Environmental Engineering and Management Journal July 2018, Vol.17, No. 7, 1583-1590
http://www.eemj.icpm.tuiasi.ro/; http://www.eemj.eu

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ENVIRONMENTAL PERFORMANCE OF SAJOR-CAJU MUSHROOM PRODUCTION BASED ON FARM SIZES IN THAILAND

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Abstract

Unlike other vegetables, mushroom production requires several substrate ingredients, energy to sterilize the substrate, water to humidify the fruiting house and waste management of the spent substrate and used materials. This work studied the environmental impacts and eco-efficiency of sajor-caju mushroom *(Pleurotus sajor-caju (Fr.) Sing.*) production in terms of climate change potential, acidification potential, water depletion potential and fossil fuel depletion potential, using life cycle assessment (LCA) method. The results showed that the mushroom production in small and large farms had nearly the same environmental performance. Their environmental impacts were lower and their eco-efficiencies were higher than those for medium-sized farms. This means the medium-sized farms would cause more environmental impacts in order to obtain the same profit as the other two farms. It was found that there was inefficient use of both substrate and energy in the medium-sized farms. This is probably because the medium-sized farm had relatively low financial limitations, compared to the small farms, and relatively less concern over efficient use of resources, compared to the large farms. The reduction of sawdust and rice bran, used as substrate ingredients, as well as wood, used as energy source for sterilization, to the same amounts as those used in the small farms could reduce environmental impacts (5-25%) and improve eco-efficiencies (10-40%) of the medium-sized farms to be close to those for large and small farms.

Key words: climate change, environment, farm size, life cycle assessment, mushroom

Received: May, 2014; Revised final: August, 2014; Accepted: September, 2014; Published in final edited form: July 2018

1. Introduction

Sajor-caju mushroom (*Sajor-caju (Fr.) Sing.*) is in the oyster mushroom family. It is a common mushroom with the second largest production volume in Thailand (DOAE, 2012a). In 2012, the total production was 5,679 ton (DOAE, 2012b). Unlike other vegetables, mushroom production requires preparation and sterilization of substrate which comprises several ingredients. After mixing and putting substrate ingredients in a plastic bag, the substrate is sterilized by steam. Then spawn is put inside the substrate bag and incubated in a humidified house. After harvest, the spent plastic bags and substrate are burnt or left unmanaged. It can be seen that energy and water are required and air emissions are released from these processes. Emissions of CO_2, CH_4 and N_2O contribute to climate change potential while SO_2 and NOx can cause terrestrial acidification. The production of substrate ingredients, energy and other raw materials used in the farms also consumes fossil and water resources as well as releases emissions to air. Although these environmental burdens take place outside the farms, they arise from the sajor-caju production and thus their environmental impacts should be included.

Life Cycle Assessment (LCA) methodology is an efficient tool to evaluate environmental impacts quantitatively. It considers the use of resources and the emissions from a product's life cycle, i.e., from the

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stages of raw material provision, production, use, to disposal and recycling. Data on resources used and emission substances under the scope of the study are collected and then classified according to their environmental impact potential. For example, CO_2, CH_4 and N_2O are classified as climate change substances. Each substance is given a characterization factor according to its impact potential. For example, characterization factors of 1 kg CO_2, 1 kg CH_4 and 1 kg N_2O are 1, 25 and 298 kg CO_2 eq, respectively (BSI, 2008). Then the characterization factor of each substance is multiplied by the amount of the substance. The sum of the multiplication is the impact of the concerned category. The methodology of LCA has been explained in detail elsewhere (Dong et al., 2016; ISO, 2006a, 2006b; Finnveden et al., 2009; Tongpool et al., 2010). Using LCA, Gunady et al. (2012) studied greenhouse gas emissions from production of button *Agaricus bisporus* mushroom in Western Australia. They found that life cycle greenhouse gas emissions of the button mushroom was 2.8 kg CO_2eq/kg and that the main impact contributor was the transport of raw materials such as peat, compost and spawn.

While the farm activities affect the environment, the environment influences farm productivity and economy. Kanellopoulos et al. (2014) illustrated that future farming systems were challenged to adapt to changes in climate, market and environment in order to remain competitive and to meet increasing demand for food. To remain viable, smaller farms were said to require technological development to increase yields and compensate for substantial increase in price of inputs. Technology and resource management in different sizes of farms were shown to have impacts on performance and economic viability of the farms. Pishgar-Komleh et al. (2012) reported that, in Esfahan province of Iran, the energy input for potato production of large farms (larger than 5 ha) was relatively low while the total energy output was relatively high, compared to small (up to 1 ha) and medium-sized (1-5 ha) farms. They also found that the amounts of seeds and chemical fertilizers applied in the large farms were relatively low due to better management. However, Manjunatha et al. (2013) found that, in the southern part of India, small farms (up to 1.01 ha) showed better resource use efficiency than large farms (> 1.01 ha). In Slovenia, small farms (up to 5 ha) were relatively more profitable and the large farms (> 20 ha) were more technically efficient (Bojnec and Latruffe, 2013). It was reported that the number of medium-sized farms (5-20 ha) in Slovania has been decreasing because they were too small to be economically efficient but they were too large to be profitable.

Environment, economic and social factors are concerned in sustainable development. The indicator measuring progress toward economic and environmental sustainability is eco-efficiency. It was defined as the value of the product or service, divided by environmental influence (Blengini et al., 2017; Verfaillie and Bidwell, 2000). The environmental impact, economic benefit and eco-efficiency of different sizes of mushroom farms have not been reported elsewhere.

Therefore this work compared the environmental performance of sajor-caju production of small, medium and large farms. The concerned environmental impact categories were climate change, terrestrial acidification, water depletion and fossil fuel depletion. The key impact contributors were also investigated and measures to reduce environmental impacts as well as increasing eco-efficiency proposed.

2. Case studies presentation

2.1. Environmental impact assessment

As shown in Fig. 1, the production processes at sajor-caju farms include mixing and sterilizing substrates, inoculating with spawn, maintaining environmental controls for spawn run and fruiting, as well as harvesting and managing wastes. Wastes are burnt in the open air or used as fuel for steam generation or left unmanaged or sent to landfill, depending on individual farm practice.

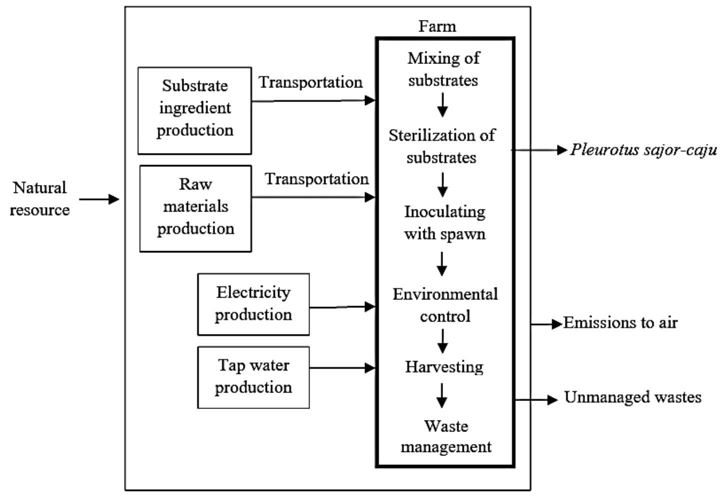

Fig. 1. Scope of data collection under the study

The data of inputs (such as substrate ingredients, plastic bags, and fuel) and outputs (such as air emissions, wastes) of each process were collected by interviewing the farmers in Ratchaburi province, Thailand. Sizes of mushroom farms were divided into small, medium and large farms, having an annual production of less than 20-ton, 20-40 ton and more than 40 ton, respectively (DOA, 2012). The obtained data came from fifteen large farms, eight medium farms and eight small farms that together contributed 22 % of total sajor-caju production of the country in 2012 (DOAE, 2012b). Then the inputs and outputs (inventory) for each farm size were weight averaged according to the annual production to obtain the averaged inventory of 1 kg sajor-caju production. Amounts of air emissions from urea fertilizer and combustion of wood, LPG, gasoline and burning of wastes were calculated using emission factors of IPCC 2006 (Eggleston et al., 2006) and EMEP/EEA 2013 (EEA, 2013). Carbon dioxide from wood combustion was not counted due to carbon neutral rule. The inputs applied to sajor-caju production processes are produced outside the farms and then transported to the farms. Therefore the data of resources consumption and emissions due to transportation and production of the inputs were included in the environmental impact assessment. These data were obtained from the Thai National LCI database (MTEC, 2013) and the Ecoinvent database (Ecoinvent Centre, 2007).

Then the total resources and emissions were classified and multiplied by characterization factors according to their environmental impact potential, using the methodology of ReCiPe midpoint (H) (Goedkoop et al., 2009) in order to quantify impacts in the categories of climate change (unit: kg CO_2 equivalent (eq)), terrestrial acidification (unit: kg SO_2 eq), water depletion (unit: m^3) and fossil fuel depletion (unit: kg oil eq). SimaPro 7.3.3 software (Pre Consultants, 2013) was used to facilitate the calculation and to reduce any possible mistakes.

2.2. Eco-efficiency

The cost of raw materials, energy, transportation and labor used for the production of sajor-caju in each farm was obtained by interviewing the farmers and suppliers. The sale price at sajor-caju farm was 30 Baht/kg (about 1 US$/kg) in 2013. The profit at the farm was equal to the difference between the sale price and the total cost. Eco-efficiency of sajor-caju production was derived from the profit of 1 kg sajor-caju divided by the environmental impact of 1 kg sajor-caju production.

3. Results and discussion

3.1. Environmental impact assessment

The inventory for production of 1 kg sajor-caju is shown in Table 1. The medium-sized farms used higher amount of substrate while the large farms used more electricity than the others. It can be seen that, due to the use of machinery, the amount of electricity used in the large farms was about two and eleven times of that used in the medium and small farms, respectively. In the sterilization process, the medium and small farms used only wood as an energy source. The large farms used both wood and LPG. It was reported that energy content of wood and LPG was 15.99 and 49.3 MJ/kg, respectively (DEDE, 2011). Therefore the energy applied for the sterilization process in the medium-sized farms was the highest (94.5 MJ), compared to the small (71.3 MJ) and large (76.6 MJ) farms. Water consumption for steam generation in all farms was nearly the same but the water applied to humidify the fruiting houses of the large farms was only half of that used in the small and medium farms. This is because every large farm used sprinkler system, providing a better control of water usage, which is not the case for small and medium farms.

The environmental impacts of 1 kg sajor-caju are shown in Fig. 2. The impacts from production, transportation and mixing of the substrates were denoted as "substrate". The impacts from the production and transportation of fuel and water used for sterilization, as well as air emissions from fuel combustion during sterilization were denoted as "sterilizing". The environmental burdens from inoculating spawn and environmental controls for spawn run and fruiting were shown as "inoculating" and "fruiting", respectively. The contribution of "harvest" came from the production and transportation of plastic bags used during harvesting. The contribution of "waste" came from management of wastes after the harvest.

It is shown that the sajor-caju production of the medium-sized farms caused the highest environmental impacts. The main impact contributors in all categories were "sterilizing" and "substrate". The climate change potentials of the large, medium and small farms were 1.1, 1.4 and 1.2 kg CO_2 eq/kg sajor-caju, respectively. This was much lower than the level obtained for button mushroom (*Agaricus bisporus*) production in Australia (2.34 kg CO_2eq/kg) reported by Gunady, et al. (2012). In the category of fossil fuel depletion, about 0.2 kg oil eq was consumed by the production of 1 kg sajor-caju which was one third of shiitake production (0.6 kg oil eq/kg) (Tongpool and Pongpat, 2013). However, the impacts of sajor-caju in these two categories were higher than those for normal produce, such as tomato, onion, bush bean, baby corn and potato (0.1-0.5 kg CO_2 eq/kg, 0.03-0.07 kg oil eq) (Tongpool et al., 2011).

"Sterilizing" was a major impact contributor in the categories of climate change and terrestrial acidification, while the "substrate" was the main contributor in the categories of water depletion and fossil fuel depletion. Both "sterilizing" and "substrate" recorded for the medium-sized farms were higher than those of small and large farms.

Table 1. Inventory of 1 kg sajor-caju produced at large, medium and small farms

List		*Unit*	*Farm size*		
			Large	*Medium*	*Small*
Input	***Mixing of substrates***				
	Sawdust	kg	2.0725	2.4779	2.3343
	Rice bran	kg	0.1084	0.1495	0.0969
	Urea fertilizer	kg	0.0015	0.003	0.0015
	Other ingredients	kg	0.0583	0.04845	0.0392
	Pakaging e.g. bag, neck ring	kg	0.0256	0.0274	0.0269
	Total weight of substrate	kg	2.2663	2.7063	2.4988
	Electricity	kWh	0.0042	0.0030	0.0014
	Transportation	ton-km	1.4711	1.7131	1.5100
	Sterilizing of substrates				
	Wood	kg	4.7650	5.9070	4.4527
	Liquefied petroleum gas (LPG)	kg	0.0084	0	0
	Transportation	ton-km	0.1236	0.1673	0.1533
	Tap water	m^3	0.0008	0.0010	0.0020
	Water from well or river	m^3	0.0012	0.0013	0.0001
	Inoculation with spawn				
	Transportation	ton-km	0.0002	0.0002	0.0002
	Spawn	kg	0.0091	0.0102	0.0101
	Environmental control for spawn run and fruiting				
	Pesticides	kg	2×10^{-5}	4×10^{-5}	2×10^{-5}
	Water from well or river	m^3	0.0031	0.0065	0.0016
	Tap water	m^3	0.0018	0.0060	0.0094
	Gasoline	m^3	2×10^{-7}	5×10^{-7}	5×10^{-7}
	Electricity	kWh	0.0226	0.0117	0.0011
	Transportation	ton-km	0.0001	0.0002	0.0002
	Harvesting				
	Transportation	ton-km	0.0042	0.0041	0.0041
	Plastic bag	kg	0.015	0.015	0.015
Output	Sajor-caju in plastic bag	kg	1	1	1
	Unmanaged solid wastes	kg	1.2832	1.8662	1.6520
	NOx	kg	0.0070	0.0087	0.0065
	SO_2	kg	0.0008	0.0010	0.0008
	NH_3	kg	0.0030	0.0038	0.0028
	CO_2	kg	0.0466	0.0298	0.0194
	CH_4	kg	0.0230	0.0284	0.0215
	N_2O	kg	0.0003	0.0004	0.0003

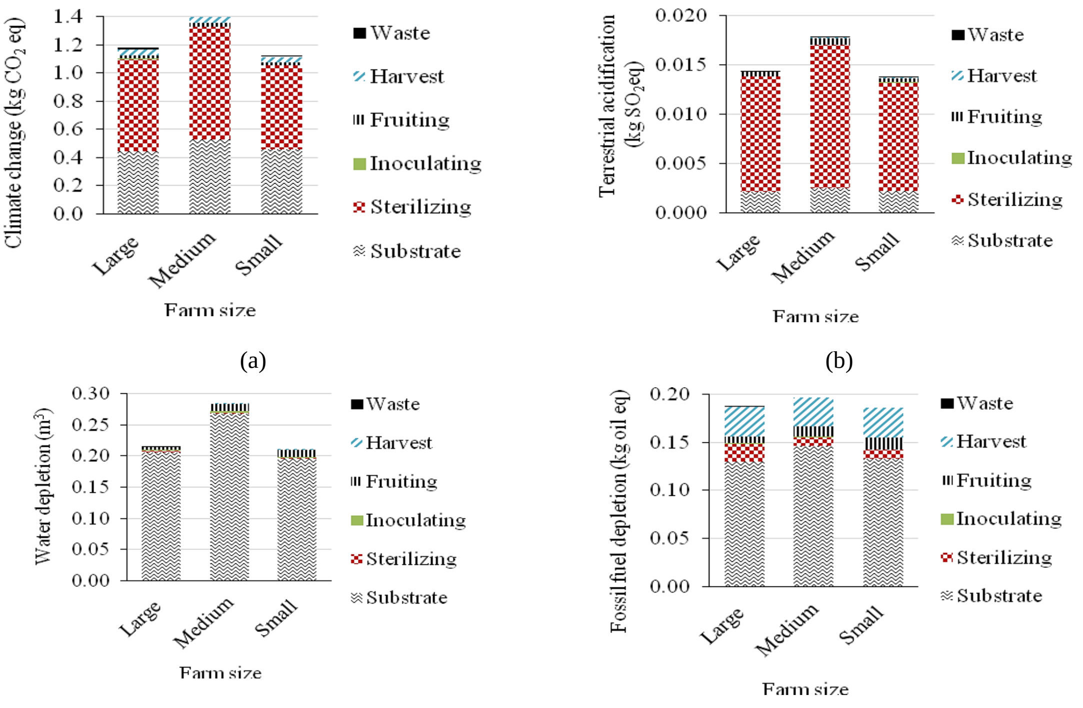

Fig. 2. Environmental impacts of 1 kg sajor-caju production of the large, medium and small farms, in the categories of: (a) climate change, (b) terrestrial acidification, (c) water depletion and (d) fossil fuel depletion

Fig. 3 shows components contributing to the impact of "sterilizing" in the medium-sized farms. It can be seen that the emissions from "sterilizing" contributed almost 100% in the categories of climate change and terrestrial acidification. These emissions came from wood combustion which releases relatively high amounts of CH_4, N_2O and SOx, compared to LPG combustion, considering the same given energy (Eggleston, et al., 2006; EEA, 2013).

Fig. 4 shows components that caused "substrate" of the medium-sized farms to have high environmental impacts. It can be seen that the production of sawdust, rice bran, packaging and transportation of sawdust were the main sources of the impacts. This corresponded to the data shown in Table 1 that the medium-sized farms used relatively large amounts of sawdust, rice bran and packaging. Although rice bran, broken rice and rice husk are by-products of milled rice production, they have economic values. As a result, the environmental burdens from the milled rice production were allocated to all products according to their economic values; 71% to milled rice, 23% to broken rice, 4% to rice bran and 2% to rice husk. This ratio was derived from the multiplication of the market price and the amount of each product obtained from rice milling. The amounts of rice products from the rice milling were obtained from Nadsathaporn (2007). Sawdust and slab are also by-products of lumber production. Since all products can be sold, the environmental burdens from the lumber production were allocated to all of them according to the mass ratio; 50% to lumber, 10% to sawdust and 40% to slab (MTEC, 2013).

Although Table 1 shows that water used for humidifying fruiting houses of the small and medium farms was 2-3 times of that used in the large farms, Fig. 2e (water depletion category) reveals that its contribution to life-cycle water depletion of sajor-caju was insignificant compared to the water consumption of "substrate" dominated by rice bran production (Fig. 4).

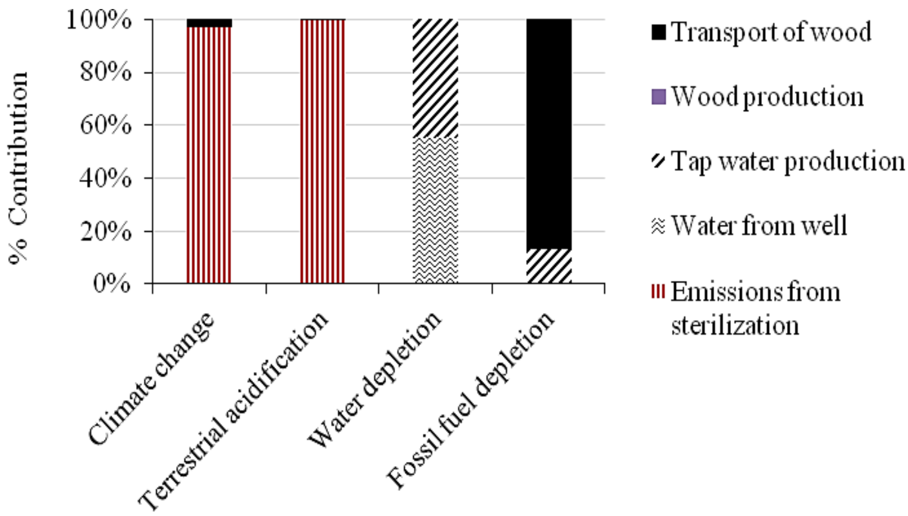

Fig. 3. Impact components of "sterilizing" in the medium-sized farms

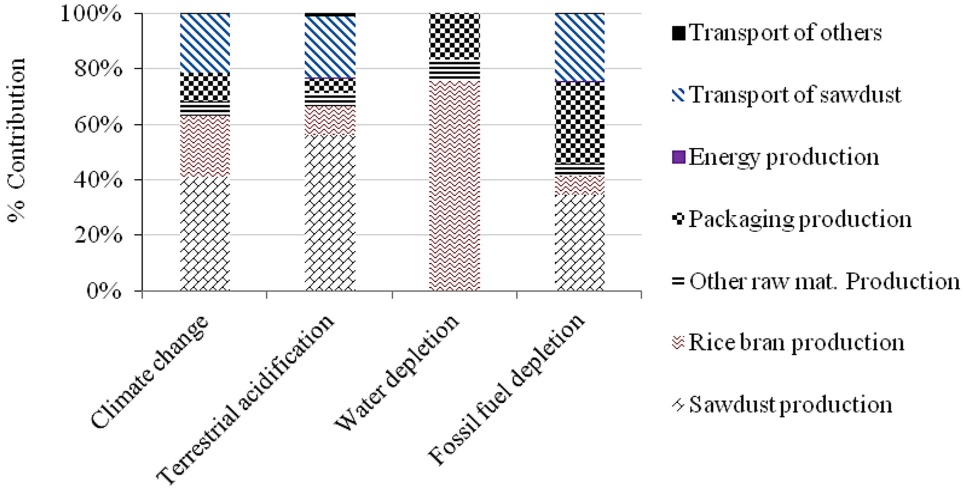

Fig. 4. Impact components of "substrate" for the medium-sized farms

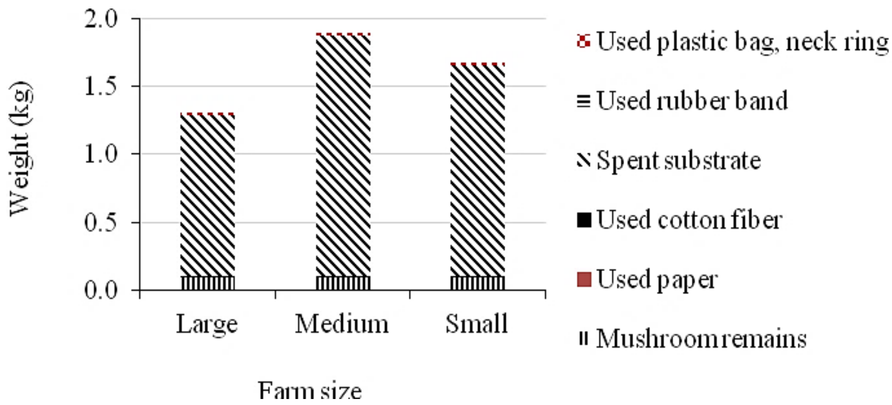

Fig. 5. Components of wastes from the production of 1 kg sajor-caju in the large, medium and small farms

Moreover, the impact of the "fruiting" (Fig. 2) was relatively small although a large amount of electricity was used in the environmental control for spawn run and fruiting (Table 1). Components of wastes from the small, medium and large farms are shown in Fig. 5. The medium-sized farms produced the highest amount of wastes, most of which were spent substrates. Hence, in medium-sized farms, more attention should be paid to efficient use of substrate.

3.2. Eco-efficiency

Table 2 shows the cost of raw materials, energy and labor as well as profit for the production of 1 kg sajor-caju. The major cost came from sawdust, rice bran, packaging, wood and labor. The total cost in small farms was relatively low and thus the profit was relatively high. This leads to high eco-efficiencies of sajor-caju production in small farms as shown in Fig. 6. Medium-sized farms showed the lowest eco-efficiencies as a result of having the lowest profit and the highest environmental impacts (Table. 2). This means that medium-sized farms would cause more environmental impacts in order to obtain the same profit as the small and large farms.

Table 2. Cost of raw materials, energy, labor and profit for the production of 1 kg sajor-caju in the large, medium and small farms

Details		***Cost (Bath)***	
	Large size	***Medium size***	***Small size***
Cost			
Sawdust	2.8925	3.4776	3.2972
Rice bran	0.8405	1.1955	0.7646
Urea fertilizer	0.0533	0.0891	0.0511
Spawn	0.6243	0.7032	0.6944
Packaging	2.0989	2.1794	2.1541
Other materials	0.6616	0.6090	0.5735
Electricity	0.0739	0.0406	0.0069
Gasoline	0.0064	0.0209	0.0203
Wood	1.0417	1.1918	1.2737
LPG	0.1550	0	0
Labor	2.0393	1.4097	1.5109
Total	10.4874	10.9168	10.3467
Profit	19.5126	19.0832	19.6533

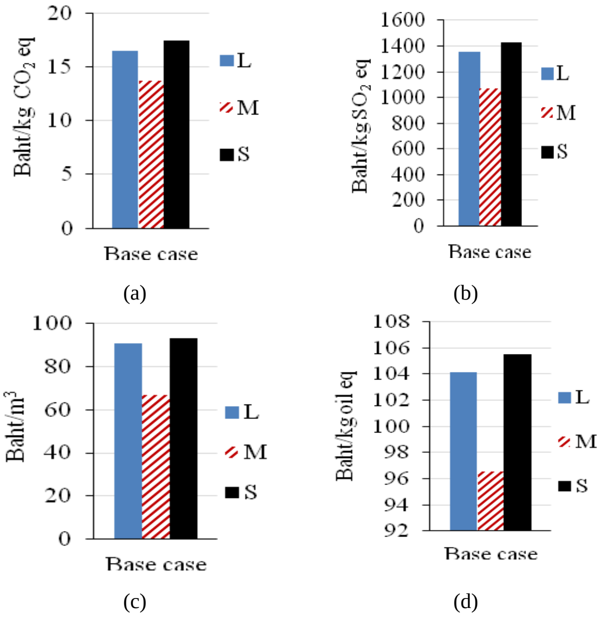

Fig. 6. Eco-efficiencies of sajor-caju production for the large (L), medium (M) and small (S) farms, in the categories of (a) climate change, (b) terrestrial acidification, (c) water depletion and (d) fossil fuel depletion

The reason that the small and large farms had similar environmental performance and the medium-sized farms performed worst can be related to the resource management in each type of farm. In the small farms, the amounts of wood and substrates used for sajor-caju production were relatively low, implying that raw materials usage was more carefully controlled, probably because of financial limitation. In the large farms, the amounts of substrates, wastes and water used for humidifying the fruiting house were the lowest, implying that attention was given to efficient use of resource.

In the medium-sized farms, the amounts of wood, substrates and wastes were relatively high, implying that efficient use of resources was not a concern, due to relatively low financial limitation, compared to the small farms.

3.3. Improvement of environmental performance

It was shown that, in the medium-sized farms, a relatively large amount of substrate was used and subsequently left after the harvest. This implies that it is possible for these farms to reduce the substrate amount while still achieving the same production yield. As sawdust and rice bran largely contributed to environmental impacts (Fig. 4) and total cost (Table 2) of the sajor-caju production, it is proposed that the medium-sized farms use the same amounts of sawdust and rice bran as those of the small farms. It was revealed in section 3.1 that the medium-sized farms used more energy in the sterilizing process than the other two sizes of farm. Moreover, the emissions from the sterilizing process were the main impact contributors (Fig. 3). Therefore it is proposed that the amount of wood was also reduced to the same amount of that used in the small farms.

The results from this option, shown in Table 3, demonstrated that 5-25% of environmental impacts of sajor-caju could be reduced. The climate change potential of the medium-sized farms decreased from 1.40 to 1.14 kg CO_2eq/kg which was closed to that of the small farms (1.13 kg CO_2eq/kg) and slightly lower than that of the large farms (1.18 kg CO_2eq/kg). Water depletion potential was reduced from 0.28 to 0.21 m^3/kg, which was close to those of the small and large farms. The profit of the medium-sized farms was consequently increased from 19.08 to 20.00 Baht/kg. The change in both profit and environmental impacts resulted in 10-40% increase in eco-efficiencies (Table 3). These new eco-efficiencies were slightly higher than those recorded for the large farms.

4. Conclusions

The environmental impacts of sajor-caju production are derived mainly from the production, transportation and sterilization of substrates. Medium-sized farms showed relatively high environmental impacts and relatively low profit and eco-efficiency, compared to small and large farms. It was found that there was inefficiency use of substrate and energy in the medium-sized farms. After the sawdust, rice bran and wood were reduced to the same amounts as those used in the small farms, the environmental performance of medium-sized farms was improved to be close to that of the large and small farms.

Acknowledgements

This study was accomplished through the financial support of National Science and Technology Development Agency (NSTDA) Thailand, under the Thailand National LCI Database Project, Thailand Advanced Institute of Science and Technology and Tokyo Institute of Technology (TAIST-Tokyo Tech), and Faculty of Engineering, Kesetsart University. We acknowledge the department of agriculture and farmers in Ratchaburi province, Thailand, for data provision. We thank Dr. John Thomas Harry Pearce for proof reading the article.

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Table 3. Environmental impacts and eco-efficiencies of 1 kg sajor-caju produced at medium-sized farms after the amounts of sawdust, rice bran and wood were reduced

Eco-efficiency			*Environmental impact*			*Impact category*
% Increase	*Unit*	*New value*	*% Reduction*	*Unit*	*New value*	
29.1	Bt/kg CO_2eq	17.6	18.8	kg CO_2 eq	1.135	Climate change
32.9	Bt/kg CO_2eq	1420	21.1	kg SO_2 eq	0.014	Terrestrial acidification
39.5	Bt/m^3	93	24.9	m^3	0.214	Water depletion
10.6	Bt/kg oil eq	107	5.3	kg oil eq	0.187	Fossil fuel depletion

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