Potential of Traditional Sago Starch: Life Cycle Assessment (LCA) Perspective

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Abstract. Half of the world's sago production comes from Indonesia, and about 90% of Indonesia's sago originates from Papua, including West Papua [1]. There are three types of technology used to produce sago starch in Indonesia, namely traditional, semi-mechanical and mechanical processes. In Papua generally the processing of sago starch is carried out with traditional processes. This study is intended to evaluate the environmental impacts caused by the traditionally processed sago starch products using the product life cycle (LCA) approach. Environmental impacts are estimated by analyzing the carbon footprint of GHG emissions resulting from 1 ton of dry sago starch. The scope of the product life cycle is limited to the stage of harvesting, transportation and extraction to produce dry sago starch. The results of the study show that the impact of GHG emissions generated to produce 1 ton of sago starch is 17.9 kgCO2eq. The biggest contribution came from the extraction process, especially from the drying process which was 12.25 kgCO2eq (68%). This value of impact is much lower when compared to corn starch (2700 kg CO2eq), potato starch (2402 kg CO2eq) and cassava starch (4310 kg CO2eq). This is mainly due to the low requirement of energy input of this traditional technology.

1. Introduction

Indonesia's sago production is around 50% of world sago production, and around 90% of Indonesia's sago potential is in Papua, including West Papua [1]. The production area of sago in Papua Province is around 4 700 000 ha and in West Papua around 510 000 ha [2]. The high potential of Indonesian sago can drive the development of Indonesia's sago industry. Data of sago area and production for 2004-2017 is presented in table 1.

Merauke regency is one of the regencies in Papua, which has a land area of 4.6 million hectares consisting of 3.1 million hectares in the form of forest cover including sago forest and 1.5 million hectares in the form of non-forest cover [3]. The processing of sago starch in this regency is carried out in traditional way, not yet supported by adequate sago starch processing technology. This is because the people still adhere to local customs which require that the processing of sago be carried out by manual processes without the use of machines.
Table 1. Area and sago production by farming category, 2004-2017.

| Year | Area (Ha) | Production (Ton) |
|------|-----------|------------------|
|      | Smallholders | Government | Private | Total | Smallholders | Government | Private | Total |
| 2004 | 87.113     | -          | -       | 87.113 | 14.544 | -          | -       | 14.544 |
| 2005 | 94.458     | -          | -       | 94.458 | 15.301 | -          | -       | 15.301 |
| 2006 | 94.528     | -          | -       | 94.528 | 14.202 | -          | -       | 14.202 |
| 2007 | 102.601    | -          | -       | 102.601| 85.960 | -          | -       | 85.960 |
| 2008 | 48.115     | -          | -       | 48.115 | 31.767 | -          | -       | 31.767 |
| 2009 | 100.319    | -          | -       | 100.319| 87.955 | -          | -       | 87.955 |
| 2010 | 102.174    | -          | -       | 102.174| 89.629 | -          | -       | 89.629 |
| 2011 | 102.601    | -          | -       | 102.601| 85.960 | -          | -       | 85.960 |
| 2012 | 106.957    | 20.200     | -       | 127.157| 93.265 | 39.044     | 132.309 |
| 2013 | 107.906    | 20.200     | -       | 128.106| 93.893 | 61.168     | 155.061 |
| 2014 | 115.284    | 20.200     | -       | 135.484| 249.488| 61.168     | 310.656 |
| 2015 | 176.215    | 20.200     | 196.415| 277.129| 146.817| 423.946    | 440.516 |
| 2016 | 193.080    | 20.200     | 213.280| 283.511| 157.005| 310.061    | 440.516 |
| 2017 | 199.778    | 20.200     | 219.978| 328.444| 161.199| 489.643    | 440.516 |

Source: Directorate General of Estate Crops

Traditional sago processing starts from the process of harvesting, transportation, and extraction. Each stage of these processes contributes to GHG emissions. GHG emissions are the release of greenhouse gases into the atmosphere in certain areas within a certain period of time which causes the earth's surface temperature to rise because of the ability of greenhouse gases to absorb solar radiation, which should be reflected outside the earth. According to the Intergovernmental Panel on Climate Change [4], the greater the total GHG emissions from an activity, the greater the value of potential warming generated (GWP) and the greater the activity has an impact on environmental damage. Total GHG emissions are calculated using a carbon footprint assessment. The carbon footprint is a measurement of GHG emissions that contribute to global warming which is expressed in units of kg CO2eq for each kg of products [5].

To find out the amount of GHG emissions released from sago starch production, a carbon footprint is assessed by using the Life Cycle Assessment method. LCA is an analytical method used to collect and evaluate inputs, outputs and potential environmental impacts of a product or service throughout its life cycle [6]. In addition to analyzing the impact of a product life cycle, the LCA method can be a means of developing improvement alternatives that can be used by policy makers in determining the more sustainable processes and products.

This research work was carried out in the local community village of Wasur, Merauke Regency, which aims to analyze the carbon footprint generated from each process stage in the traditional sago starch production. GHG emissions impact is represented in the form of kg CO2eq per one ton of dried sago starch produced. Thus, the output of this study is expected to serve as a database of environmental performance of one of Indonesia's sago processing methods and can provide recommendations for improvements related to energy use and waste treatment in sago starch production.

2. Methodology

This study uses the LCA methodology to evaluate the input, output, and potential environmental impacts of the life cycle of sago starch. This method consists of four stages, namely the determination of objectives and scope, inventory analysis, impact analysis and interpretation.

2.1 Purpose and scope

The purpose of this study is to analyze the input-output flow of materials throughout the life cycle of sago starch and to determine the impact to the environment. The variety of sago plants processed by the Wasur community in Merauke Regency is Metroxylon sago Rottboll (sago molat), which is not
spiny. In general, the saplings produced by “sago molat” are much less than the other type of sago grown there (sago tuni). The scope of analysis is cradle to gate, which starts from harvesting natural sago trees in the forest, transportation, and extraction processes (figure 1).

![Diagram of traditional sago starch production process]

**Figure 1.** General LCA flowchart of traditional sago starch

Figure 1 describes the system boundaries of the sago starch life cycle used in this study, which consists of tree felling and cutting of sago stems, transportation of raw materials from the location to the extraction site, and extraction processes. The functional unit selected as a basis for determining the impact of GHG emissions is 1-ton dry sago starch. Inventory analysis was carried out by conducting an inventory of all input and output flows involved, in units of mass and energy per ton dried sago starch produced. Furthermore, each process/operation unit within the system boundary will be explained in detail starting from the harvesting process, stem cutting, transportation, skin stripping, pith destruction, squeeze, sedimentation, and drying to obtain dry sago starch.

### 2.2 Inventory analysis

This stage is carried out by collecting primary and secondary data related to the life cycle of sago starch to analyze the carbon footprint. SIMAPRO software (version 8.5.0.0) along with a database...
from ECOINVENT (version 3.3) is used to assist with this inventory analysis. Because sago is produced by cutting sago trees from the forest, sago trees are considered as the input of nature and therefore standing tree data is used (taken from SIMAPRO). Other input data on harvesting and transportation, such as weight and length of stem, weight of solid wastes, and distance from forest to extraction site are measured. In the extraction process, the weight of bark, residual pulp (extracted pith), volume of water used and waste generated (solid and liquid) are measured directly. The summary of all process input data from which the calculation of the impact of emissions made is given in Table 2.

Table 2. Summary of inventory analysis

| Inventory                        | SIMAPRO Analysis          |
|----------------------------------|---------------------------|
|                                  | Input from nature         | Input from technosphere | Output to technosphere | Final waste flow |
| Harvesting and transportation    | Woods/unspecified, standing/kg | -                      | Sago stem              | Waste, organic  |
| Bark stripping                   | -                         | Sago stem               | Sago pith              | Waste, organic  |
| Pith disintegration              | -                         | Sago pith               | Disintegrated pith     | Waste, organic  |
|                                  | Water                     | Disintegrated pith      | Starch solution        | Waste pulp      |
| Squeezing                        | -                         | Starch solution         | Wet sago starch        | Waste water     |
| Sedimentation                    | Wood and wood waste       | Wet sago starch         | Dry sago starch        |                |
| drying                           | Wet sago starch           | Dry sago starch         |                         |                |

Primary data directly measured from field are used as input category from technosphere and output category to technosphere. Secondary data taken from SIMAPRO library are used for input category from nature and final waste flow. These inventory data are then used to estimate the environmental impact of sago starch.

2.3 Impact assessment
The impact assessment stage is carried out by converting inventory data into an assessment of the environmental impacts that arise. The GHG emission indicator is carried out by analyzing the carbon footprint of the sago starch from the calculation of the estimated amount of CO2 emissions using SIMAPRO software which refers to the IPCC (2006) equation guide with the following formula:

\[ E = AD \times EF \]

where,

- \( E \) = Emissions
- \( AD \) = Activity data
- \( EF \) = Emission factor (kg CO2eq/AD)

2.4 Interpretation
The last stage of the LCA method is to interpret the results of the inventory analysis and environmental impact assessment by summarizing and analyzing conclusions in accordance with the objectives and scope that has been determined. The interpretation phase is carried out to conclude the final results of the assessment of the environmental impact of the life cycle of sago starch and provide advice to improve energy and water efficiency and reduce GHG emissions released in the traditional sago starch extraction process.
3. Results and discussion

3.1. Traditional Sago Starch Production

Sago starch production is traditionally carried out by the local population. The starch is used as a staple food for everyday consumption. Sago tree felling is carried out in mutual cooperation using simple equipment, such as machetes or axes. The harvested sago stems are cleaned and cut to size 1-2 m long, and are then transported to the extraction site by linking the sago stem pieces with sago leaf midribs and pulled manually by human power as far as 2 km. The extraction sites are primarily chosen based on the availability of the water supply.

At the extraction stage, activities carried out include skin stripping, pith disruption, squeezing, sedimentation and drying. Here the sago stems are removed from their bark, approximately 5 cm thick, using axes to get the starch-rich sago pith. The piths are disintegrated or disrupted by a device called “owyuh ombuk” (a kind of manual rasper) and the work of disintegrating the sago pith is called “undapa”. The process is done in such a way that the pith is quite crushed and the starch is easily separated from the pith fibers. The disintegrated pith will be brown in colour when stored in open air in more than a day. Therefore, the rasped pith must be extracted on the same day. “Undapa” can be continued the next day until all stems are disintegrated. In this traditional way, cutting a whole sago tree can be completed within 1-3 weeks.

The disintegrated pith is then beaten by using wood rod to ease the starch extraction during squeezing. Extraction of sago flour is done by hand squeezing, and assisted with watering. In some areas, the water used comes from swamps in the location. In Merauke, the sago flour extraction facility is called “sahani”, which is made from sago bark and equipped at the end with coconut fibers as a filter. The sago starch solution extracted is then flowed on the sago bark and got filtered. The sago starch is then deposited, and separated from the supernatant. Starch obtained from this traditional method is still wet. To dry it, the local tribe will wrap the sago starch with sago or banana leaves and burn it until the desired level of dryness.

3.2 Life Cycle Inventory

Results of inventory analysis are grouped according to the stages of the process started from the harvesting to drying. The mass balance of the traditional sago starch extraction process can be seen in Table 3.

Table 3. Mass balance of each stage of sago starch processing

| Processes          | Input Material | Quantity (kg) | Output Material | Quantity (kg) |
|--------------------|----------------|---------------|-----------------|---------------|

Harvesting | Sago tree | 1200 | Sago stem | 975
--- | --- | --- | --- | ---
Bark stripping | Sago stem | 975 | Pith | 790
 | Bark | 185
Pith disintegration | Pith | 790 | Disintegrated pith | 632
 | Pith waste | 158
Squeezing | Disintegrated pith | 632 | Starch solution | 679
 | Water | 470 | Wet pulp | 423
Sedimentation | Starch solution | 679 | Wet starch | 252
 | Supernatant | 427
Drying | Wet starch | 252 | Dry sago starch | 127

* in this study human energy is not taken into account

Based on the mass balance above, the yield of dry sago starch obtained was 13%. Starch content in piths obtained from commercially harvested sago stems varied between 18.8% and 38.8% [7]. The manual handling and traditional extraction method results in relatively low yield of sago starch produced.

3.3 Carbon footprint analysis

The carbon footprint of traditional sago starch production is calculated using SIMAPRO software which uses the basic formula in the form of inventory data multiplied by material emission factors. Emission factor (EF) is the amount of GHG emitted from a material used in the production of a product in units of kg CO\(_2\) equivalent / unit of material weight. The results of the carbon footprint assessment throughout the life cycle of dry sago starch products are presented in figure 2.

![Figure 2. Results of assessment of carbon footprint on traditional sago starch production](image_url)

From the results of the carbon footprint assessment, it is known that the total GHG emissions from 1 ton of dry sago starch is 17.9 kg CO\(_2\)eq. Each stage of the production process has different level of emissions impacts, and the biggest contribution is at the drying stage, which contributes to 12.25 kg CO\(_2\)eq / ton of sago starch (68%). This is because the drying process by burning wet sago starch with
solid wastes of sago trees causes high carbon emissions. The second largest contribution comes from squeezing process that generates solid waste in the form of 423 kg of wet sago pulp, which contributes to a carbon footprint of 1.74 kg CO2eq / ton dry sago starch (10%). Overall, however, the value of this emission impact is still much lower when compared with the impact value on potato starch and corn starch, which are 2402 kg CO2eq and 2700 kg CO2eq [8], respectively, and cassava starch of 4310 kg CO2eq [9]. This low impact value is mainly due to the minimum use of energy input in traditional sago processing.

3.4 Interpretation
From the results of the assessment of the carbon footprint, there are various opportunities for developing process improvements to reduce GHG emissions in the production of traditional sago starch. One of the opportunities is by utilizing sago pulp for various purposes. Process development scenarios that can be applied to the sago starch extraction process can be seen in Table 4.

| Process scenario | Activity                        |
|------------------|---------------------------------|
| **Utilization of sago pulp** | 1. Processing for animal feed  |
|                  | 2. Processing for sago pulp flour |
|                  | 3. Composting                    |
|                  | 4. Processing of bioethanol      |
| **Other drying method** | Use of sun drying for sago starch |

4. Conclusion
The environmental impact caused by the traditional sago starch production process through a carbon footprint assessment has been calculated to be 97.9 kg CO2eq / ton dry sago starch. The largest carbon footprint contribution comes from the drying process, which is 29.4 kg CO2eq / ton dry sago starch (30%). In addition, the squeezing process generates solid waste in the form of 423 kg of wet sago pulp which contributes to a carbon footprint of 17.4 kg CO2eq / ton dry sago starch (18%). Therefore, it is necessary to develop several scenarios of production improvement, especially to further utilize sago pulp for other products and by applying alternative drying processes using sunlight.

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