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The Water Footprint of Oyster mushroom (*Pleurotus ostreatus*) Cultivation under Small-scale Polybag Farming Conditions in Sri Lanka

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ABSTRACT

Purpose: *Water footprint (WFP) is a widely used environmental indicator to compare and identify the strategies for better water use efficiency. The Objectives of the present study were to calculate and analyze the WFP of Oyster mushroom cultivation under small-scale farming conditions in Sri Lanka.*

Research Method: *Water footprint was estimated as the sum of water used for preparing the mushroom growing substrate and the on-farm water requirement for the production of a ton of mushrooms. Production parameters and on-farm water usage of three small-scale Oyster mushroom farms were recorded.*

Findings: *WFPs of growing substrates were low (591 - 642 m^3/ton) and varied within a narrow range. The main on-farm water-consuming activities were the preparation of growing media, water for sterilization of media, spraying of water during the growing cycle, floor cleaning, and laborer's water consumption. WFP of mushroom cultivation under the conditions specified in this study was 1181 m^3/ton. Being the largest component, mushroom growing media accounted for 95% of the WFP. On-farm water requirement was found to be as low as 4.4 L/kg. WFP of mushrooms was lower than those reported for eggs, broiler meat, pork, beef, lentil, and soy meat. Nevertheless, the WFP of mushrooms, when expressed per unit of calorie or protein was higher than that of egg and soy meat.*

Originality/ Value: *As the first reported WFP calculation for mushrooms in Sri Lanka, this study identified mushrooms as a water-efficient food item. Improvement in yield and shortening of the growing cycle were identified as the means of reducing the WFP of mushroom cultivation in Sri Lanka.*

Keywords: *Oyster, polybag farming, Sri Lanka, water footprint*

INTRODUCTION

Food production systems are the largest contributor to global environmental burdens such as global warming and climate change, water scarcity, soil and water quality deterioration, acidification of land and water bodies, land use changes, and biodiversity losses (MacMillan & Middleton, 2010). Environmental-friendly food production systems and diets are crucial in tackling global environmental challenges (Kim *et al*., 2020; Poore and Nemecek, 2018; Tilman and Clark, 2014). Assessment of environmental impacts is a pre-requisite for making food production and consumption more environmental-friendly and sustainable (Marchettini *et al.,* 2003).

In the face of global challenge of water scarcity (Mountford, 2011), water footprint is widely used to determine and compare the water use efficiency of food production systems and

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products (Chapagain and Hoekstra, 2010; Gerbens-Leenes *et al.,* 2013; Mekonnen and Hoekstra, 2011, 2012). Furthermore, an analysis of the WFP of a product can be used to identify the strategies to increase water use efficiency.

Water footprint is sum of water consumed and polluted per unit of production along the production chain (Hoekstra *et al.,* 2011). Total WFP is consisted of three main categories *viz.* blue, green, and grey WFP. Blue WFP indicates the consumptive use of fresh surface or groundwater. Green WFP indicates the volume of rain water used during a production process while, grey WFP refers to the volume of water required to assimilate the pollutants that are generated during the production process steps (Hoekstra *et al.,* 2009).

Mushroom is a global food item. Due to its ability to convert lignocellulose agricultural by-products and wastes into nutritious/medicinal food item at low environmental cost (Gunady *et al.,* 2012; Leiva *et al.,* 2015; Robinson *et al.,* 2019), mushroom has been identified as a promising candidate for circular food production systems (Grimm and Wösten, 2018). One kg of global per capita mushroom consumption in 1978 has increased to 4.7 kg in 2013 (Royse *et al.,* 2017). During 2010-2020, global mushroom production increased from 6.9 to 10.4 Mn tons (Ho *et al.,* 2020). Mushroom is gaining popularity in Sri Lanka both as a vegetable curry and as an alternative to animal-source food items (Ranathunga *et al.,* 2010). Mushroom production is particularly popular as a small and medium-scale household-level enterprise aiming at local markets. Since mushroom is equally popular among both vegetarians and non-vegetarians, the estimation of WFP of mushroom is important to compare the environmental impacts of different dietary patterns as well.

WFP of many crop and livestock products are reported in the literature (Mekonnen and Hoekstra, 2011, 2012). Environmental indicators such as global warming potential, direct energy, and fossil fuel use for mushroom cultivation have been reported in the literature (Gunady *et al.,* 2012; Leiva *et al.,* 2015; Robinson *et al.,* 2019). However, studies on water use-efficiency indicators of mushroom cultivation are limited and conflicting values have been reported. For example, Robinson *et al.* (2019) reported 290 L/kg of WFP while SureHarvest (2017) and American Mushroom Association reported embedded water values of 20 L/kg and 16 L/kg, respectively.

Oyster (*Pleurotus ostreatus*) is the most popular mushroom among Sri Lankan mushroom cultivators. This experiment calculates the WFP of Oyster mushroom cultivation under small-scale, indoor, polybag farming conditions in Sri Lanka, with the view of comparing the WFP of mushrooms with other counterpart food items and identifying means to increase the water use efficiency of the production process.

MATERIALS AND METHODS

WFP of mushrooms was calculated using the methodology described by Hoekstra *et al.* (2009). Based on the extension materials of the Department of Agriculture and on the expert consultations, common ingredients and the compositions of the mushroom media used in Sri Lanka were identified. The water footprint values of those ingredients were derived from literature (Table 01).

There were no published reports on the WFP of poultry litter. The WFP of paddy husk was assumed to be equal to the WFP of poultry litter. Considering the WFP of paddy (1673 m^3/tones) and product fraction of paddy husk (0.2) (Hoekstra & Mekonnen, 2010), the WFP of poultry litter was calculated as 1673 x 0.2 = 334.8 m^3/ ton.

Table 01: Water footprint values of the items used in common mushroom media in Sri Lanka as reported in literature

Ingredient	WFP (m^3/tons)	Reference
Sawdust (Rubber)*	645.16	(Schyns *et al.,* 2017)
Rice polish	316.8	(Hoekstra and Mekonnen, 2010)
Rice bran	316.8	Assumed as same as the rice polish (Hoekstra and Mekonnen, 2010)
Mung bean	5053	(Mekonnen and Hoekstra, 2011)
Poultry litter	334.8	(Chapagain and Hoekstra, 2010)
Paddy	1673	(Hoekstra and Mekonnen, 2010)

** Derived from Schyns et al., (2017) for Roundwood timber for India.*

Based on the ingredient composition of the media and the WFP values of each ingredient, WFP values of growing media were calculated (Table 2). To determine the water used during the production process, information was collected from three small-scale mushroom production farms in Kamburupitiya Divisional Secretariat area of Matara District. Those farms usually produce approximately 240 - 250 bags per harvesting cycle. According to Ranathunga *et al.,* (2010), 98 % of the mushroom farmers in Si Lanka operate small and medium-scale units where only 2 % of the farmers are engaged with the exports. A schematic presentation of the steps of mushroom cultivation used in the farms is given in Figure 01. The amount of water used in each step was either measured or estimated, based on process observation and farmers' information. Sri Lankan farmers generally use 200 L steel-barrel for the sterilization process of mushroom cultivation. The 200 L barrel with water filled up to around 5 - 6 inches height (Roughly volume of water = 35 L) was heated using firewood to generate steam at high pressure (15 *psi*) and temperature (121 ^{0}C) which were required for the sterilization of substrate containing bags (Gamage and Ohga, 2018). Same method was adopted by the three farms selected in the study for the sterilization of the substrate containing bags.

Average water usage per person per day in Sri Lanka is reported to be 119 L (Kaushalya *et al.,* 2020). One mushroom growing cycle runs 90 days. Therefore, the total labor water usage during 8 hours of work within one mushroom cycle was calculated as (0.119/3) x 90 = 3.57 m^3

Approximately 240 - 250 bags were prepared from 100 kg of one batch of growing media as mentioned above. The yield of a mushroom cycle was obtained from farmer records. Accordingly, average mushroom production per bag was 250 - 300 g in 2 ½ to 3 months' period. A 5 % removal rate normally occurred and ultimately 228 – 238 bags remained for harvesting at the end of a harvesting cycle. Information collected from three small-scale mushroom cultivation farms for one harvesting cycle was used for the analysis. The total direct (farm water) and indirect (growing media) water volume (m^3) calculated for a growing cycle was divided by the yield (tons) to determine the WFP of mushrooms (m^3/ton).

RESULTS AND DISCUSSION

The water footprints of three commonly used mushroom media in Sri Lanka are given in Table 2. Since water used for the preparation and sterilization of media was found to be negligible (Table 03), only the water contribution from ingredients was considered in the calculation.

Apart from mung bean and mineral supplements, all the other ingredients considered in this analysis are either agricultural wastes or by-products. Consequently, the WFP of mushroom

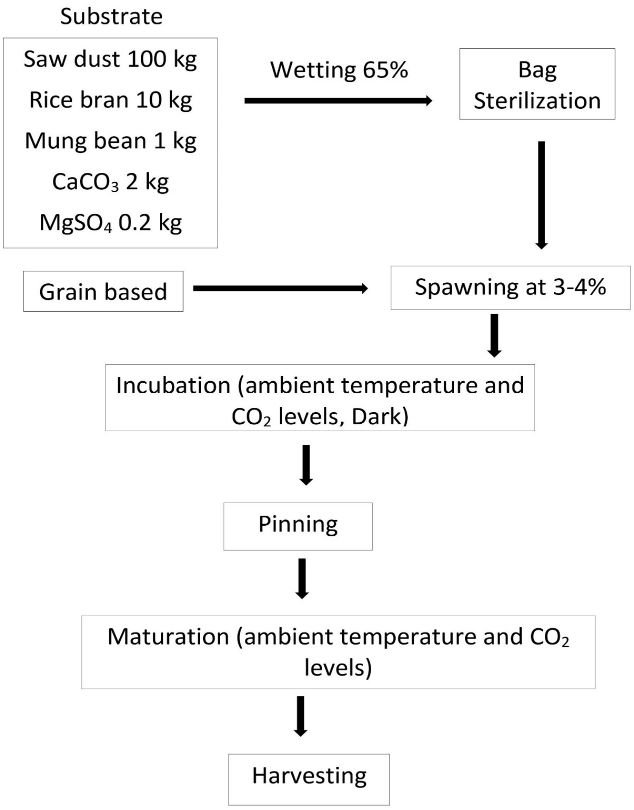

Figure 01: Schematic representation of the oyster mushroom growing process

growing media was found to be low. Information about the WFP values of mushroom media are scanty. All over the world, commercial mushroom media is mainly comprised of lignocellulose agricultural by-products or wastes such as wood chips, straw, and saw dust (Grimm and Wösten, 2018). According to the standard method of WFP calculation, WFP of the by-product is calculated as; WFP of the primary product from which the by-product is derived x the fraction of the by-product (termed as product fraction) that is generated during the production process (Hoekstra *et al.,* 2011). Cereal straws, another widely used mushroom growing medium is also reported to have low WFP values (Ibidhi and Salem, 2019). Therefore, it can reasonably be assumed that WFP of mushroom media is low as far as agricultural by-products and wastes are used as the main substrate of the growing media. Among the three substrates used, Oyster substrate 2 which includes the poultry litter reported the lowest WFP, closely followed by the substrate used for Makandura white, containing saw dust and rice polish.

Being a waste of broiler production, WFP of poultry litter is considered to be equal to that of paddy husk which is the conventional litter material for poultry production in Sri Lanka. Since fibrous agricultural by-products or wastes such as sawdust, wood shaving, pine peanut shell, shredded paper, peat, maize cobs and cereal straw are the main litter material for poultry in many countries (Wiedemann and Watson, 2018), WFP of media may not vary widely depending on the type of litter material. Furthermore, ingredients and their percentages in the media were also more or less similar. Mainly due to the above reasons, WFPs of the mushroom growing substrate were low and varied within a narrow range. Saw dust and rice bran; the largest components were also used at similar amounts in all three media. The total weight of a medium mixture varied due to the type and the amount of other few ingredients used. Consequently, the total weight of a mixture was different. This intern also influenced the differences of WFP of substrates.

Table 02: Water footprint of three commonly used mushroom substrates in Sri Lanka

Type of media and cultivation	Ingredient	Amount (Kg)	Total WFP (m^3/tons)	Calculated contribution from each ingredient (m^3)	WFP (m^3/ton)
Oyster Substrate 1	Saw dust (rubber)	100	645.16	64.516	642.0
	Rice bran	10	316.8	3.168	
	Mung bean	1	5053	5.053	
	$CaCO_3$	2	0	0	
	$MgSO_4$	0.2	0	0	
	Total	113.2		72.73	
Makandura white	Saw dust (Rubber)	100	645.161	64.516	595.0
	Rice polish	10	316.8	3.168	
	Dolomite	2.5	0	0	
	Gypsum	1	0	0	
	$MgSO_4$	0.25	0	0	
	Total	113.75		67.68	
Oyster Substrate 2	Saw dust (Rubber)	100	645.161	64.516	591
	Rice bran	10	316.8	3.168	
	Poultry litter	5	334.8	1.674	
	$CaCO_3$	2	0	0	
	$MgSO_4$	0.2	0	0	
	Total	117.2		69.3	

The calculation procedure and the contribution of different activities (direct and indirect) towards the WFP of mushrooms are presented in Table 3. Under the conditions of this study, the WFP of Oyster mushroom production was calculated as 1181.21 m^3/tons. Much lower water requirement values have been reported for US mushroom production. For example, Robinson *et al.,* (2019) have done a Life Cycle Assessment (LCA) with a broader system boundary encompassing water use for electricity generation and reported 290 L of fresh water usage/kg of mushroom production under intensive large-scale conditions. Differences in the methodology used, system boundary, the scale of operations, and production and management conditions between two studies might be the reasons for the discrepancy between the values. Numerous WFP studies (Mekonnen & Hoekstra, 2011, 2012) have reported such variations for a given item, depending on the conditions. Meanwhile, 20 L of embedded water volume/kg has been reported by SureHarvest (2017). Lack of systematic studies, less descriptive methodologies, and differences among study conditions, scale of operations and the production conditions make the comparison of the reported WFP values difficult.

Being the largest component and the substrate, which acts as the feeding material for mushroom growing contributed 95 % to the total water footprint. Contribution of feed water to the WFP of livestock products such as eggs (Chaminda and Attapattu, 2013) and broilers (Atapattu, 2011) are also reported to be as high as 90 %. Of the WFP of mushrooms, the contributions of saw dust, labor water, mung bean, and rice bran were 83.6 %, 4.6 %, 6.5 % and 4.1 %, respectively. To the WFP of poultry meat, major contributors were water-intensive ingredients such as maize, soybean, and palm oil in the feed. In livestock production, substitution of above ingredients in feeds with by-products such as rice bran reduces the WFP. Whereas, in the case of the WFP of mushrooms, rice bran becomes a culprit against more-water efficient items such as saw dust.

The farm water requirement reported in this study (4.4 L/kg) is lower than the value (9 L/kg) reported by Robinson *et al.,* (2019). The water requirement for on-farm operations was 5.7 % while reminder was due to off-farm water contributions. In contrast, water for on-farm operations accounted only about 1 % of the WFP of broiler (Atapattu, 2011) and egg production (Chaminda and Attapattu, 2013). On one hand, it can be assumed that higher contribution from on-farm operations provides more opportunities to make adjustments to further reduce the WFP of mushroom production. However, consideration of the items that come under on-farm contribution suggests that, apart from requesting laborers to use water thriftily, few opportunities are available to reduce on-farm water usage any further. Off-farm activities, on the other hand, also provide little opportunities, since items considered are mainly water-efficient by-products or wastes. Though numerous strategies including substrate enrichments have been reported to increase the yield of mushrooms (Pathmashini *et al.,* 2009; Pereima, 2017; Rajapakse *et al.,* 2010), the use of items with higher WFP such as cereals or pulses may lead to increase the WFP. In these circumstances, the best strategy for the reduction of the WFP of mushrooms would be to optimize the other management conditions that give higher yield at a shorter period.

Table 03: Contribution of the components of mushroom growing media and growing cycle activities to the water footprint of Oyster mushroom cultivation

Step	Ingredient	Amount (kg)	Total WFP (m^3/tons)	Calculated WFP for each ingredient (m^3)	Total WFP of each step (m^3)	% Contribution to the total WFP
Oyster Substrate 1	Saw dust (rubber)	100	645.16	64.516	72.737	94.52%
	Rice bran	10	316.8	3.168		
	Mung bean	1	5053	5.053		
	$CaCO_3$	2	0	0		
	$MgSO_4$	0.2	0	0		
	Preparation of growing media (for 100 kg of saw dust)[a]				0.131	
	For sterilization of bags				0.035	
	Total media				72.903	
Production	For spraying per harvesting cycle (90 days)				0.36	5.48%
	For floor cleaning after harvesting				0.3	
	For labor usage				3.57	
	Total production cycle				4.23	
	Total water requirement				77.133	
	Total average harvest per one batch (tons)				0.0653	
	Total footprint (m^3/tons)				1181.21	

[a] *One-month-old or less saw dust was used for the substrate preparation*

In Sri Lanka, mushrooms are considered an alternative to animal protein sources. Among non-vegetarians as well mushrooms are popular as a curry or other side dish of the diet. WFPs of mushrooms as determined in this study and some selected food items are presented in Table 4. Numerous studies (Blas *et al.,* 2016; Harris *et al.,* 2020; Vanham *et al.,* 2013) have shown that animal products are the major contributor to the WFPs of diets. Lower WFP reported by the oyster mushrooms, compared with the animal source food items and some popular plant protein sources such as lentil and soybean oil cake (soy meat) indicates that mushrooms in diets, reduce the water footprint of the diet while providing nutrients.

Lentil is the most consumed pulse item and probably the most popular curry in Sri Lanka (Ariyawardana and Collins, 2013). Soya meat is also popular both among vegetarians and non-vegetarians (Silva *et al.,* 2020). Therefore, in order to have a better idea, WFPs of mushrooms, some selected animal source food items, lentils and soybean meal were also compared in terms of L/100 kcal and L/100 g of each food item (Table 4). WFP of mushrooms when expressed as L/100 kcal is lower than that of nuts (363 L/100 kcal) but much higher than those of cereals and pulses, as reported by Mekonnen and Hoekstra (2011). Expression of WFP per unit of nutrient reduced the superiority of mushroom as a water-efficient food item, compared to other animal source food items, soybean meal (soy meat). In terms of L/100 kcal, eggs and particularly soybean meal outperformed mushrooms. Meanwhile, in terms of L/100 g of proteins, eggs, broiler meat and again soybean meal outperformed mushrooms. The deferences between mushrooms and other livestock products also reduced, both in terms of per unit of calory and protein. However, compared with those comparable items, mushroom cultivation has reported a number of better environmental footprint values (Grimm & Wösten, 2018; Zied *et al.,* 2020; Dorr *et al.,* 2021). Therefore, the low WFP reported herein further supports the claim that mushrooms are a food item with low environmental impact.

Most of the inputs of mushroom cultivation are by-products or waste of another production processes and most of the production steps use ground or surface water. This study did not attempt to partition the WFP into blue, green, and grey water. There may be a small grey water contribution from rice bran and mung bean that may arise from gray water footprints of respective items. During the production process, no hazardous chemical that may pollute the water bodies was observed. Therefore, it can reasonably be assumed that gray water component of the WFP of mushrooms could be low.

Table 04: Comparison of water footprint, water footprint per unit of calory and protein of Oyster mushroom with selected livestock products, soybean meal and lentils

Food item	WFP (m^3/ton)	Source	WFP	
			L/100 kcal	L/100 protein
Oyster mushroom	1181	Present study	282	4072
Eggs	3734 [a]	Chaminda and Atapattu (2013)	261	3011
Broiler meat	7546 [a]	Atapattu *et al.,* (2011)	478	2351
Pork	9370 [b]	Mekonnen and Hoekstra (2012)	539	12696
Beef	15415 [b]	Mekonnen and Hoekstra (2012)	1329	6588
Soybean meal	1779 [b]	Mekonnen and Hoekstra (2011)	49	349
Lentil	5874 [b]	Mekonnen and Hoekstra (2011	506	6527

[a] *Sri Lankan conditions (Global average egg = 3265; broiler meat = 4325);* [b] *Global averages*

CONCLUSIONS

The water footprint of Oyster mushroom production under small-scale production conditions in Sri Lanka was 1181 m^3/ton. Mushroom growing substrate contributed 95 % to the total WFP. WFP of common mushroom media ranged from 591-642 m^3/ton. On-farm water requirement was estimated to be 4.4 L/ kg. WFP of mushroom was lower than that of eggs, broiler meat, pork, beef, lentil and soy meat. However, when expressed as WFP per unit of protein and calory, eggs and soy meat outperformed mushrooms. This study concludes mushrooms as a water-efficient food item. Increase of the yield at a shorter growing period is identified as the most feasible way to reduce the WFP further.

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