Framework of life cycle assessment on nutmeg syrup processing

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Abstract. This study aimed to design the life cycle assessment (LCA) framework on two methods of the nutmeg syrup production process. The difference between those two ways based on how to eliminate tannin in nutmeg flesh, namely: using a salt solvent and albumin. There are three environmental impacts considered in the framework: gas emissions, noise levels, and human energy consumptions. Nutmeg syrup processing has a long process that each step consists of several activities which require resources, including humans, raw materials, water, energy, machine, and tools. The environmental impact needs to be measured for the sustainability of the industry. The stages carried out in this study, including field observations, data collections, establishing LCA framework based on ISO 14044 involving defining goal and scope, identifying inventory analysis, assessing environmental impacts, recommendations for reducing environmental impacts. This LCA framework can be used as the basic to carry out LCA on nutmeg syrup production. A decision-maker can use that LCA result to choose the best production process to reduce environmental impact so they can produce an environmentally sustainable industry.

1. Introduction

Nutmeg or Myristica fragrans Houtt in Latin is a tall, high-tree fruit plant native to Indonesia, especially from Banda and Maluku. Nutmeg plants have the advantage that almost all part of the plant can be utilized, the bark, leaves, mace (red objects that cover the seed coat), nutmeg seed, and nutmeg flesh. Nutmeg is generally used as a spice, essential oils, and medicinal ingredients. Nutmeg flesh can be used as a food and beverage such as syrup, pickled nutmeg, candied nutmeg, marmalade, nutmeg jam, dodol (Indonesia traditional food), and others [1].

Aceh Province, in particular South Aceh Regency, is one of the nutmeg producing centres. Many processed food and beverage products are made from nutmeg, one of which is nutmeg syrup. In general, the nutmeg syrup industry is still a small and medium scale industry whose production process is semi-manual.

Manufacturing of nutmeg syrup impacts the environment, such as solid and liquid waste, gas emissions, noise, and others. The environmental impacts that occur due to the use of resources such as
energy, air, raw materials, and machine activities that cause noise. These impacts need to be identified, measured and evaluated as a basis for improving the process and reducing environmental impacts.

Life Cycle Assessment (LCA) is one of the methodologies for assessing the environmental impacts produced by industrial activities. Life cycle assessment (LCA) is an approach to estimate and assess the environmental impacts during the life cycle of a product. It can be climate change, stratospheric ozone depletion, tropospheric ozone (smog) creation, eutrophication, acidification, toxicological stress on human health and ecosystems, the depletion of resources, water use, land use, and noise and others [2]. In other words, LCA is a method used to identify the impact of a product on the environment. The LCA method is widely used by various parties to assess the environmental impact caused by a process during the product cycle, including taking raw materials, production processes, products used by consumers until the product is disposed of or sent to a waste treatment facility. LCA assesses the environmental burden based on an inventory analysis of the use of resources, energy, water, fuel, and other materials, so it loads can be identified and analyzed using several different alternatives to reduce the environmental impact caused. Environmental impacts measured in previous LCA studies include the potential for global warming [3], [4], gas emissions [5], [6],[7], energy consumption [3], net energy ratio [8], etc.

Some research about nutmeg based products especially syrup industry had been conducted among others carried out by Sipahelut [9] who tested the antibacterial and antifungal activity of essential oil of the nutmeg flesh. Djubaedah et al. [10] examined the effect of the treatment of nutmeg flesh on the quality of nutmeg syrup. Sahelangi [11] tested effect adding albumin toward quality of the syrup. Juwita [12] evaluated consumer perception of nutmeg products. Juwita [13] studied conditions and profitability of the nutmeg industry. Wicaksono [14] mitigated the product Launch Failure of Nutmeg Juice.

There had been many studies conducted on LCA in small, medium, and large industries. Some LCA study in small, medium enterprises (SMEs) of food and beverage had conducted among others chocolate product [15], dairy products [16],[17], tanning SMEs [18], fried cassava chips production [19], traditional durum wheat bread [20], tea industry [21], wine fermentation [22], spirulina-based food products [23], etc.

According to literature review, there are no studies to measure the environmental impact due to the activity of the nutmeg syrup production process. That is our motivation to conduct LCA studies in the nutmeg syrup industry. This study aimed to develop the framework of LCA for the nutmeg syrup industry by comparing two methods of the production process. Different techniques based on how to remove tannin from nutmeg flesh. The first method is done by soaking in a salt solution and the second method using albumin. We considered the environmental impact for both methods were gas emission, human energy consumption, and noise. The study began with field observations, data collection, and compiled an LCA framework for the industry. We use LCA methodology based on ISO 14044 2006 [24], which consisted of determining goals and scope, identifying inventory analysis, measuring environmental impact, and interpretation.

2. Research Method

The tools and materials used in this study are:

1. A stopwatch that is used to measure the time of each worker's activity in making syrup.
2. Body scales used to weigh workers' weight.
3. Sound Level Meter used to measure the noise level of the nutmeg syrup production process.
Figure 1 shows the flowchart of the stages of research, and Figure 2 describes the LCA framework.

![Flowchart study LCA of nutmeg syrup](image)

**Figure 1. Flowchart study LCA of nutmeg syrup**

![Life cycle analysis framework (ISO 14044 2006[24])](image)

**Figure 2. Life cycle analysis framework (ISO 14044 2006[24])**

3. Results and Discussions
   3.1. Goal and Scopes
   The purpose of this LCA is to measure gas emissions, human energy consumption, and the noise for the two methods of nutmeg syrup processing. The syrup is a drink containing a thick liquid that has high sugar content. Fruits or spices added to the syrup to get a natural flavour or to get the benefits of the fruit or spice. Before processing, the tannin content is first removed to eliminate the bitter and bitter taste. Two ways to get rid of tannins are to soak nutmeg with 5% salt for 12 hours, [10] and the addition of 1% albumin to nutmeg juice [25]. The scope of measurement based on the system limitation of LCA gate to gate that is starting from raw materials receiving, production process until finished goods.

   3.1.1 Unit functions definition
   Before collecting data, first, determine the parameters used and the units. In this study, the amount of resources required based on the need to make 1 litre of syrup. Some parameters and the units used in this LCA can be seen in Table 1.

   **Table 1. Parameters and the units required for this LCA study**

   | Parameters                      | Units |
   |---------------------------------|-------|
   | Goal and scopes                 |       |
   | Life Cycle Inventory            |       |
   | Life Cycle Impact Assessment    |       |
   | Interpretation                  |       |
The amount of nutmeg flesh needed to produce 1 liter of syrup  kg
The amount of sugar needed to produce 1 liter of syrup  kg
The amount of salt needed to produce 1 liter of syrup  kg
The amount of albumin needed to produce 1 liter of syrup  kg
The amount of water needed to wash nutmeg flesh  Litre
The amount of water needed to make nutmeg juice  Litre
The amount of electricity power needed to make 1 liter of syrup  Kwh
The amount of gas needed to make 1 liter of syrup  Kg
The amount of solid waste produced  Kg
The amount of byproduct produced  Kg
Noise level generated by machine  dB
The amount human energy required  calorie
Weight of worker  Kg
Time for each activity  minute
Type of gas emission generated
Type of waste generated

3.1.2 Input–output allocation

This factor divides the input and output produced in a production process. The basis for determining the allocation can be mass, energy, and the added value generated by each output. In this study, this allocation can be illustrated as in Figure 3. The detailed production process of making nutmeg syrup can be seen in Figure 4 for tannin removal with salt solvent and Figure 5 with albumin.

Figure 3. Input-output allocation
3.2 Inventory Analysis

Inventory analysis is the process of collecting data needed in an LCA. The data required includes the use of raw materials, fuel, human energy consumption, and waste generated, including solid waste, liquid waste, and gas waste. One important thing in determining the environmental impact caused is through the flow of the nutmeg syrup production process. The data collected is then recapitulated in the Life Cycle Inventory (LCI) table, as shown in Table 2.

![Diagram of nutmeg syrup production process with salt solvent](image1)

**Figure 4.** Production process of nutmeg syrup with salt solvent [10]

![Diagram of nutmeg syrup production process with albumin](image2)

**Figure 5.** Production process of nutmeg syrup with albumin [25]

### Table 2. Resource requirements

| Type of raw material | Unit | The amount required |
|----------------------|------|---------------------|
| Nutmeg flesh         | Kg   | ...                 |
| Water                | Litre| ...                 |
| Sugar                | Kg   | ...                 |
| Salt                 | Kg   | ...                 |
| Albumin              | Kg   | ...                 |
| Tannin removal with salt solvent | | ... |
| Tannin removal with albumin | | ... |

3.2.1 Energy requirements

The nutmeg industry is generally of small and medium capacity so that the production process is carried out semi-manually. Some activities use machines, and others use human power. Energy requirements data in this study consists of energy requirements for machines and energy released by humans to carry out activities. Tables 3 and 4 respectively show the energy requirements for the production process using salt and albumin. Calculation of human energy using the method in the SNI 7269 2009 about the Assessment of workloads based on the level of calorie needs according to energy expenditures. Workload assessment is carried out by measuring workers’ weight, observing workforce activities, and
calculating calorie requirements based on energy expenditure according to the calculation table in SNI 7269 2009. Workload total can be seen in equation 1 and 2 [26].

\[
WL_{average} = \frac{W_L(T_1) + (W_LxT_2) + \ldots + (W_LxT_n)}{T_1 + T_2 + \ldots + T_n} \times 60 \text{ kcal/hour} \tag{1}
\]

\[
\text{Total WL} = WL_{average} + BM \tag{2}
\]

Where \(B_{K_n}\) = workload activity n (minute), \(T_n\) = activity time n (minute), BM = basal metabolism, BM for male = weight (kg) x 1 kcal per hour, BM for female = weight (kg) x 0.9 kcal per hour.

Calculation of energy from fuels is done by converting the amount of fuel need to power in kilocalorie units. LCI of energy requirement for two type production process can be seen in Table 3.

### Table 3. Energy requirement for two type of production process

| Activity                               | Using salt solvent |      | Using albumin |      |
|----------------------------------------|--------------------|------|---------------|------|
|                                        | Human energy (kcal) | Electricity (kwh) | LPG (kg) | Human energy (kcal) | Electricity (kwh) | LPG (kg) |
| Cleaning and peeling nutmeg           | a                  | -    | -             | j    | -    | - |
| Soaking nutmeg flesh into salt solvent| b                  | -    | -             | -    | -    | - |
| Chopping nutmeg                       | c                  | -    | -             | k    | -    | - |
| Crushing nutmeg                       | -                  | d    | -             | -    | i    | - |
| Filtering nutmeg juice                | e                  | -    | -             | m    | -    | - |
| Adding sugar into nutmeg juice        | f                  | -    | -             | n    | -    | - |
| Adding albumin                        | -                  | -    | -             | o    | -    | - |
| Cooking nutmeg syrup                  | -                  | h    | -             | -    | p    | - |
| Packing syrup                         | i                  | -    | -             | q    | -    | - |

3.3 Life Cycle Impact Assessment

This stage identifies and evaluates the amount of potential environmental impacts (gas emissions, waste) that occur throughout the LCI. The impacts can also be in the form of ecological health, public health, resource depletion, and social welfare. Field observation showed that the nutmeg syrup production process brings about two types of waste. Those are solid waste from nutmeg pulp and liquid waste from the washing process. Gas emissions generated from the use of electricity and gas fuel.

**Gas emissions**

Gas emissions produced from the use of electrical energy in the destruction of nutmeg and the use of LPG liquid petroleum gas fuels. LPG fuels produce gas emissions in the form of carbon monoxide (CO), carbon dioxide (CO\(_2\)), hydrocarbons (HC), and nitrogen oxides (NO\(_x\)) [27,28]. The electricity usage produced CO\(_2\), SO\(_2\), and NO\(_x\) emissions. Calculation of emissions for both burning fossil fuels and electricity usage can be calculated as follows:

**Electricity gas emissions:**

\[
\text{CO}_2 \text{ emission} = EC \times 0.84 \text{ kg CO}_2/\text{kWh} \tag{3}
\]

\[
\text{NO}_2 \text{ emission} = EC \times 4.17 \text{ g NO}_2/\text{kWh} \tag{4}
\]

\[
\text{SO}_2 \text{ emission} = EC \times 8.1 \text{ g SO}_2/\text{kWh} \tag{5}
\]

Where,

\(EC=\)electricity consumption (kwh)

**Gas emissions for fossil fuel usage:**

\[
\text{CO}_2 \text{ emission} = QF \times NC \times 74100 \text{ kg CO}_2/\text{TJ} \tag{6}
\]

\[
\text{CH}_4 \text{ emission} = QF \times NC \times 10 \text{ kg CH}_4/\text{TJ} \tag{7}
\]

\[
\text{N}_2\text{O \text{ emission}} = QF \times NC \times 0.6 \text{ kg N}_2\text{O}/\text{TJ} \tag{8}
\]

Where \(QF\) = Fuel consumption (L) and \(NK\) = Net calorie value (TJ/L)
3.4 Interpretation
At this stage, it identifies issues affecting the nutmeg syrup industry’s environment based on LCI and LCIA. Activities that produce emissions are part of the crushing of nutmeg and cooking syrup. Based on the results of gas emissions measurements for both operations, process improvements can be made to reduce emissions. It can be conducted by replacing gas energy with alternative fuels giving a large impact on lower gas emissions. The use of manually operated equipment can lead to the use of human energy, which can cause muscle fatigue when used in excess. If the noise level is found to exceed the WHO regulation of 80 dB, it can be carried out using sound dampening.

4. Conclusion
The LCA framework is established as a basis for measuring the environmental impact of the nutmeg syrup industry by two production process methods, videlicet removing tannins with salt and albumin. This study uses a system boundary, namely gate to gate. This LCA compares the environmental impact of issuing gas emissions, human energy consumption, and sound levels for the two process methods. The production process that has a lower environmental impact is the best in terms of the environment. The results of this LCA can be used to make decisions to improve the process so that it can reduce the environmental impact. Future work can measure the impact on the nutmeg syrup industry using this framework based on actual data. Other environmental aspects, such as social, economic, work accident, work completion, and others, can be included in the framework.

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