

## **African Shea Butter Properties Related to Common Extraction Technologies: A Review**

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### **Abbreviations and acronyms**

A-Arachidic

CB-Cocoa Butter

CBE-Cocoa Butter Equivalent

DAG-Diacylglycerols

FA-Fatty Acid

FFA-Free Fatty Acids

FTIR- Fourier transform infrared spectroscopy

ICCO-Cooperation- Stichting Interkerkelijke Organisatie voor Ontwikkelingssamenwerking

IV-Iodine Value

L-Linoleic

Ln-Linolenic

NBF-‘‘Norme sur le beurre de karité non raffiné’’

O-Oleic

P-Palmitic

PV-Peroxide value

St-Stearic

SB-Shea butter

StOSt-Stearic-Oleic-Stearic Triacylglycerols

SSS-Saturated-saturated-saturated Triacylglycerols

SUS- Saturated-unsaturated-saturated Triacylglycerols

SUU-Saturated-unsaturated-unsaturated Triacylglycerols

TAGs-Triacylglycerols

TUTM-Testometric Universal Testing Machine

UTM-Universal Testing Machine

UV-Ultra-Violet

**Abstract**

Shea butter is an important lipid material for food, cosmetic and pharmaceutical industries. Most of the shea butter consumed in the world comes from Africa. The extraction protocol is not standardized among all regions of production. It can be done using either traditional or improved (semi-mechanical) processes. The quality of shea butter and its composition depend on multiple factors such as the edaphic parameters, morphology and harvesting method of the fruits, treatment applied to fruits, nuts and kernels, respectively. In this paper, all traditional and improved extractions processes reported, including the enormous possible variants, were reviewed and summarized. Several optimal conditions have been defined for both the traditional and the modern processes. Nevertheless, we are far from processes harmonization, and therefore from the best conditions of shea butter processing. The screw press extraction was the most widely used among the modern processes due to its yield of butter extraction of about 82 %. Microwave-assisted extraction gave the highest butter yield, 88 %, and traditional shea butter extraction was about 20 %-35 %.

**Keywords :** Shea butter . Extraction process . Traditional extraction . Semi-mechanical extraction

## 1. Introduction

The shea tree (*Vitellaria paradoxa* C.F. Gaertn., 1807), a species of the *Sapotaceae* family, is a tree that grows naturally throughout a Sahelo-Saharan strip in Africa. Subspecies *V. paradoxa paradoxa* can be found in the West African shea zone, and subspecies *V. paradoxa nilotica* occurs normally in East and Central Africa (Gallagher et al., 2016; Nahm et al., 2013; Tom-Dery et al., 2018). The shea fruit is formed by a green epicarp, a fleshy mesocarp and a relatively hard shell containing the shea nut. The fruit is an edible berry consumed and appreciated by African populations for its nutritional value. The shea fruit is an edible berry with a pulp proportion >55 % and contained 5.23 % protein, 6.32 % fiber, 3.59 % ash, 14.08 % total sugars, 79.48 % moisture and minerals (Ca, K, Mg, P) (Kouglénou et al., 2012). The kernels are a rich source of fat. They usually contain about 60% of fat (Olaniyan & Oje, 2011). The "shea belt" includes eight African countries (Benin, Burkina Faso, Côte d'Ivoire, Ghana, Mali, Nigeria, Sudan and Uganda) who have the potentials of producing 70,000 - 300,000 tons of shea butter (SB) per year, and the major producing countries are Nigeria, Mali, Burkina Faso and Ghana. In Burkina Faso, for example, the shea trees cover 70 % of the territory (François et al., 2009).

The fat extracted from the kernel, well-known as SB, has gained popularity due to its composition. It can be used in a wide variety of applications as in food, soap, cosmetic, pharmaceutical, medical and engineering industries (Olaniyan and Oje, 2011). According to Stichting Interkerkelijk Organisatie voor Ontwikkelingssamenwerking (ICCO Cooperation), the shea industry sector has grown by 600% in the past 20 years. In West Africa, more than 350,000 tons of SB are exported each year (ICCO Cooperation, 2018). In Burkina Faso, SB is the fourth most important exported product after gold, cotton and livestock and contributes about 6 million USD annually to the country exportation revenue. Being produced mainly by women, it plays an important socio-economic role in the daily life of people (Badini et al., 2011).

The SB production involves many steps, including fruit collection, nut processing and butter production, and remains exclusively women's activities (Elias and Carney, 2007; Greig, 2006). It is an arduous and time-consuming work in its traditional process. Recently, mechanization of some steps of SB production was introduced (Badini et al., 2011). Nevertheless, SB traditional non-mechanized manufacturing is still widely used in Africa because of the population's preferences and private consumption.

The quality of SB and the extraction yield depends mainly on the extraction technique used. There is no single standardized method for extracting SB; on the contrary, the extraction processes are highly variable according to ethnic groups, region, country. They also depend on the intended butter use: soap, food, or cosmetic/pharmaceutical applications. Moreover, the extraction processes existing for SB can be classified into several classes: artisanal or traditional, semi-mechanized, chemical, and enzymatic.

This paper aims to introduce all extraction techniques and processes used in Africa in the SB production and compare the influence of these processes on the physicochemical properties of the obtained SB. All the singularities of traditional and semi-mechanized steps are discussed, and some experimental processes at laboratory scale (chemical, enzymatic, mechanical extraction) are also included.

## 2. Shea Butter Composition

The composition of the SB is directly influenced by climate and species and all processing steps. The main components of SB are shown in **Fig. 1**. Shea butter is of great interest in food, cosmetic and pharmaceutical industries. **Tables 1** and **2** contain the standard ranges of SB parameters for food and cosmetic applications.

For food industry, the composition of the saponifiable portion is what makes SB an interesting raw material. Shea butter contains oleic acid (O) as major fatty acid (FA) (34-62 %), stearic acid (St, 25-55.7 %), palmitic acid (P, 1.9-10 %) and linoleic acid (L, 1-10 %) (Abdul-Hammed et al., 2020; Akihisa et al., 2010; Badu et al., 2018; Codex Alimentarius, 2017; Dubois et al., 2008; F. Honfo et al., 2014; JBL et al., 2010; Kouglblénou et al., 2012; Lipp and Anklam, 1998; Mbaiguinam et al., 2007; Morin and Pagès-Xatart-Parès, 2012). This FA form a high amount (more than 50 %) of the saturated-unsaturated-saturated triacylglycerols (SUS TAG), which include stearic acid-oleic acid-stearic acid (StOSt, 13-45 %) and palmitic acid-oleic acid-stearic acid (POSt, 3.5-8.5 %) (Loh Moong Ming, 2008). In food industry, the same high amount of SUS TAG is in naturally cocoa butter (CB), that makes SB suitable for use as cocoa butter equivalent (CBE), in chocolate and other confectionaries products (Loh Moong Ming, 2008; Talbot and Slager, 2008). Moreover, due to its higher melting point compared to CB, combined with its high concentration in saturated FA and its crystallization profile, SB is a possible alternative to palm oil.

The great interest of SB in the cosmetic industry is due to its particular unsaponifiable content (5-7 %), which is much higher than any other vegetable oil (**Fig. 1**) (United States Agency for International Development, 2004a, 2004b, 2006). This amount of unsaponifiable matter is remarkably high and rich if compared with other commercial vegetable oils, for example, crude pressed palm oil (~1%) (Mozzon et al., 2020), soybean and cottonseed oil (1.2-1.5%) (Gutfinger & Letan, 1974), and CB (0.35-0.53%) (Foubert et al., 2004). Crude Avocado oil is an alternative since it contains 4-9% of unsaponifiable matter in the mature fruit, and this amount can be even higher in the immature fruits (15-40%) (Lozano et al., 1993).

In the pharmaceutical sector, SB is used as a raw material for drug formulation or alone as a drug in treating arthritis, eczema, herpes lesions, and nutraceuticals for lowering cholesterol (Lovett, 2010; Animasaun et al., 2019). The unsaponifiable portion of SB revealed a wide range of interesting and valuable bioactive components, including triterpenic compounds, catechins, tocopherols, polyisoprene hydrocarbons (kariten), and catechins. It shows antioxidant, anti-inflammatory, antitumor, UV-protective, and protease-inhibition properties. Among terpenic compounds, the phytosterols such as  $\alpha$ -spinasterol,  $\Delta$ -7-stigmasterol,  $\Delta$ -7-avenasterol,  $\beta$ -sitosterol, stigmasterol, campesterol, and 24-methyl-cholest-7-enol, accounted for 5-8% of the unsaponifiable fraction (Nahm et al., 2013). The main terpenic compounds are triterpenes alcohol ( $\alpha$ -amyirin,  $\beta$ -amyirin, lupeol, and butyrospermol) which amounted to 68-75% of total unsaponifiable (Vincenzo et al., 2005). Total catechin content ranged from 0.4-9.5% of extracted dry weight (Akihisa et al., 2010; Alander, 2004; Allal et al., 2013; Honfo et al., 2014; Maranz et al., 2003; Nahm et al., 2013). The total tocopherol content is 29 to 805  $\mu$ g/g of SB, and the  $\alpha$ -tocopherol was the most abundant form, accounting for up to 64 % of the total value (Davrieux et al., 2010; Maranz and Wiesman, 2004), while  $\beta$  and  $\delta$  fraction were  $< 1.5\mu$ g/g (Allal et al., 2013).

### **3. Extraction Processes**

There are two main extraction processes used in general, whatever the country, the region, or the ethnic group. The traditional or artisanal one, predominate, and the semi-mechanical one. It is worth noting that the main producers of all the crude butter produced in West Africa are the woman (60 %) (United States Agency for International Development, 2004b).

#### **3.1. Artisanal/Traditional Extraction Process**

The processing of shea involves two steps: pre-extraction and butter extraction. The steps of the traditional extraction scheme can be found in **Fig. 2**.

### 3.1.1. Pre-extraction

Pre-extraction steps significantly affect the extraction yield, protein, triglycerides and some minor components contents, and SB quality (Bup et al., 2011). These steps include activities such as fruits (*a* and *b*), nuts (*c*), and kernels (*d*) pre-treatments in **Fig. 2**. Moreover, flowcharts that detailed the main steps in an artisanal pre-extraction and extraction process can be found in **Fig. 3 and Fig 4**.

*Step a:* The first task in pre-extraction step is fruit collection fallen from the trees, which is done manually.

*Step b:* The second step consists of fruit pre-treatment: removing the pulp that can be done mainly, fruit boiling, piling, landfilling, soaking, or drying. The products obtained at the end of this step are the nuts. The butter obtained through boiling have a soft texture and an intense smell Tame et al., (2015).

*Step c:* After sun-drying and shelling to achieve 7–8 % moisture to prevent fungal contamination, nuts are then boiled within one week (Lovett, 2015). The product issue from this step is the kernels.

*Step d:* This step is aimed at drying, frying, smoking, or steaming the kernels. Drying consists of crushing the kernels (around 12 mm thickness) and drying them under the sun for 5-8 days or in an oven. The crushing can be done either mechanically or manually. Kernels are dried under the sun, in the solar dryer, or in an electric dryer (Dandjoma et al., 2009). Solar and electric dryers reduce nuts and kernels drying duration and procure homogenous drying. Sun-drying is the best as it achieves better quality (Dandjoma et al., 2009; Womeni, et al., 2007). The drying duration is important as it can influence the butter quality. It has been noticed that kernels thickness less than 6 mm requires sun-drying duration < 1 day; and thickness higher than 16 mm irrespective of drying duration, achieve higher acidity content. The boiling method resulted in more FFA (up to 6 %) (Honfo et al., 2013). Boiled kernels increased FFA content (~6 %), kernels fat (~41 %), moisture content (~2 %), unsaponifiable matter (~7 %), tocopherols (~125 mg. g<sup>-1</sup>), peroxide value (PV ~8 meq.O<sup>2</sup>.kg<sup>-1</sup>), and iodine value (IV ~53 mg I<sub>2</sub>100.g<sup>-1</sup>).

The frying process is an alternative method (Ibanga et al., 2015). Kernels thinner than 8 mm and fried for 2 to 8 min at 150 °C had the highest unsaponifiable matter content (Womeni et al., 2007b). Smoking is another way to treat kernels, using an oven made with clay chimneys (**Fig. 4**, purple arrow). Steaming also becomes an alternative to sun drying because it produces a SB with low acidity (~5 %) compared to SB obtained after sun drying (~9 %) (Mbaiguinam et al., 2007). Indeed, steaming inhibits enzymes growth, responsible for the hydrolysis of TAGs. All dried kernels are stored in jute sacks, woven baskets, or well-vented traditional granaries (Lovett, 2015).

### 3.1.2. Extraction

The butter extraction is done in two steps: (e) obtention of kernels paste and (f) production of shea oil and then SB. Several ways of doing can be noted for each step (**Tables S1 and S2**) as different types of extraction processes exist depending on the locality, ethnic groups, and regions (François et al., 2009; Ibanga et al., 2015; Honfo et al., 2013; Parkouda, 2015). They are all summarized (step by step) in **Fig. 3 and 4**.

*Step e:* Crushed kernels are grounded in a grindstone or mechanical grinding mill to a fine paste. This step consists of paste treatment: heating, boiling, kneading, or churning, depending on extraction protocol. Paste churning is the predominant treatment and can be done manually or mechanically.

*Step f*: The fine paste is mixed with cold water and malaxed until an aerated emulsion is formed. By additional use of cold water, the “emulsion” floats to the surface like “a cream”; afterward it is hand-removed, boiled, decanted and further cleaned (Lovett, 2015). **Fig. 3** describes three different processes, which are called “dry process” (purple arrow), “frying process” (green arrow) and “fermentation process” (orange arrow). Some common steps are found in these three processes and are highlighted in blue. The last step is, in all cases, emulsion collection. Comparing the “frying” and “fermentation” processes, the common steps are fruits underground fermentation, nuts drying and washing; and the churning step in the extraction part itself. Among the “dry” and “fermentation” processes, only two common steps can be highlighted: kernels crushing and oil settle.

**Fig. 4** reports 2 different butter manufacturing processes: “nuts boiling process” (green and orange arrows) and “nuts smoking process” (purple arrow). Kpegba et al., (2017) reported 4 different traditional processes in Togo: classical churning with kernel roasting, churning without kernels roasting, Peuhl (sub-Saharan African ethnic group) churning, and direct boiling. Peuhl churning is similar to the process described in **Fig. 3** - green arrow. The direct boiling process is done by kernels roasting and paste boiling, followed by skimming.

The SB artisanal extraction can be summarized as follows: 1) kernels are shelled, roasted, boiled, fried, smoked, soaked, or boiled, and then milled to obtain a paste; 2) water is then added and 3) then the mixture is vigorously “churned”. Traditional “churning” consists in manually vigorously mixing the paste with water (hot or cold) to make a creamy emulsifying compound appearing on the upper surface. The women knead this brown paste with their hands and continue to add water until a white butter rises to the surface (Gouyahali et al., 2012). The water is removed, and the creamy fat layer is washed and heated for 1–2 hours until it is clear.

### **3.2. Semi-Mechanized and Improved Shea Butter Extraction**

#### **3.2.1. Semi-mechanized Extraction**

The mechanical extraction press principle involves separating the oil, water and shea nut cake from pre-prepared water–paste emulsion shown in **Fig. 5**. The extraction machine encompasses a movable unit driven by a motor/engine. The separated entities (oil, water and cake) occur in layers and according to their mass. The drum can be filled with up to 10 kg of kernels loading capacity. The light oil and floating are then discharged into 2 bailing devices fitted in the drum. The process must be repeated until a clear oil is obtained (Y. Coulibaly et al., 2009). Also, in **Fig. 5**, the blue arrow describes common steps within centrifuge and screw press extraction. Oil mechanical expression involves the application of pressure, using hydraulic or screw press, to extract oil. This process is economical compared with the other extraction methods (Orhevba et al., 2013). Screw press extraction reduces challenges of the traditional method of SB extraction, increases production, improves the yield and probably butter quality. Crimaldi et al., (2017) have also evaluated preheating of hemp seeds on the yield using press extraction and found higher yield with high extraction temperature, and low screw rotational speed.

Comparatively, traditional SB extraction rates are about 20 %-35 %, 40 % for semi-mechanized methods, and 42 % to 50 % using the fully mechanized method (United States Agency for International Development, 2004b). A similar yield was obtained using a mechanical rig platform extraction process. For example, the pressing process was optimized under different pressures and temperatures combinations, and a yield of 35.39 % was obtained when the parameters were 82.24 °C, 9.69 MPa, and 2.50 mm.min<sup>-1</sup> respectively (Olaniyan & Oje, 2011).

The advantages of SB mechanizing extraction are numerous: saving time (up to 70 %), reducing women arduous work, and increasing supply and incomes (Greig, 2006). In Mali, during the 2009-2014 shea seasons, the

traditional butter production process required the highest amount of human (mainly women) energy (6100 kJ/kg of SB), *versus* improved process, improved-mechanized, traditional-mechanized and further improved-mechanized, respectively to (5900 kJ/kg; 2600 kJ/kg; 2500 kJ/kg; 2000 kJ/kg of SB) (Naughton et al., 2017). After having quantified and compared the environmental and human energy implications between traditional and improved SB production processes, the authors concluded that reducing human energy also reduces environmental impact and increases butter production. This is because each process step impacts the environment due to the over-reliance on fossil fuels.

In Tamale (Ghana), a prospective study on 126 participants evaluated the effects of SB processing on the environment as well as allocative efficiency. The results showed that semi-mechanized process was more efficient than the traditional process in terms of resources efficiency: firewood, water, and working time (Jibreel et al., 2013). According to the marginal methodology product, SB resources efficiency was analyzed by Issahaku et al., (2011). They compared different SB manufacturing: traditional, improved, and press extraction. The results showed that human resources were much more used in the traditional methods than the other methods. Allocative efficiency was attributed to the press technique, although butter quality is not the best.

Since 1991, in Mali, a Non-Governmental Organizations has developed two mechanized systems to facilitate women's work: a prototype animal-driven grinder/kneader machine and a motorized crusher with a centrifuge extractor. However, the animal-driven system was not as popular as the second system (Hyman, 1991). Motorized extraction devices are the main difference between traditional and semi-mechanized processes (**Table 3**). The use of millstone to crush kernels and manual press to extract butter were considered in 1994 as an improved technique to extract butter (S. Coulibaly et al., 1994). By screw press extraction, pressure is applied by winding down the screw (Fintrac Inc., 1999). This process described by Gezahegn et al., (2016) consists of boiling nuts after pulping and sun-drying them (**Fig. 5**, orange arrow). After shelling, kernels are oven-dried. The optimal extraction conditions were 30 min conditioning duration, 9.7 g/100 g moisture content, and 70°C die temperature of screw expeller. Pre-treated kernels were pressed in a screw oil expeller at 20 rpm screw speed. After extraction, the oil collected was filtered and centrifuged (low-speed centrifuge at 5030 g for 30 min) to get crude butter.

There are many semi-mechanized pieces of equipment, ranging from presses of all types to centrifuges and other prototypes such as Testometric Universal Testing Machine (TUTM), microwaves. The use of semi-mechanical methods is limited by the availability of spare parts, difficulties in the applicability of some technologies, and butter stability in some cases.

### 3.2.2. Other Extraction Methods

Another experimental procedure for SB extraction is shown in **Fig. 6**. Solvent extraction (purple arrow **Fig. 6**) is less and less appreciated nowadays in a century where the "green label" is very popular. Hexane is widely used to extract oils and fats thanks to its narrow boiling point (63-69 °C), easy oil recovery, and non-polar nature (Kumar et al., 2017; Liu and Mamidipally, 2005). However, hexane reacts with the pollutants to produce ozone and photo chemicals into the environment (Hanmoungjai et al., 2000; Kumar et al., 2017). It's also a toxicity compound that affects the neural system when inhaled by humans because of solubility in neutral lipids (U.S. Environmental Protection Agency, 2005). Wholesome, the solvent extracted oil consumption is condemned due to the possible presence of some traces of the solvent that may remain in the butter even after evaporation (Apea & Larbi, 2013). The solvent extraction has a higher cost due to the price of the reagents, which may not be easy and accessible for

small scales. Besides, this production has environmental problems and requires more technical skills to be performed (Abdul-Hammed et al., 2020). Solvent extraction with optimized parameters: n-hexane as solvent, particle size of shea kernel of 2.06 mm, and extraction temperature of 68 °C lead to a higher yield (66.47 %) (Ajala et al., 2016). However, FFA obtained by solvent extraction were higher (23.89 % versus 9.00 %) than FFA obtained by the artisanal method. A higher yield (30% versus 24%) and FFA content (2 versus 0.9%) was also observed in solvent extraction compared to conventional press extraction of chia oil (Ixtaina et al., 2011).

The enzymatic extraction (green arrow, **Fig 6**) can be an alternative extraction method of SB and can be employed in an industrial scale production (Ajala et al., 2015). Enzyme reactions are highly specific, with no side effects. Cellulase, protease, glucanase, amylase, hemi-cellulases, and pectinases are enzymes that have been used for edible oil extraction (Otu et al., 2015). In these steps, according to Ajala et al., (2015): kernels crushed and sieved were added to distilled water in a beaker, the mixture was heated for 5 min in a water bath and cooled to room temperature at pH = 5. After adding a defined quantity of enzymes, the mixture was boiled to deactivate the enzymes. The collected emulsion was centrifuged and oven-dried to constant weight. All enzymes listed above have been tested. If further optimized, the pectinase extraction process can achieve a higher yield of about 43 %. In *Euterpe oleracea* fruit (Açaí), different enzymes were tested too, and the best yield using enzymatic extraction was by combining 3 or 4 commercial enzymes (65%) instead of only one enzyme (30%) (Ferreira et al., 2018).

Other SB mechanized extraction techniques have been reported, such as microwave-assisted and supercritical CO<sub>2</sub> extractions (**Fig. 6** - orange arrow). By microwave-assisted process, solid matrices can be extracted, solvent use is reduced, and equipment cleaning is also remarkably decreased. Microwaves involve electromagnetic radiations, and to avoid interference with radio communications, domestic and industrial microwaves generally operate at 2.45 GHz. The microwave energy effect strongly depends on the solid matrix and solvent nature and has a heating mechanism. The nature of solvents is used to cover a wide range of polarities (Kaufmann & Christen, 2002). Supercritical CO<sub>2</sub> extraction system comprises an extractor (cylinder in rustproof steel) brought up inset with three cyclone separators (Nkouam et al., 2007). It is connected to a membrane pump which is adapted to achieve the desired extraction pressure quickly. A flowmeter measures the flow rate during experimentation. Extraction occurs as follows: 1) Shea fruits shelled are stored for 1 to 24 months at room temperature in a ventilated room (temperature  $18 \pm 2$  °C, relative humidity  $38 \pm 6$  %); 2) Lipids extraction consists of cut kernels, oven-dried them (48 h at 50 °C), and then ground them by household grinder for about 20 seconds; 3) CO<sub>2</sub> extraction consists of transferring lipids in contact with the gas; 4) Gas binds itself by affinity to the butter (30-45 min), and flows from the bottom to the top of the extractor; 5) Oil is separated from the gas by depression in separators and then recovered; 6) Extractor temperature is maintained at 50 °C, and in the separators at 70 °C. When oil accumulated mass becomes constant, extraction can be stopped. The comparative study using supercritical CO<sub>2</sub> and hexane showed that butter extracted with CO<sub>2</sub> have highest acid values, 19.88 and 23.07 %, but the lowest IV 22.57 and 37.66 g/100 g, depending on the temperature and relative humidity used  $33 \pm 1$  °C and  $37 \pm 6$  % (Nkouam et al., 2007). In summary, solvent extraction results in a higher butter extraction yield and less acidity oil. However, butter quality is poorer due to the solvent, which is toxic for people and dangerous for the environment. Also, the production cost is impacted by the price of hexane.

#### 4. Effect on Shea Butter Quality Properties

#### 4.1. Effect of Process and Packaging on Shea Butter Quality Properties

As explained, different techniques exist to extract SB: traditional, semi-mechanized (press, motorized grinder, centrifuge system), solvent, and other modern techniques (microwave-assisted, enzymatic, supercritical CO<sub>2</sub>). A comparison between different extractions methods showed that microwave-assisted extraction leads to a higher extraction yield at about 88% (Nde Bup et al., 2016), followed by screw press extraction ~82.20 % (Yonas et al., 2016), solvent extraction yield (66.9 %), enzymatic (43 %), supercritical (39.5 %), mechanical method (37 %) and then the traditional process with 28 % (Ajala et al., 2015). The different SB were evaluated using Fourier transform infrared spectroscopy (FTIR), and they showed no significant differences depending on extraction methods. According to Iddrisu et al., (2019), chemical and biotechnological extraction are more efficient than traditional and mechanical extraction. Various conditions, shown in **Table 4** can be used to improve crude butter quality and yield. Among extraction methods, microwave-assisted extraction provides a better yield extraction (88%), according to Nde Bup et al., (2016). This could be explained by the fact that this technique is automated, reduces time and solvent consumption, and presents the possibility to make repeated extractions. A lower FFA content could be achieved by microwave-assisted extraction on the one hand, and on the other hand, the process used crushed kernels and roasting (Honfo et al., 2017; Nde Bup et al., 2016). However, (Nurah & Julius, 2018), shea kernels roasting time and temperature, and butter clarification time significantly affected oil yield, unsaponifiable content, and PV. The roasting conditions would facilitate non-enzymatic oxidation resulting in the production of peroxides. The enzyme-assisted method combined with traditional extraction improved solid fat content and extraction yield. This action is probably due to the appropriate enzyme which can broke cells to release fat, and improve butter quality (Beauty et al., 2018).

In order to improve crude butter organoleptic properties, some practices consist in using part of the plants in the extraction process. For example, boiling the emulsion with *Rumex acetosa* flowers, Polygonaceae family, allow the obtention of whiter butter at the end of extraction, (Bréhima et al., 2007). This is due to the antioxidant activities of flavonoids and polyphenols of the plant (Korpelainen & Pietiläinen, 2020). Another example is boiling kernels with *Hymenocardia acida Tul.*, leaves, Phyllanthaceae family, to improve yield extraction (Nkouam, 2007).

Packaging materials also influence butter quality. Their impacts on SB microbiological and physicochemical qualities in tropical environments were also investigated (Honfo et al., 2011). The efficacy of five materials (traditional woven basket papered with jute bags, plastic container with its lid, aluminum container covered by plastic bag, plastic bag and calabash with its cover) were evaluated. Basket papered with jute bags was less effective to ensure SB microbiological and physicochemical qualities after one month of storage. In order to maintain microbiological safety and physicochemical properties, plastic containers and plastic bags were indicated since the use of plastic containers also prevents coliform infection. Nuts processing (drying and roasting duration), kernel quality, and hygienic packaging effects on butter physicochemical and microbiological were also evaluated. The authors found out that the optimal conditions to ensure high standards quality parameters were: 1) nuts dried for 1 week maximum to avoid mold formation, increase of PV and lower unsaponifiable matter content; 2) kernels moldy sorted and removed to avoid rancidity and possible mycotoxin contamination; 3) kernels roasted in portions of 500 g at 120-150 °C for a maximum of 5 min, as acid and PV increase rapidly after 5 min roasting. Under these conditions, the butter meets food industry requirements (**Tables 1 and 2**) and would be of interest for the pharmaceutical industry due to the high content of unsaponifiable (R.-M. Megnanou & Niamke, 2013). Untreated

butter extracted by traditional methods were microbiologically contaminated with *Pseudomonas*, *Klebsiella*, *Staphylococcus*, *Bacillus*, *Aspergillus*, or *Candida* species (total viable counts: 103-106 cfu/g), (Oyedele et al., 2020). To avoid this, some authors recommended butter heat treatments ( $\geq 100\text{ }^{\circ}\text{C} \times \geq 30\text{ min}$ ) and hot filtration (at  $60\text{ }^{\circ}\text{C}$ ). The composition and quality of the extracted butter are thus related to the extraction method, being traditional, semi-mechanized, or improved processes.

#### **4.2. Effect on Artisanal/Traditional Extraction on the Composition and Quality in Shea Butter**

According to Bup et al., (2011), butter quality can be influenced by nuts physical pre-treatments. The effect of boiling, soaking, and drying of 11 different traditional extraction processes commonly used in Sub-Saharan Africa was investigated. The results showed that all these pre-treatments significantly affected butter quality. Regarding total tocopherol content, irrespective of the treatment,  $\alpha$ -tocopherol (53 to 83%) constituted the primary type. Among pre-treatment, samples that were not dried prior to butter extraction gave higher content ( $\sim 80\%$ ) than samples dried before extraction. For the FA profile, palmitoleic acid (0.14–3.8%) was found in more than 80% of the samples.

Butter extracted by kernels boiling followed sun-drying gave more FFA (6%), moisture content (2%), unsaponifiable matter (7%), tocopherol compounds ( $125\text{ mg g}^{-1}$ ), PV ( $8\text{ meq.O}_2.\text{kg}^{-1}$ ), IV ( $53\text{ mg.I}_2.100\text{ g}^{-1}$ ), and higher fat content (41%), than smoking followed by sun-drying process (Honfo et al., 2013). About 100 different volatile compounds were identified in traditional “black” (included roasting step) and “white” (without roasting step) SB from Tchad and Cameroon, by solid-phase micro-extraction and gas-chromatography mass-spectroscopy (Krist et al., 2006). Major components in white SB were 2-ethylhexanoic acid (14.7%), acetic acid (10.5-9.9%), trans-2-undecenal (9.1%), trans-2-octenal (8.3%), 2-ethyl-1-hexanol (7.2%). In the black SB, predominant volatile compounds were 2-methylfuran (5.4%), acetyl-pyrrole (3.4%), styrene (3.3%) and dodecane (3.3%).

The comparison between optimized and traditional SB was done by Megnanou et al., (2007). Traditional butter was obtained from the different markets. Optimized butter (yellow and beige) was produced in laboratory by reducing nuts sun drying, boiling time, kernels roasting time and temperature. *Cochlospermum tinctorium* decoction was used to obtain beige color. Results showed that quality varied with SB color. The yellow SB had the highest IV ( $31.42\text{ mg. I}_2.100\text{ g}^{-1}$ ) and the lowest PV ( $14.70\text{ meq.O}_2.\text{kg}^{-1}$ ). The beige SB had the lowest acid ( $12.80\text{ mg. KOH/g}$ ) and moisture content (3.36 %) values. However, heavy metals such as lead (4.84 to 91.60 mg/kg) and nickel (1.27 to 3.07 mg/kg) have been found in traditional SB. There is a significant difference between optimized and traditional SB.

#### **4.3. Effect on Semi-Mechanized or Improved Extraction on the Composition and Quality of Shea Butter**

Color can affect significantly SB physicochemical parameters, except for PV and refractive index Megnanou & Niamke, (2015). Application of the drying-frying process to shea kernels influenced SB chemical quality index and melting properties (Womani et al., 2006). Indeed, increasing the thickness of the kernels increases the acidity of the butter. Butter acidification is minimal when frying kernels less than 8 mm thick at  $140\text{-}180^{\circ}\text{C}$  for 4-6 minutes at the mass ratio of 0.045-0.070. Thus, more than 74% of the variations in the PV can be explained by variations in the thickness of the kernels, the set frying temperature, the weight ratio of kernels to butter in the bath, and the frying time. In the semi-mechanized method using heating device and oven with forced ventilation,

by reducing shea nuts cooking and drying time, FFA content was significantly reduced, but PV content was increased (Dongmo et al., 2014). Moreover, PV was significantly affected by cooking time and nuts/water ratio.

The FFA content of butter extracted by Soxhlet from nuts prior parboiled can be decreased to half (5.1-5.5 %) compared to butter extracted from nuts sun-dried without parboiling (10.3-10.6) (Mbaiguinam et al., 2007). Shea butter spectra by FTIR before and after supercritical CO<sub>2</sub> extraction process (at 40 °C, 40 MPa and CO<sub>2</sub> flow rate 3 mL.min<sup>-1</sup>) were similar because this process did not change functional groups distribution (Yamamoto et al., 2018). It was shown that the FA profile was mainly composed of palmitic acid (C16:0), stearic acid (C18:0), oleic acid (C18:1), and linoleic acid (C18:2). Pressure and temperature of supercritical CO<sub>2</sub> extraction were the influential variables on the butter extraction.

## **5. Conclusion**

The traditional process of shea butter production begins with the collection of ripe fallen fruits from the trees. Obtention of nuts, treatment of nuts to obtain kernels, production of paste from kernels, and extraction of oil or emulsion from paste are diverse, depending on the region, the ethnic group, even sometimes on the producer's know-how. The obtained butter is not standardized; consequently, its direct utilization in food and pharmaceutical industries is limited. Nevertheless, crude shea butter is traditionally used in food preparation, hair and skincare, raw material in traditional medicines. The semi-mechanical methods decrease the labor burden and improve extraction yield. The difficulty limits its implementation to put these technologies into effect and lack of spare parts. The produced butter is more standardized and more fitted to use in the industry. Shea butter contains many unsaponifiable that are of interest to the cosmetic industry. Unsaponifiable are described in the literature as being responsible for the anti-UV effect of shea butter, and this property deserves more attention.

## **6. Acknowledgements**

Authors would like to thank Université de Liège (Science des Aliments et Formulation, Gembloux Agro-Bio Tech; and Laboratoire de Chimie Analytique Pharmaceutique, CIRM); to the Académie de Recherche et de l'Enseignement Supérieur – Commission de la Coopération au Développement (ARES-CCD) as technical and financial partner; to the postdoctoral fellowships and funding from ULiège University Research Council -STEMA funding OTP N° DIVE.0899-J-P conceded to Dr da Silva, T.L.T.

## **“Declarations”**

The authors did not receive support from any organization for the submitted work.

Financial interests: Author Bertrand W. F. Gombri has received research support from ARES-CCD. No financial interests for all others authors.

The authors have no conflicts of interest to declare that are relevant to the content of this article.

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

The authors have no financial or proprietary interests in any material discussed in this article.

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## Figure captions:

### Fig. 1:

Panoramic composition of the saponifiable and unsaponifiable fractions of crude butter or kernels extracts (Abagale et al., 2016; Allal et al., 2013; Honfo et al., 2014; Israel, 2015; Kapseu et al., 2001; Alain Karleskind, 1992; Lipp & Anklam, 1998; Maranz & Wiesman, 2004; Morin & Pagès-Xatart-Parès, 2012; Peers, 1977; Ray et al., 2013; Stübiger et al., 2015; Okullo et al., 2010; Ajala et al., 2016; Akihisa et al., 2010; Badu et al., 2018; Davrieux et al., 2010; Dubois et al., 2008; Megnanou et al., 2014; Segman et al., 2012; Talbot et al., 2014; Zhang et al., 2017; Alander, 2004; Krist et al., 2006; Nahm et al., 2013; Vincenzo et al., 2005).

### Fig. 2:

Steps outline of shea butter traditional extraction process.

### Fig. 3:

Flowchart of different routes for an artisanal extraction process for shea butter: dry process steps (Dandjoma et al., 2009) in purple arrow; frying process steps (Ibanga et al., 2015) in green arrow); fermentation process steps (François et al., 2009) in orange arrow; and common frying and fermentation process in black arrow; common dry and fermentation steps in gray arrow; common dry, frying and fermentation steps are following the blue arrow.

### Fig. 4:

Flowchart of different routes for an artisanal extraction process for shea butter: smoking process steps (Honfo et al., 2013) in purple arrow; boiling process steps (green arrow (Honfo et al., 2013) in orange arrow (Parkouda, 2015); common smoking and first boiling process steps (gray arrow), and common process steps smoking and both boiling (blue arrow).

### Fig. 5:

Semi-mechanized and screw press extractions processes (Centrifugal process (Y. Coulibaly et al., 2009) in purple arrow; Screw press extraction and centrifugation steps (Gezahegn et al., 2016) in orange arrow; and common extraction steps (blue arrow).

### Fig. 6:

Soxhlet, enzymatic, and microwave processes for shea butter extraction (Soxhlet extraction with n-hexane (purple arrow), microwave-assisted extraction (orange arrow), enzymatic extraction (green arrow), and Soxhlet and microwave common steps (gray arrow). Common in all extraction steps are following the blue arrow.

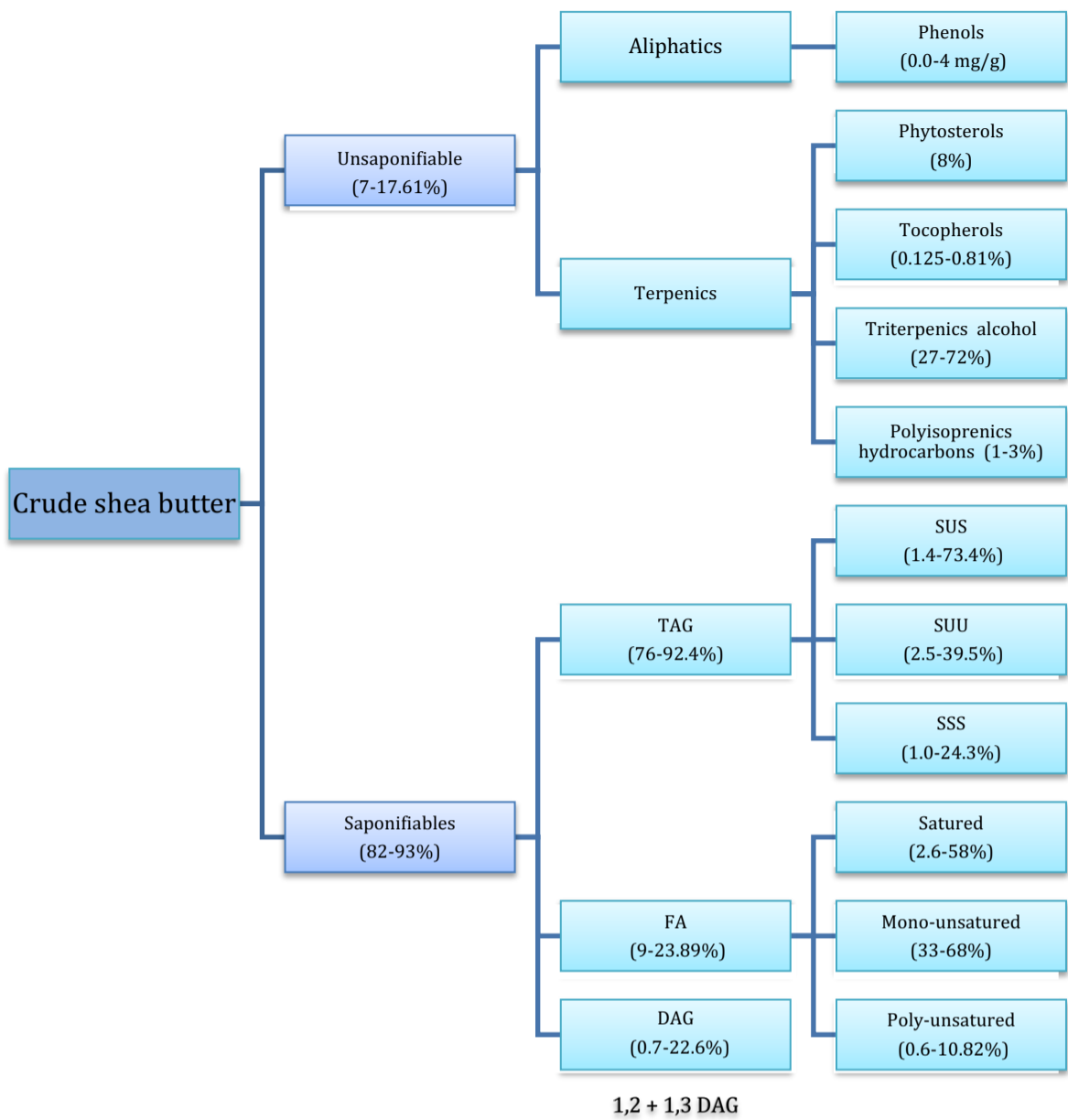


Fig. 1

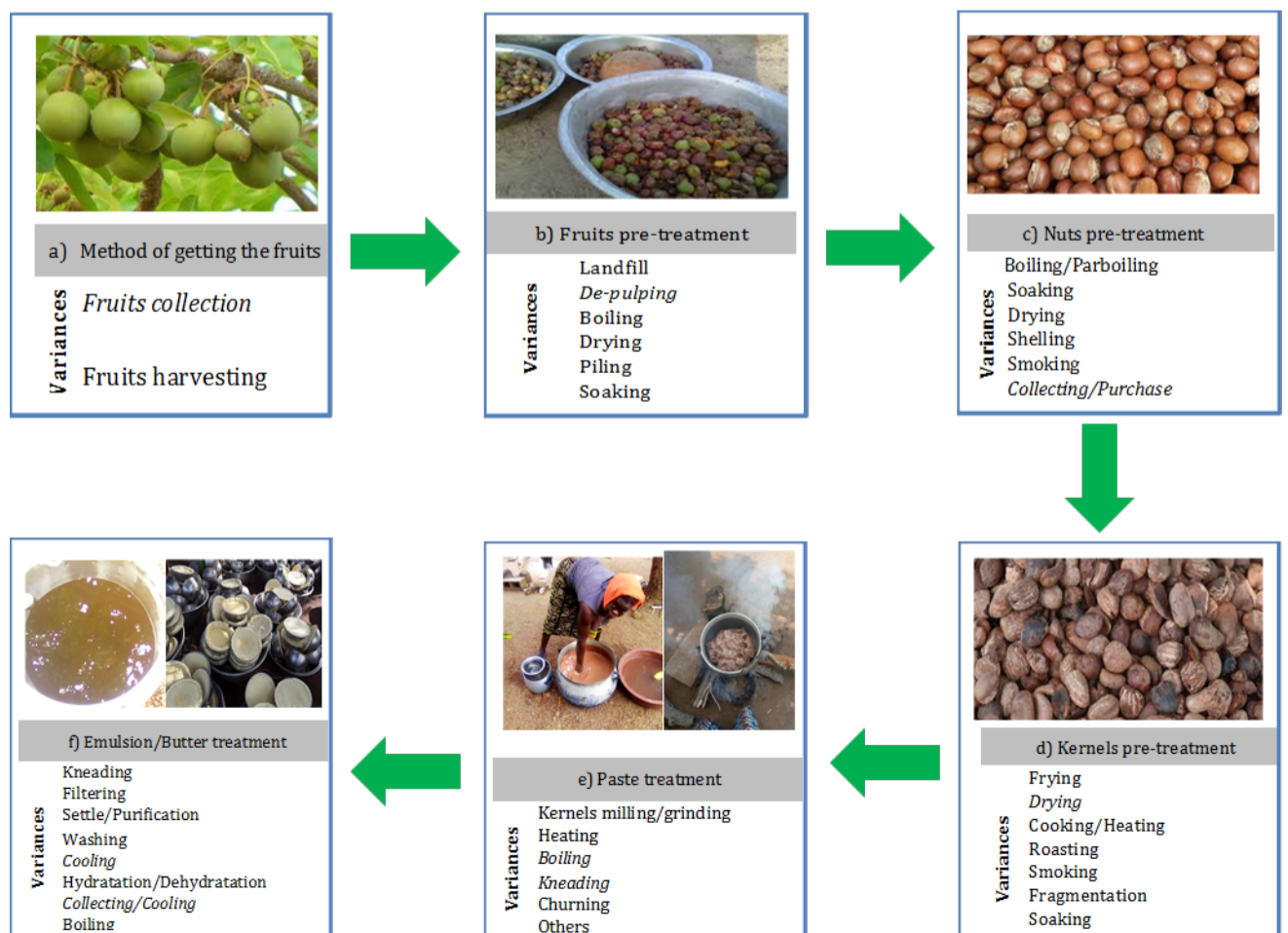


Fig. 2

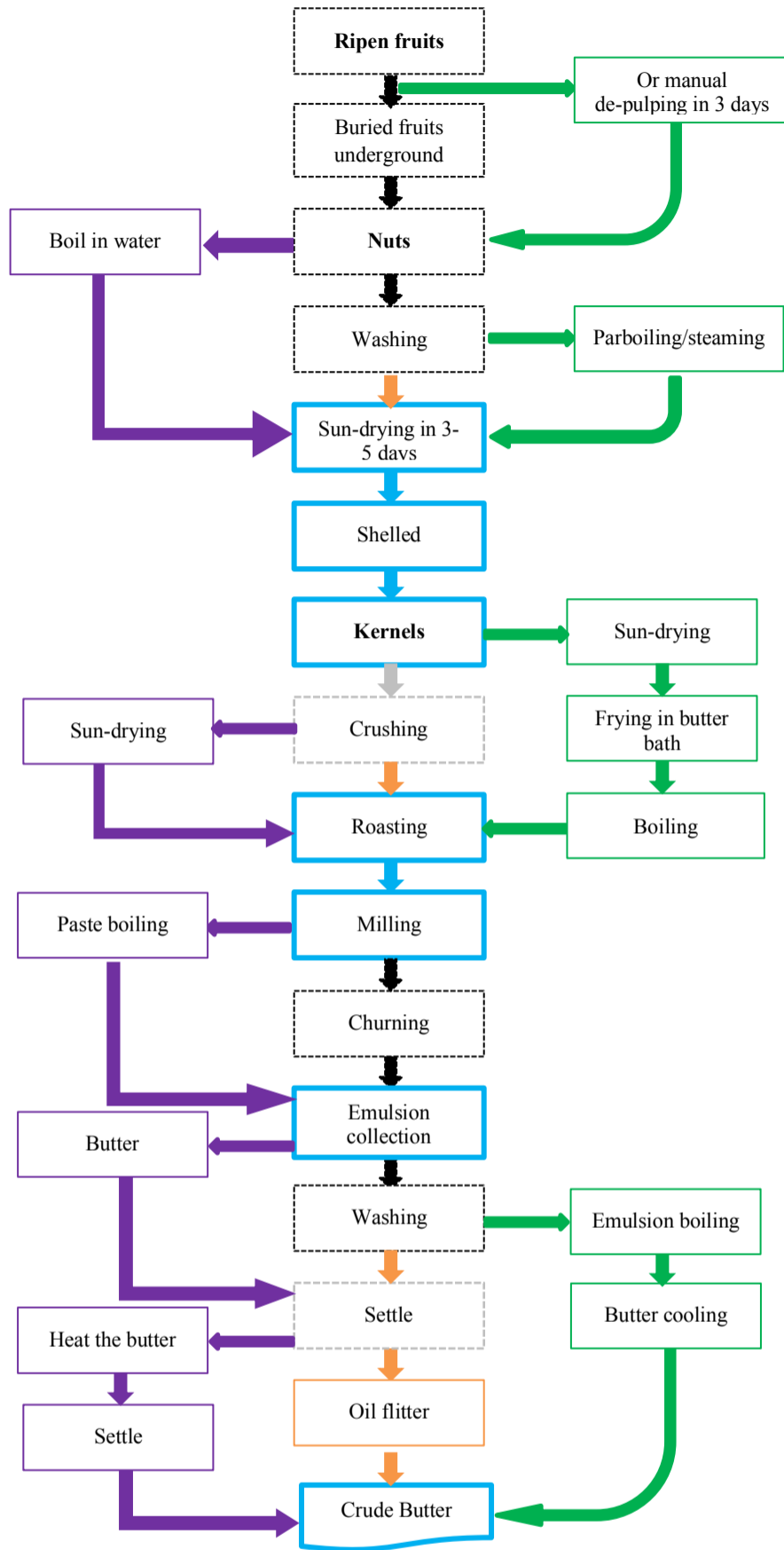


Fig.3

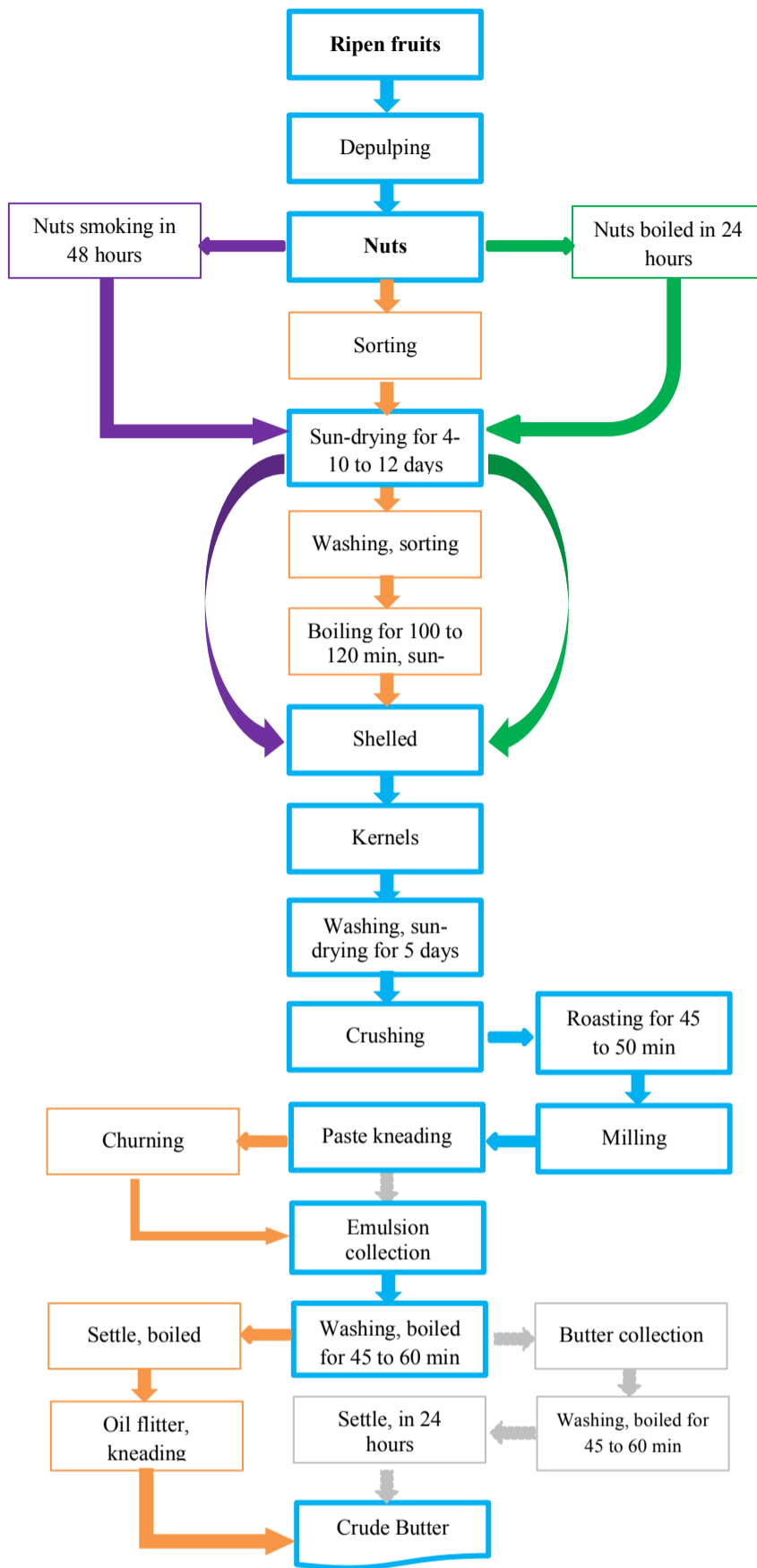


Fig. 4

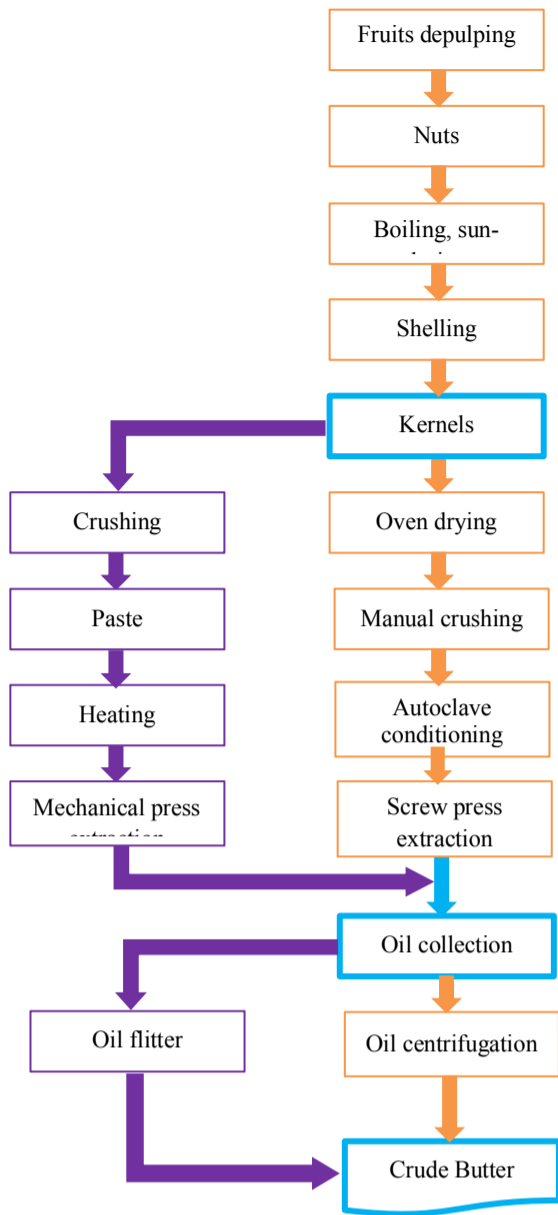


Fig. 5

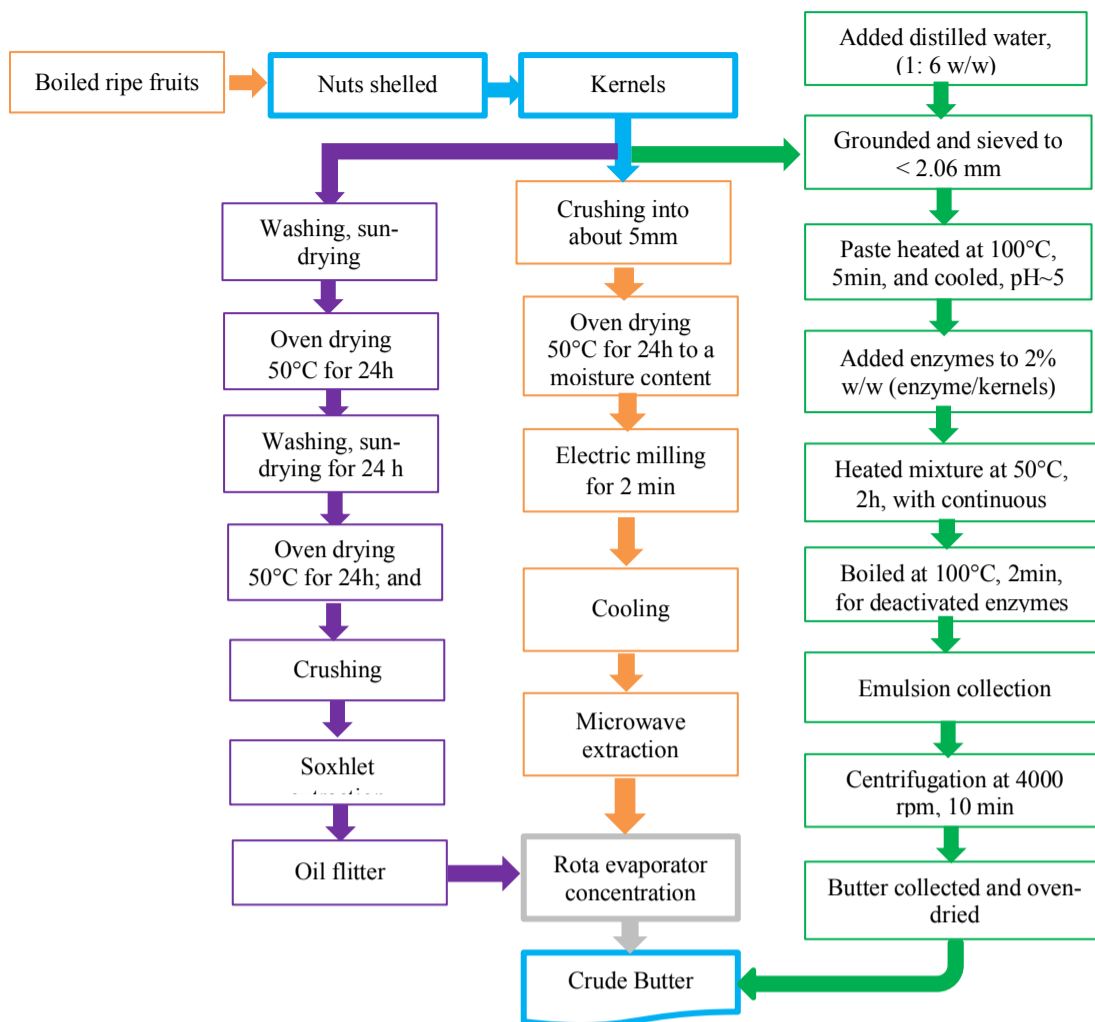


Fig. 6

**Table 1:** Physicochemical characteristics of shea butter according to the Codex Alimentarius (2017)

Parameters	Range
Relative density (at 20 °C)	0.91-0.98
Density (at 40 °C)	0.89-0.93
Saponification value (mg KOH/g fat)	160-195
Iodine value (g I <sub>2</sub> /100g)	30-75
Unsaponifiables matter (% w/w)	1-19
Refractive index at 44 °C	1.4620-1.4650
Melting point (°C)	35-40

**Table 2:** Quality properties for unrefined shea butter according to the NBF standard (François, 2018)

Parameters	Unrefined shea butter					
	Grade 1 <sup>a</sup>		Grade 1 <sup>b</sup>		Grade 1 <sup>c</sup>	
	Concentration					
	Min	Max	Min	Max	Min	Max
Moisture content	–	0.05	0.06	0.2	0.3	2
Free fatty acids (%)	–	1	1.1	3	3.1	8
Peroxyde value (meq/kg)	–	10	11	15	15.1	50
Impurities (% w/w)	–	0.09	0.1	0.2	0.3	2

<sup>a</sup>: First category intended for the cosmetic and/or pharmaceutical industries and for direct consumption;

<sup>b</sup>: Second category intended for the agri-food industries;

<sup>c</sup>: Third category for soap factories and direct consumption after refining.

**Table 3:** Different shea butter extraction devices

Devices	Authors
Hydraulic press extraction	(Hyman, 1991)
Motorized grinder and centrifuge system	(Hyman, 1991)
Mechanical press extraction	(Coulibaly et al., 2009)
	(Yé et al., 2007)
	(Naughton et al., 2017)
Screw press extraction	(Coulibaly et al., 2009)
	(Fintrac Inc., 1999), (Seweh et al., 2016)
	(Gezahegn et al., 2016), (Lovett, 2015)
Mechanical rig platform, Testometric Universal Testing Machine (TUTM)	(Mohagir et al., 2009)
	(Olaniyan & Oje, 2007, 2011, 2013)

**Table 4:** Summary of the optimum conditions to improve shea butter extraction

Nuts and kernels pre-treatment/morphology	Paste, oil or butter treatment/extraction	Physico-chemical and microbiological properties obtain	Device or extraction mode	Authors
<b>Drying and frying for 6 min the crushed kernels (&lt; 12 mm) at &gt; 140 °C, mass ratio &lt; 0,06.</b>	-	Fast reduction in kernels moisture content to 10-15%	-	(Womeni et al., 2004)
<b>Crushed kernels size about 4mm and drying at 45°C</b>	Milling and drying by prototype forced convection cabinet at 45°C	Improve butter yield extraction (40.21%)	Air convection oven	(César Kapseu et al., 2007)
<b>Boiling kernels between 100 to 140 ° C</b>	Paste milling at 60°C. Extraction by low pressure (45kg/cm <sup>2</sup> )	To improve butter yield extraction to 65.9% - 68.5%	Manual screw press	(Obeng et al., 2010)
<b>Compression cage heating crushed kernels (70°C)</b>	Platform heating temperature~82°C UTM applied pressure at 8.8 MPa Loading speed rate to 2.50 mm.min <sup>-1</sup>	Extraction yields 35%; 58.6% for oil recovery efficiency, and 2.8% extraction loss	Mechanical expression by UTM	(Olaniyan & Oje, 2011)
<b>Kernel moisture content about 9.7 g/100 g; crushed kernels, then autoclave conditioning for 30 min</b>	Screw expeller die temperature for 70°C	Improve refractive, acid and peroxide values	Screw press extraction	(Gezahegn et al., 2016)
<b>Kernel moisture content about 6.5 g/100 g; crushed kernels autoclave conditioning for 30 min</b>	Screw expeller die temperature for 65.5°C	Improved butter yield extraction about 82.2 g/100g	Screw press extraction	(Yonas et al., 2016)
<b>Crushed kernels roasting for 15 min at 171°C</b>		Improved yield extraction (44-53%); and low FFA content 0.5-3%		(Honfo et al., 2017)
<b>Kernels roasting at 106°C for 120 min</b>	Butter boiled for 90 min	Improved butter yield extraction (7.65% to 25.26%), Low PV (12.8 to 5.4), FFA (25.78 to 16.12), and unsaponifiable matter content (2.52 to 26.71).	Traditional wet extraction	(Nurah & Julius, 2018)
<b>Increasing kernels crushing speed and duration</b>	Decreasing speed of stirring	Improve crusher and increasing oil yield	Semi-mechanized: sheller, crusher, steam roaster, miller and mixer	(Shehu et al., 2018; Gana et al., 2019)
<b>Nuts boiling for 70-110 min at 75-80 °C; drying temperature for &lt; 40h at &lt; 54°C; and nut/water ratio for &lt; 400 g/L</b>		Reduce the FFA content (0.06% to 12.60%), PV (< 10 meq/kg), and increase butter yield extraction (7.2–25.9%)	Soxhlet method	(Dongmo et al., 2014)
	Microwave heating for 23 min at 75°C, and solvent/solute ratio for of 4:1 (v/v) Extraction duration for 10 hours and solvent/solute ratio for 10:1	Improved butter yield extraction was 88%, reduce FFA content < 2%	Microwave assisted extraction	(Nde Bup et al., 2016)
		Butter yield extraction was 58.60% and 72.00% for Pectinex and Viscozyme L, respectively	Enzymatic extraction by commercial enzymes	(Otu et al., 2015)
	Extraction temperature: 50°C at 180 min; ratio water/kernels 6:1 (m/m), extraction at pH 5	Butter yield extraction was 32.71%. Physicochemical properties were preserved as well as butter extracted by other techniques	Enzymatic extraction by mix (v/v) pectinase, α-amylase, cellulase, glucoamylase and xylanase	(Ajala et al., 2015)
<b>Crushed and roasted kernels</b>	Mix 1:1:1 (v/v/v) enzymatic (lipase, pectinase and cellulase) extraction with paste kernels	To improve solid fat content. Butter yield extraction at 70%	Enzyme-assisted traditional process	(Beauty et al., 2018)

**Table S1:** Overview of the processes steps commonly used in shea butter pre-treatments as fruit handling, and fruits and nuts treatment by traditional processing

Fruits picking		Fruits pre-treatment						Nuts pre-treatment						Authors		
Co	Har	B	L	D	B	S	P	S	Bo	S	S	S	S	B	Shellin	
lle	vest	oi	a	e-	oi	u	il	oa	ili	m	u	he	u	oi	g	
cti	ing	li	n	p	li	n	i	ki	ng	ok	n	lli	n	li		
on		n	df	ul	n	-	n	ng	/	in	-	ng	-	n		
		g	ill	pi	g	d	g		St	g	D		D	g		
				n		r			ea		r		r			
				g		y			mi		y		y			
						i			ng		i		i			
						n					n		n			
						g					g		g			
	x	x		x		x						x			x	(Couliba ly et al., 1994)
				x								x	x		x	(Women i et al., 2007)
				x								x		x	x	(Lovett, 2004)
x					x	x										(Addaqu ay, 2004)
x												x			x	(Women i et al., 2004)
					x											(Akingb ala et al., 2006)
												x				(Bréhim a et al., 2006)
								x	x	x						(Nkoua m, 2007)
					x											(Mbaigui nam et al., 2007)
																(César Kapseu, 2009)
	x				x								x		x	(Couliba ly et al., 2009)
																(Françoi s et al., 2009)
																(Pages, 2009)
																(Dandjo ma et al., 2009)
																(Bridier & Kombol o, 2009)
																(Badini et al., 2011)
																(Honfo et al., 2012)
																(Lovett, 2015)

**Table S2:** Overview of the processes steps commonly used in shea butter traditional extraction in the kernels, paste and emulsion/butter treatment.

Smoking	Kernels pre-treatment					Paste treatment			Emulsion/Butter treatment					Authors	
	Su-ndrying	Boiling	Soaking	Fragmentation	Roasting	Kernels milling/crushing	Boiling/Heating	Kneading	Churning	Washing	Collecting/Coiling	Boiling	Filtration		Settling
				x	x	x			x			x			(Coulibaly et al., 1994)
	x				x	x	x					x			(Womeni et al., 2007)
		x	x			x		x	x			x			
	x		x	x								x	x		
			x	x									x		(Kassamba B., 1997)
			x	x	x			x	x			x	x		
x			x		x	x								x	
	x		x	x	x			x				x		x	(Addaquay, 2004)
	x			x	x		x				x				(Womeni et al., 2004)
			x	x	x			x			x				(Akingbala et al., 2006)
	x		x	x	x			x	x		x		x		
			x	x	x		x	x	x		x		x	x	(Bréhima et al., 2006)
	x		x	x	x			x	x		x	x	x		
		x	x		x			x	x		x	x			(Nkouam, 2007)
x			x		x	x					x				
x		x			x			x			x	x			(Mbaiguina et al., 2007)
x			x		x			x			x	x		x	
			x	x	x			x			x	x		x	(César Kapseu, 2009)
				x	x			x	x		x	x	x		(Coulibaly et al., 2009)
x			x	x	x			x	x		x	x	x		(François et al., 2009)
			x	x	x			x	x		x	x	x		(Pages, 2009)
		x	x		x		x	x			x		x		(Dandjoma et al., 2009)
			x	x	x		x	x	x		x	x	x		(Bridier & Kombolo, 2009)
x		x			x		x		x	x	x		x		(Warra, 2011)
x		x	x	x	x			x	x		x	x	x		(Badini et al., 2011)
x			x	x	x			x	x		x		x		(Honfo et al., 2012)
x			x	x	x			x	x		x		x		
x			x	x	x		x				x	x			(Lovett, 2015)

