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Review article

# Implementation of the supercritical carbon dioxide technology in oil palm fresh fruits bunch sterilization: A review

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ABSTRACT

In palm oil production, sterilization is a vital process that can affect the quality of the extracted palm oil. The purpose of sterilization of oil palm fresh fruit bunch (OP-FFB) is to inactivate lipase activity and lipophilic microorganisms, soften the pulp of the fruits and facilitate the stripping process. The current practice of thermal sterilization in the palm oil industry, which utilizes conventional steam sterilization, is ineffective for lipase degradation and microbial inactivation in OP-FFB. The conventional steam sterilization technique operates at temperature 130 °C–160 °C, elevated pressures of 0.15–0.4 MPa, and sterilization time of 60–90 min. This sterilization method also requires huge amounts of water, which in turn demand higher energy usage and generates large quantities of palm oil mill effluent. Thus, waterless sterilization seems as a better option in yielding a high quality palm oil as well as protecting the environment. Supercritical carbon dioxide (SC-$CO_2$) has been found to be a promising sterilization technology in the inactivation of various enzymes and lipophilic microorganisms. This technology inactivates enzymes and microorganisms physico-chemically relatively low temperature (≤ 60 °C) and moderate pressures (8–40 MPa) without generating residual waste. Thus, the application of SC-$CO_2$ bears the potential to sterilize OP-FFB, as a waterless sterilization technology. The present review was conducted to assess the possible use of SC-$CO_2$ in OP-FFB sterilization and make comparisons to the existing OP-FFB sterilization method. This study also appraises the effectiveness of SC-$CO_2$ in the inactivation of enzymes and microorganisms that lessen the quality the palm oil.

## 1. Introduction

The demand for vegetable oils in food industries has been increasing due to the increase in human populations as well as the importance of its usage in food preparations. In 2016, the world oil palm consumption was about 58.31 million tonnes, comprising the highest consumed vegetable oil in 2016, making oil palm by far the world's number one fruit crop [1]. The oil palm alone is capable to fulfill the continuously growing world demand for vegetable oils that is estimated to reach 240 million tonnes by 2050 [2]. A considerable amount of palm oil are used in other products aside from food industry and these include cosmetics, pharmaceuticals, surfactants and washing agents). Oil palm is cultivated mostly in humid tropical countries, namely Indonesia, Malaysia, and Thailand as well as African countries [3]. Malaysian palm oil accounted for 16.8 million tonnes of the total global trade of oil and fats in 2016 with 37% of the world's palm oil production [1].

It is essential to produce crude palm oil (CPO) with excellent quality and stability, specifically with regards to its acidity and oxidation, in order to achieve good quality refined oils [3,4]. Previous studies have shown that lipase in oil palm fruits, caused the degradation of triacylglycerols in the palm oils releasing free fatty acids [4–6]. Lipases or triacylglycerol acylhydrolases, (EC 3.1.1.3) is capable of hydrolyzing ester bonds in triacylglycerols, releasing free fatty acids and glycerols. Since palm oil is basically made up of triglycerides, hydrolysis by lipase

*Abbreviations:* atm, atmosphere of pressure; abs, absolute; *A. niger*, *Aspergillus niger*; *B. subtilis*, *Bacillus subtilis*; *B. tear*, *Bacillus tear*; CPO, crude palm oil; EFB, empty fruit bunch; OP-EFB, oil palm empty fruit bunch; *E.coli*, *Escherichia coli*; FFA, free fatty acid; $H_2CO_3$, carbonic acid; kg, kilogram; MHz, megahertz; min, minute; Nm, nanometer; OP-FFB, oil palm fresh fruit bunch; *P. aeruginosa*, *Pseudomonas aeruginosa*; *PKO*, palm kernel oil; *POME*, palm oil mill effluent; *S. aureus*, *Staphylococcus aureus*; SC-$CO_2$, supercritical carbon dioxide

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causes an increase in the free fatty acid (FFA) levels in CPO [7]. The major fatty acids predominant in palm oil are oleic and palmitic acids. Aside from the acidity, FFA level is one of the most frequently determined criterion as part of the quality indices during the production, storage, and marketing of palm oil products [8]. At present, CPO produced by Malaysian palm oil mills is required to comply either with the trade specification or the revised quality standard for CPO ex-bulking, as published in Malaysian Standards of MS 814 [1,5].

It is evident that sterilization of OP-FFB is a crucial step in palm oil production, the main purpose of which is to inactivate microorganisms with lipolytic activities, in particular lipase activity. The high temperature steam also serves to soften the fruit pulp and facilitate the stripping of the fruits from the OP-FFB [5,9]. Studies reported that the quality of palm oil is directly attributed to the degree of lipase inactivation by sterilization [9]. At present, the most common sterilization method in palm oil industry is using saturated steam at temperatures 130 °C–160 °C [5]. In essence, it has been recognized that the steam sterilization technique employed in palm oil mills to sterilize the oil palm fresh fruit bunches (OP-FFB) is incapable of inactivating lipase producing microbes present in the OP-FFB [9–12]. Such weakness in the current sterilization spawns CPO that has higher FFA and is likely to be of lower grade. Hydrolysis by lipase also creates mono- and diglycerides, which greatly affect crystallization and other downstream processing. As a consequence, it has become a concern that the resulting refined oil would not meet the demand of the international premium quality standard [1,7]. Hence it is vital that the CPO produced are of the finest quality with low FFA, since low FFA is the major criterion in assigning prices to the CPO [7].

In addition to its lack of capacity to completely inactivate lipase activity and lipase producing microbes, use of steam also generates huge amounts of palm oil mill effluent (POME) [13]. POME is a brownish liquid, of viscous consistency containing high amounts of organic pollutants needs to be effectively treated before discharged to protect inland waters [13]. As an alternative approach to steam, supercritical carbon dioxide (SC-$CO_2$) can be used as a sterilization tool. SC-$CO_2$ has been vastly used in extraction and to a lesser extent in food and medical device sterilization. Recent work has proven SC-$CO_2$ to be an effective technology in the inactivation of various enzymes and lipolytic microorganisms [10]. Among the potential advantages of the SC-$CO_2$ sterilization include the inactivation of enzymes and microorganisms at a relatively low temperature and moderate pressure without generating residual waste [10,14]. The $CO_2$ at a supercritical fluid state is physiologically safe, inexpensive, non-flammable, nontoxic and has the ability to solubilize lipophilic substances [14]. Based on these premises, the application of SC-$CO_2$ bears the potential as a sterilization option for OP-FFB, endowing the process as a waterless sterilization and the exclusion of POME generation. With the annihilation of lipase and lipase producing microbes, the concern on the FFA augmentation in the CPO is abated with the concomitant assurance of the CPO products having the premium quality to compete in a competitive global vegetable oil market.

The present review was conducted to assess the possible use of SC-$CO_2$ in OP-FFB sterilization in contrast to the existing OP-FFB sterilization method. In conjunction to assessing the use of SC-$CO_2$ sterilization, this study also appraises the effectiveness of SC-$CO_2$ in the inactivation of enzymes and microorganisms that are capable of lowering the quality the palm oil. An added feature of this review is the presentation on the details of the SC-$CO_2$ inactivation mechanisms of the microorganisms.

## 2. Palm oil processing from the oil palm fresh fruit bunch

Oil palm trees in Malaysia were brought in from West Africa with the first commercial oil palm estate in Malaysia set up in 1917 at Tennamaran Estate, Selangor [15]. The size of the palm fruits is about that of a small plum and a single fruit bunch weighing 10–20 kg can have up to 2000 individual fruits [15]. Each fruit is made up of fleshy mesocarp within which is a hard kernel (seed) protected by a shell called endocarp. Crude palm oil is the primary product of palm fruits obtained from the mesocarp, while palm kernel oil (PKO) is derived from the kernels and is considered a secondary product. Although both oils originate from the same fruit, palm oil is chemically and nutritionally different from the PKO. Palm oil is one of two mesocarp oils available commercially [16].

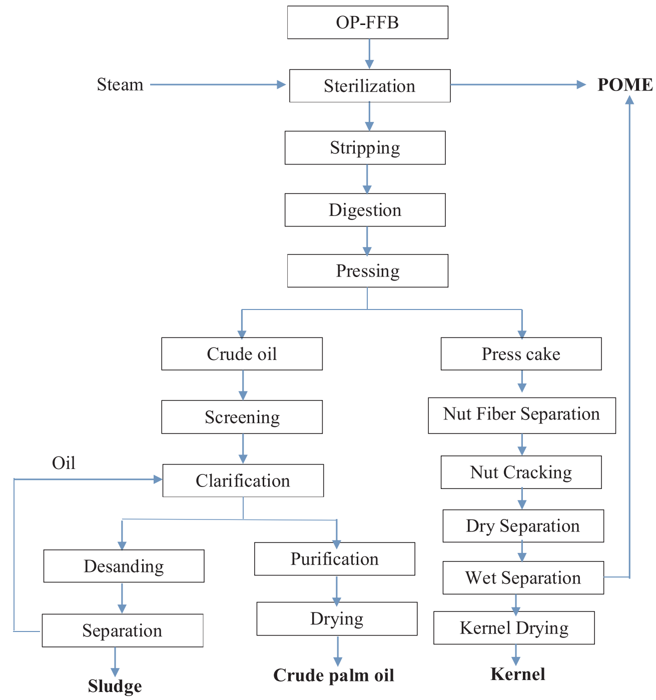

**Fig. 1.** Schematic diagram for the palm oil processing from fresh fruits bunch in a palm oil industry (Source: Simedarby research Sdn Bhd, Carry Island, Malaysia).

In palm oil production, there are several unifying operations involved, wherein, the sterilization is the first step of OP-EFB processing for palm oil extraction in a palm oil mill. The details of the palm oil processing from fresh fruit bunches in the palm oil industry is presented in Fig. 1. (Source: Sime Darby Research Sdn Bhd, Carey Island, Selangor, Malaysia). Palm oil is semi-solid at room temperature; a characteristic brought about by its 50% saturation level [16]. In its virgin form, the oil is bright orange-red in color due to its high content of carotene. The typical composition of fatty acids in palm oil is 45% palmitic acid, 40% oleic acid, 10% linoleic acid and 5% stearic acid [16,17]. Palm oil and its products possess good resistance to oxidation and heat at prolonged elevated temperatures, thus making palm oil an ideal ingredient in frying oil blends [17].

## 3. Sterilization of oil palm fresh fruit bunch

Sterilization of FFB in palm oil processing typically uses steam at 0.276 MPa for 70–90 min mainly to arrest oil quality degradation due to enzymatic activity. It also serves several other reasons, including eliminating auto-oxidation, and facilitating the digestion process by weakening the pulp structure of the fruits [9,10]. The sterilization uses a large amount of steam for an extended period to ensure the heat is able to infiltrate the inner layers of the FFB and in between the packed FFB. Larger sized FFB weighing 6–7 kg, requires an hour of steam treatment and for smaller FFB of 3–5 kg, a half hour exposure is necessary. Not all of the steam are consumed in heating the FFB, since about half of the steam might be lost as condensate and end up as palm oil mill effluent or POME [18–20]. Despite the drawbacks of the current