct impact on the quality of the artisanal red palm oil; new development with less extraction units of a higher capacity will allow to implement an efficient treatment of mill effluents, thus reducing the environmental impact on water quality in surrounding water courses and rivers; mini-mills are also energetically self-sufficient as they use heaters that are not burning firewood, reducing again the environmental pressure around the mills.

Inside the supply areas of industrial mills, if the mill is saturated during the high production period, the situation becomes exactly the same as outside of mill supply area. If the mill is not saturated during the high production period, it is then a pity to process FFBs through artisanal extraction units, then losing one-third of the oil and polluting the rivers. As we described the reasons for smallholders to process by themselves, industrial mills have to redesign their relationship with smallholders. Win–win partnerships between smallholders and agro-industries can lead to improvements in smallholders' yields, and to increases in the part of FFB originating from smallholdings supplied to industrial mills rather than to small-scale mills (Nkongho et al., 2015; Rafflegeau et al., 2010). Smallholders are not only interested in defining the price of FFB, but also in technical advice; extension services; and supply of certified selected planting materials and of fertiliser, micro-credit and so on.

The present situation of water pollution of the rivers in tropical Africa by a multitude of artisanal extraction units should lead researchers, governments, civil society and actors of development to urgently find adapted solutions for existing extraction units. Secondly, smallholders and producers must be informed and trained for the preservation of the quality of the waters surrounding their artisanal extraction units. This is a major issue hampering the sustainable development of artisanal red palm oil production.

African consumers are expecting more uniformity in quality among artisanal red palm oils which they buy in the local markets. They also need more information about the health properties of red palm oil, which is naturally rich in E vitamins and β-carotene. There is a need for halting the bizarre trend of African people consuming less red palm oil and more refined palm oil. The worst African trend consists in 'bleaching' artisanal red palm oil by over-heating it at home, in order to change the colour of the oil before its incorporation in non-traditional meals. In other parts of the world, the same health reasons led to the promotion of red palm oil consumption rather than refined oil which is poorer in vitamins.

8 Where to look for further information

Biochemical information about palm oil composition and information concerning palm oil consumption's impact on health can easily be found in many scientific papers from specialised journals on chemistry and nutrition. Information about extraction units, artisanal palm oil production and economic analyses is mostly available as grey literature. As the technological development of extraction equipment has already been undertaken, technical information describing artisanal extraction units is available in expert assessment reports which are unfortunately not always available online.

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