Quality comparison of indirect sun-drying and sulphur fumigation methods on copra production and storage

L Panjaitan¹, M Achrom¹, B Suherman¹, Nursusilawati¹, M R Fauziaty¹, K T Kurniasih and J Wungkana²

¹Applied Research Institute of Agricultural Quarantine, Bekasi, West Java, Indonesia
²Indonesian Palm Crops Research Institute

Corresponding author email: jerrywungkana20@gmail.com

Abstract. As the most valuable product of coconut, copra demands good handling on its production to reduce cost in the extraction step. This work aimed to evaluate indirect sun-drying and sulphur fumigation methods to dry copra and their effects during storage. Five treatments of different dosages of sulphur fumigation (30, 35, 40, 45, and 50 gr/m³), one non-fumigated indirect sun-dried treatment (NFNS), and one direct sun-dried treatment were done to observe the difference in the copra's quality. Analysis showed that sulphur fumigation and NFNS treatments did not affect physical parameters like color, hardness, and water content. Furthermore, sulphur fumigated samples were found superior to the other treatments in terms of pest and microorganism activities even after two months of storage. Generally, the sulphur and free fatty acid (FFA) contents did not exceed the allowable threshold. Interestingly, however, it was found that the fumigated copras have the lowest while the NFNS treatment shows the highest percentage of FFA contents. Therefore, this study also suggests a 50 gr/m³ dosage of sulphur to maintain the copra quality during a longer storage time.

Keywords: coconut, copra, sulphur fumigation, sun-drying, free fatty acid

1. Introduction
The most well-known product from coconut (Cocos nucifera) is coconut oil. In 2019, Indonesia was the second-largest exporter of crude coconut oil (CCO) before the Philippines [1], and it contributed USD 188,135,000 to its economy. Since coconut plantations in Indonesia are mainly managed by small farmers, this value represents thousands of farmers who rely on coconut as their income source.

In order to obtain coconut oil, dry extraction is widely used by oil refiners. This method uses copra, a fully matured dried coconut endosperm, in the extraction method. Copra is usually made by drying the coconut endosperm either by direct sunlight or using dryers [2]. Copra will undergo cleaning, crushing, conditioning, high-pressure extraction, screening, and filtration to get crude coconut oil in the next steps. At this point, the extracted oil is still inedible and needs some refining processes before it is safe for human consumption [3].

The efficiency of the coconut oil refining process is also considerably determined by the free fatty acid (FFA) content in the crude coconut oil. In the refining process, this compound will be removed to meet the standard quality of edible vegetable oil [4]. However, this process demands high energy usage, and thus it will raise the production cost. Therefore, the low FFA content of the crude coconut oil is preferable by producers. For this requirement, regulating the moisture content in copra is indispensable to control the growth of microbes.
Good quality copra demands a low moisture content in the product and the absence of fungi on the surface of the copra. According to Nampoothiri et al. [5], moisture content and FFA level in A-grade quality copra must be under 6 and 1 percent, respectively. Generally, these requirements can be achieved by using a direct sunlight drying process. However, this method can only be optimum during the dry season and will lack performance in the rainy season as the sunlight intensity will be lower.

Sulphur fumigation has been extensively used in postharvest handling to prolong the shelf-life of agricultural products. In addition, it is widely used as a preservative on traditional Chinese medicine herbs [6], grapes [7], ginseng [8], longan fruit [9], etc. When sulphur reacts with oxygen, it will be converted into sulphur dioxide, well-known for its effectivity in inhibiting yeast growth and enzymatic browning [10]. However, aside from its inhibitive properties, sulphur dioxide has been scrutinized for its adverse effects on human health and the quality of the product [11]. Therefore, many countries have strictly regulated the use of sulphur fumigation on agricultural products.

According to some information from our stakeholders, sulphur fumigation has been used by some farmers in Indonesia to produce white copra. However, this method is still far from being clearly understood, especially relating the optimum dosage to meet the export standard. Therefore, in this paper, we elaborate on the effect of sulphur fumigation on some characteristics of copra, and thus it can be used by coconut farmers to maintain their copra productivity and quality.

2. Materials and methods

Mature coconut fruits and sulphur powder for this experiment were purchased from a local supplier. The variety of the coconut was the tall type coconut from South Sumatra. Before being chopped into two parts, the fruit was dehusked first to get the “ball” (kernel with shell). During the chopping process, coconut water was disposed of from the kernel.

2.1. Drying chamber

Six two-shelf chambers were used for the fumigation treatments. The dimension of the chamber is 1.5 x 2.0 x 2.0 meters with 40cm height between shelves. The UV plastics fully covered the chambers to avoid rain, insects, and dust exposure while the light wavelength still can be transmitted and maintain the heat inside the chamber. The pictures of the chambers are depicted in Figure 1.

![Coconut kernels arrangement in a fumigation chamber with UV plastic cover (a) and fumigation appearance during dusk (b)](image)

2.2. Sulphur fumigation

The chopped balls were placed on the shelves in the chambers with the white parts of the kernels in the direction of the Y-axis. Five different sulphur powder dosages (30, 35, 40, 45, and 50 g/cm³) and a non-fumigated chamber-dried (P1) treatment were used to dry the kernels in the chambers. As a control sample (K), some kernels were sun-dried on a concrete floor. During daylight, all the samples in the chambers were dried using indirect sunlight, while in the evening, fumigation was performed by igniting the sulphur powder. This process was repeated for seven days with different dosages. For the first and
second days, the given dosages were 30 and 20 percent from the dosage treatments, and only 10 percent were given each day from day three to seven. On the third day, shells were removed from the kernels to maximize the drying process of the kernels. After seven days, the dried kernels were put in net sacks and stored for two months.

2.3. Color analysis
L*, a*, and b* were observed using a colorimeter. Then, the total difference (ΔE*) was calculated using Equation 1.

\[ ΔE^* = \sqrt{(ΔL^*)^2 + (Δa^*)^2 + (Δb^*)^2} \]

2.4. Hardness test
The hardness level was measured using a hardness tester. A probe was penetrated onto the copra surface, and the value on the screen was used as the hardness value.

2.5. Moisture content
Moisture content analysis was performed following the AOAC method [12]. First, several porcelain cups were pre-heated at 102°C for 10 minutes to eliminate the water molecules that could be present on the surface of the cup. Next, about 10 grams of copra were sliced into smaller sizes to maximize the water evaporation. Samples were then placed on the cups and heated at 102°C for 6 hours in an oven. Next to that, samples were placed in a desiccator coupled with silica gels for 20 minutes. After that, samples were gravimetrically weighed using an analytical scale and calculated using Equation 2 for their moisture content.

\[ \text{Moisture} \% = \frac{\text{initial weight} - \text{dry weight}}{\text{initial weight}} \times 100\% \]

2.6. Sulphur content
Inductively coupled plasma atomic emission spectroscopy was used to measure the sulphur content of the samples.

2.7. Free fatty acid (FFA) analysis
FFA content of the copra was analysed according to SNI 01-3555-1998 [13] method about analytical test method of fat and oil. Grated copra was first soaked in N-Hexane solution for overnight to extract the oil. Then, about 50 ml 95% ethanol and 3-5 drops phenolphthalein indicator were added into each sample’s 2 - 5 grams oil. Next, the mixture was titrated with 0.1N NaOH until the pinkish color appeared. Finally, FFA was calculated as the percentage of lauric acid using Equation 3.

\[ \% \text{FFA} = \frac{200 \times \text{NaOH volume} \times \text{NaOH normality}}{\text{sample weight}} \]

2.8. Analysis of pests and microorganisms' activities
Stereo and compound microscopes were used to visually observe the morphology of pests and fungi contamination on copra. One hundred copras were taken as samples for this analysis.

2.9. Statistical analysis
The effects of fumigation on copra quality were determined using randomized block design with replication performing as blocks. All treatments were quadruplicated for all analyses except in FFA analysis, where only duplication was performed. All the data were statistically analysed using one-way analysis of variance (ANOVA) followed by Tukey test at a 5% significance level. MINITAB software was used for this analysis.
3. Results and discussion

3.1. Visual appearance and physical analysis

Fumigated copras showed a superior appearance to other treatments due to the absence of microorganism infestation (Figure 2). Compared to the sun-dried copra, the fumigated samples were found brighter, and this characteristic is the reason for the term "white copra" to this product. Although the visual appearance showed a dissimilarity, the color analysis using a colorimeter did not show a significant difference. Another interesting finding in this experiment is the same level of hardness and water content in all treatments. The result also showed that the water content of all copras was statistically still out of the range of Grade A copra, which is under 6%, although it is still acceptable by the Indonesian National Standard (12%). Besides those parameters, as was expected, the sulphur residue of fumigated copras was higher than sun-dried copra, especially on the 45 and 50 g/cm³ dosages. Although there are some regulations of excessive sulphur content on agriculture products, the limitation of copra is still unavailable. Thus, more studies on the sulphur content of refined coconut oil made from white copra are urgently needed to set a standard of excess sulphur content.

![Figure 2](image)

Figure 2. The visual appearance of copra after sulphur fumigation. No visible microorganism colony was present among the fumigated samples. From left to right: sun-dried copra, non-fumigated copra, 30, 35, 40, 45 and 50 g/cm³ sulphur fumigation dosages.

For the colour, mistaken handling during the analysis process could be the reason for the discrepancy. Meanwhile, for the latter, it seems the sun-drying process during daylight dominates the drying process instead of the drying chamber either on the fumigated and non-fumigated samples. Thus, all samples' water content and hardness level (Table 1.) were relatively at the same level.

Table 1. Colour, hardness, and water content of copra of all treatments. Sun-dried copra, non-fumigated chamber-dried copra (NFCD), 30, 35, 40, 45, and 50 g/cm³ sulphur fumigation dosages were represented by K, P1, P2, P3, P4, P5, and P6, respectively.

| Treatment | Color index |  |  |  |  |  |
|-----------|------------|---|---|---|---|---|
| L* | a* | b* | ΔE* | Hardness | Water content (%) | Sulphur residue (ppm) |
| K | 30.75 | 0.28 | 8.95 | 28.95±13.88a | 3.24±0.12a | 8.52±2.55a | 590.00±b |
| P1 | 23.47 | 1.07 | 8.78 | 36.31±12.06a | 2.93±0.37a | 6.85±0.15a | - |
| P2 | 20.33 | 0.58 | 6.70 | 39.55±7.82a | 2.72±0.25a | 8.27±2.87a | 1034.92±ab |
| P3 | 26.81 | 0.31 | 7.42 | 32.99±4.54a | 2.92±0.16a | 7.07±1.22a | 954.02±ab |
| P4 | 24.36 | 0.01 | 6.03 | 35.58±4.82a | 3.04±0.09a | 6.39±1.49a | 860.68±ab |
| P5 | 19.32 | 0.37 | 6.50 | 40.56±5.97a | 3.14±0.12a | 7.34±1.94a | 1250.84±a |
| P6 | 25.56 | 0.74 | 7.39 | 34.30±6.64a | 2.93±0.19a | 6.25±0.27a | 1220.42±a |

Values in the same column with the same letters do not differ significantly (p < 0.05).

3.2. Microbial and pest analysis

Microbial growth on copra was found at a minimum level on fumigated copras even after a 3-month storage time compared to sun-dried and NFCD copras (Figure 3). All sulphur dosages showed a
relatively similar level of effectiveness in preventing fungi growth. Meanwhile, the NFCD treatment was the highest among all treatments. This can be explained as the lack of air flow inside the chamber that resulted in higher humidity than its surrounding. After that, condensation takes place and turns the vapour into liquid that falls on the copra surface. Consequently, this water layer promotes fungi growth on the copra.

Figure 3. Comparison of fungi infestation between three different storage times: a) After treatment, b) One-month storage, c) Three-month storage. Different colors of the bars represent Aspergillus flavus (■), Aspergillus niger (■), Mucor sp. (■), and Rhizopus sp. (■) respectively.

Apart from the fungi inhbititive effect, sulphur fumigation can also prevent insect infestation on copra products, as shown in Table 2. In general, fumigated copras show a lesser emergence of insects than non-fumigated copras in two different periods of storage time. Moreover, sulphur fumigation demonstrates its effectiveness in controlling the infestation of Ahasverus advena, Ephestia cautella, and Tribolium castaneum which are commonly present in sun-dried copra. In addition to this, among all dosages, the most effective fumigation was found in the 50 gr/cm³ dosage either in 2-month and 3-month storage.

Unlike the non-fumigated copra, sulphur fumigation demonstrates a different result, although the ambient humidity in the chamber is relatively high. During a fumigation, SO₂ gas reaction with water molecules produces sulphate and sulphite ions, inhibiting fungi by causing plasmolysis, shrinkage, and death to their spores [14]. Meanwhile, the mechanism of SO₂ in discouraging insects is still not clearly understood [15]. However, since sulphur fumigation also produces toxically sulphuric acid (H₂SO₄), it could be speculative that this product is responsible for deterring insects from copra. Furthermore, SO₂ gas can also directly interact with the oxidase enzyme, which is responsible for the discoloration of agricultural products. As a result, the "bleach" effect can occur, and agriculture products' desirable appearance can be maintained [6]. Therefore, these mechanisms may explain the superiority of sulphur fumigated copras over the sun-dried copras in terms of visual appearance, fungi inhibition, and pest control.
| Species                        | Pest number per 100 copras |
|--------------------------------|----------------------------|
|                               | K  | P1 | P2 | P3 | P4 | P5 | P6 |
| **Post-treatment**             |    |    |    |    |    |    |    |
| Ahasverus advena               |    |    |    |    |    |    |    |
| Araecerus fasciculatus         |    |    |    |    |    |    |    |
| Carpophilus hemipterus         |    |    |    |    |    |    |    |
| Cryptolestes ferrugineus       |    |    |    |    |    |    |    |
| Ephestia cautella              |    |    |    |    |    |    |    |
| Oryzaephilusmercator           |    |    |    |    |    |    |    |
| Tribolium castaneum            |    |    |    |    |    |    |    |
| Liposcelis enthomophila        |    |    |    |    |    |    |    |
| Glycyphagus sp.                |    |    |    |    |    |    |    |
| **2-month storage**            |    |    |    |    |    |    |    |
| Ahasverus advena               | 2  | 5  | 5  | -  | 1  | 1  | -  |
| Araecerus fasciculatus         | -  | 2  | -  | -  | -  | -  | -  |
| Carpophilus hemipterus         | -  | -  | -  | -  | -  | -  | -  |
| Cryptolestes ferrugineus       | -  | -  | -  | -  | -  | -  | -  |
| Ephestia cautella              | 3  | -  | 3  | -  | -  | -  | -  |
| Oryzaephilus mercator         | -  | -  | -  | -  | -  | -  | -  |
| Tribolium castaneum            | -  | 3  | 2  | -  | -  | 1  | -  |
| Liposcelis enthomophila        | -  | √  | -  | -  | -  | -  | -  |
| Glycyphagus sp.                | √  | √  | -  | -  | -  | -  | -  |
| **3-month storage**            |    |    |    |    |    |    |    |
| Ahasverus advena               | 4  | 6  | 5  | 14 | 5  | 7  | 3  |
| Araecerus fasciculatus         | -  | 2  | -  | -  | -  | 1  | -  |
| Carpophilus hemipterus         | -  | -  | -  | 1  | -  | 1  | -  |
| Cryptolestes ferrugineus       | -  | 6  | -  | -  | -  | -  | -  |
| Ephestia cautella              | 13 | 13 | 2  | 5  | 2  | 6  | -  |
| Oryzaephilus mercator         | -  | 9  | -  | -  | -  | -  | -  |
| Tribolium castaneum            | 14 | 5  | 1  | 1  | 1  | 3  | -  |
| Liposcelis enthomophila        | √  | √  | √  | √  | √  | √  | √  |
| Glycyphagus sp.                | √  | √  | √  | √  | √  | √  | √  |

*√ = insect was detected, but the number was not counted*
3.3. Free fatty acid (FFA) content

Whereas NFCD copra contained a high FFA content (+/- 1.76%), the percentage in sun-dried and fumigated, copras was found under 1%, according to Grade A copra standard. It is noteworthy that the trend of FFA content of fumigated copras was similar to the fungi growth graph in Fig 3. In other words, sulphur fumigation is effective in regulating FFA formation. The occurrence of FFA in coconut correlates with the presence of fungi. In Hoover et al. [16] paper, it is mentioned that the presence of Aspergillus flavus fungus can release lipase enzyme. Moreover, this enzyme is well known for its ability to hydrolyze oil into FFA, an undesirable compound in oil refining [17].

![Figure 4](image-url)  
**Figure 4.** The pictures of insect on post-storage copras. a) Ahasverus advena, b) Araecerus fasciculatus, c) Carpophilus hemipterus, d) Cryptolestes ferrugineus, e) Ephestia cautella, f) Oryzaephilus mercator dan g) Tribolium castaneum

![Figure 5](image-url)  
**Figure 5.** Free fatty acid content of all treatments

In this research, 50 gr/cm³ sulphur dosage displayed the greatest ability in hindering copra from several deteriorating effects such as fungi and pest infestation. Due to this ability, this dosage can produce the same quality as the sun-dried copra. Therefore, this dosage can be recommended to be used by coconut farmers.
4. Conclusion
This study tries to explain the effect of sulphur fumigation in maintaining the quality of copra. Sulphur
fumigant did not affect some physical characteristics like sun-dried copra such as colour, hardness, and
water content. Sulphur fumigated samples were also found superior to the other treatments in pest and
fungi activities. As the result of fewer fungi emergence, fumigated copra has a low FFA content due to
less lipase that fungi can release. Based on these results, 50 gr/cm$^3$ sulphur dosage can be suggested as
the most effective dosage in fumigation.

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